Topics in Safety, Risk, Reliability and Quality

Adrian V. Gheorghe
Marcelo Masera
Polinpapilinho F. Katina *Editors*

Infranomics

Sustainability, Engineering Design and Governance

IRG-PrOject
[Integrated Risk Governance Project]

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TOPICS IN SAFETY, RISK, RELIABILITY AND QUALITY

Volume 24

Aims and Scope. Fundamental questions which are being asked these days of all products, processes and services with ever increasing frequency are:

What is the risk?
How safe is it?
How reliable is it?
How good is the quality?
How much does it cost?

This is particularly true as the government, industry, public, customers and society become increasingly informed and articulate.

In practice none of the three topics can be considered in isolation as they all interact andinterrelate in very complex and subtle ways and require a range of disciplines for their description and application; they encompass the social, engineering and physical sciences and quantitative disciplines including mathematics, probability theory and statistics.

The major objective of the series is to provide a series of authoritative texts suitable for academic taught courses, reference purposes, post graduate and other research and practitioners generally working or strongly associated with areas such as:

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Emergency Planning
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Special emphasis is placed on texts with regard to readability, relevance, clarity, applicability, rigour and generally sound quantitative content.

Adrian V. Gheorghe · Marcelo Masera
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Editors

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Springer

Editors
Adrian V. Gheorghe
Polinpapilinho F. Katina
Engineering Management and Systems Engineering
Old Dominion University
Norfolk, VA
USA

Marcelo Masera
Institute for Energy and Transport Joint Research Center
Petten
The Netherlands

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Preface

We define *Infranomics* as a body of discipline supporting analysis and decision making regarding modern societal vexing issues of sustainability, asset management, energy and safety, ethics, education, and engineering design. While it is in its infancy, *Infranomics* is proposed as a thesis enabling better decision making in an increasing ambiguous, complex, emergent, interdependent, and uncertain world. As modern society contends with rapid technological changes, socioeconomic institutional changes, increased globalization, and scarcity of resources, decision makers (i.e., policymakers and private entity operators, and researchers) are faced with a daunting task of ensuring the well-being of public health, security, and economy. Since no nation has unlimited resources, the time is ripe for a discipline that supports analysis and decision making to increase anticipation in an increasingly uncertain world.

In the next 25 works contributing to this book, we illuminate *Infranomics* in different aspects of modern society. The paper by Gheorghe et al., serves as the introduction to this volume. It addresses the interdisciplinary format of *Infranomics*, highlighting some potential initial areas of applications, and the category of analytical instruments adequately empowered to deal with the complex domain of the new body of discipline.

Part I contains three papers discussing sustainability of infrastructures in modern society. How can we create harmony between people, the planet, and profit? The paper by Emile Broesterhuizen et al., provides a tentative solution to this problem by examining ports, with consideration of clients and contractor vantage points. Continuing the theme of sustainability in ports is the paper written by Martijn P.C. de Jong et al. They provide an alternative design for open water ports and consider coastal impact as well as advantages and disadvantages of the proposed design. This part concludes with work done by Poonam Taneja et al., and discusses the role of flexibility in port development. They argue that flexibility is instrumental in achieving long-term financial viability and reduces environmental and social impact of the port infrastructures in uncertain economic times.

Part II contains three works discussing asset management. Kerry Brown et al., suggest that strategic management of assets requires corporate governance, policy, objectives, and interagency collaboration. A framework that enables asset acquisition, utilization, and maintenance for strategic development is presented. Martin Laue et al., operationalize the various levels of the asset management framework presented in previous work. This work considers how asset management can be embedded in organizations through the temporal, organizational, and spatial dimensions. We conclude this Part II with a section on multicriteria decision making for real estate portfolio. Monique Arkesteijn and Ruud Binnekamp show how measure asset performance to enable decision making based on decision makers' criteria and preferences.

In Part III, the book discusses safety and energy management topics. In an unpredictable world, we must develop mechanisms that can be used to alarm citizens in harm's way. However, paper by Helena Jagtman shows current approaches has limitations. Framework to enable better communication is developed based on a case study. Paper by Masaki Nishimori et al., discusses policy design for disaster-hit areas. Using the example at Fukushima Daiichi Nuclear Power Plant, authors present a framework of system design by holistically incorporating requirements stakeholders' requirements interactively and bottom-up communications. The world largest oil-imports is now, China. How did we get here and what does the future hold? Yang Saini et al., discusses these questions and how these changes could impact transportation sector.

Part IV is purposefully entitled *equity, ethics, and infrastructures* to project the image that *Infranomics* involved morals and policy. First, Neelke Doorn applies this concept to water. The statistics on water-borne diseases, people living without safe water, and flooding are staggering. To address these issues, Neelke Doorn suggests that modern society integrate governance into water systems. Kien To and John Fernández present a compelling need for designing and implementing low-emitting carbon cites in modern society-based alternative urban technologies enabling efficient use of scarce resources. This part concludes with new and exciting developments in the Engineering Systems Division at MIT concerning instilling motivation to future researcher in solve complex and sociotechnical systems problems.

Modeling and simulation is the subject of five contributions in Part V. Andreas Tolk urges for need for modeling and simulation known as *Serious Gaming* to enable manage systems of systems. An experimental game based on systems dynamic is built to explore the question of sustainability and greenhouse emissions for built environments. The procedure and the results of the game simulation model are provided in the work of Iman Mohammed and Erik Pruyt. Work by Todd Schenk is specifically written to suggest an innovative way (Role Play Simulation) to addressing hazards and threats impacting performance of critical infrastructures. To conclude this paper, Sertaç Oruç and Scott Cunningham introduce propositions regarding engineering design. In this work, the case is made for multi-actor approach that emphasizes game theoretical modeling for optimization in engineering design.

Governance enables regulation of social systems using variety of mechanisms for a better society and is the subject of four contributions in Part VI. First, Behnido Calida and Charles Keating give a new vision on the issues related to governance in the context of complex systems exposed to uncertain and ambiguous environments. Many initiatives fail not because of incompetence of stakeholders, rather Otto Kroesen and David Ndegwah suggest there is a need to understand ambiguities involved between cultural clash between nations and priorities. This paper explores governance in technology transfer in East Africa. Third, Fei Xue et al., introduce a systematic concept of structural analysis for power grids security assessment to enable governance. Authors provide new measures for criticality to enable ranking for sake of critical component survivability. Fourth, the work done by Aria Iwasawa et al., uses Surrogate Worth Tradeoff Method to select technology for design of new systems in a Multiobjective, Mixed-Discrete Nonlinear Programming problem.

The book concludes with Part VII comprises four papers contributing to learning and knowledge dissemination within the larger context of *Infranomics*. First, Christopher Magee et al., describe historical roots of Engineering Systems and methods used in the field at MIT. Next, the researchers at ODU and Universitatea Politehnica Bucharest, Romania provide a methodology that can be used to asses resilience of academic programs. This methodology can be used to assess structural complexity and vulnerability of academic problems meant to address modern society most vexing issues. The paper by Hugo Priemus explores the case for risk analysis and risk management in large-scale infrastructure project in the Netherlands. This paper illustrates how academic theory can be used to advice stronger orientation toward flexibility and the identification of viable options. The concluding paper is about a general framework, Actor-Option Framework, which can be used to model large-scale systems in transition, to enable understanding in different transition cases and integration.

As it is becoming increasingly evident that the space for technology-driven solutions to twenty-first century issues is diminishing, there is a need for multidisciplinary approach involving technical and soft elements of human social, organizational/managerial and policy, and political elements. The discipline of *Infranomics* offers an initiating collaborative effort supporting analysis and decision making in our *modern* society.

Norfolk, Virginia, May 2013 Adrian V. Gheorghe

Acknowledgment

This book would not have been possible without the help from numerous people. Our acknowledgments are indebted to Prof. Margot Weijnen of Delft University of Technology (The Netherlands) whose interests in *Infranomics* is demonstrated in years of research at and before the foundation of Next Generation Infrastructures Foundation in The Netherlands. We also acknowledge Prof. Paulien Herder of Delft University of Technology (The Netherlands) without whom this book would not have been possible. Prof. Herder was instrumental in organizing the CESUN 2012 International Engineering Systems Symposium conference in which some of the authors contribute immensely to this text.

We are thankful to Nathalie Jacobs and Cynthia Feenstra of Springer Publishing Company for their encouragement in publishing the first textbook of this topic. We would like to extend our gratitude to friends and colleagues around the globe whose input improved initial drafts of this book.

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Infranomics: A Discipline-of-Disciplines for the XXIst Century

Adrian V. Gheorghe and Marcelo Masera

Abstract This technical note aims at introducing Infranomics, as a crucial discipline for this century. Neither authorities, nor industrial or academic bodies could afford to ignore the advent of the convolution of opportunities and risks accompanying the implementation of the new generation of infrastructures. The shape of our society will be determined by the characteristics of, and the services delivered through, those infrastructures. It is argued that Infranomics is the body of disciplines supporting the analysis and decision-making regarding the Metasystem (e.g. the totality of the technical components, stakeholders, mindframe, legal constraints, etc. composing the set of infrastructures). Infranomics is the set of theories, assumptions, models, methods, and associated scientific and technical tools required for studying the conception, design, development, implementation, operation, administration, maintenance, service supply, and resilience of the metasystem. Because none of the currently existing disciplines provides a complete solution, Infranomics will be the discipline-of-disciplines grouping all needed knowledge.

Keywords Critical infrastructures · System-of-systems · Metasystem · Scientific disciplines · Resilience · Tangibles · Intangibles · Infranomics

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A. V. Gheorghe (✉)
Department of Engineering Management and Systems Engineering, Old Dominion University, Kaufman Hall, Rm. 241, Norfolk, VA 23529, USA
e-mail: agheorgh@odu.edu

M. Masera
Institute for the Protection and Security of the Citizen Joint Research Centre, European Commission, Via E. Fermi 2749 21027 Ispra, VA, Italy

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Introduction

> ***Infranomics**, after* **infra**structure *(supporting vital societal technical functions) and* **nomics** *(after Gr. νόμος nomos, set of rules), the discipline-of-disciplines studying the Metasystem.*

In 2006 we presented the concept of Infranomics [1] in the context of a Disaster Risk Management Conference. Our intuition was that the study of the resilience of Critical Infrastructures exposed to a myriad of threats requires a very specific scientific approach, integrating many disciplines. The origin of this notion of Infranomics sprung from an ad-hoc meeting held in 2004 in Christchurch, New Zealand, following a well-recognized meeting in Rotorua on “Resiliency of Critical Infrastructures” [2].

In these years, we have consolidated the belief on the need for:

1. a systematic approach to the understanding of all the interrelated aspects that constitute the critical infrastructure topic;
2. taking into consideration all tangibles and intangibles aspects, and all the concurrent concordance–discordance facets; and
3. the rigorous structuring of the decision making matter in consideration of all stakeholders.

This short technical note aims at introducing Infranomics,[1] and proposing it as a crucial discipline for this century. Neither authorities, nor industrial or academic bodies could afford to ignore the advent of the convolution of opportunities and risks [3] accompanying the implementation of the new generation of infrastructures. The shape of our society will be determined by the characteristics of, and the services delivered through, those infrastructures. In this picture, communications, mobility, commerce, energy [4], health, finance, education, environmental impact, security, and up to international relations, each and all of them cannot be treated independently.

Our society will be as efficient and as secure as the infrastructures constituting it, would allow. The texture of interconnected infrastructures, each one of them a system-of-systems [5] by itself, is evolving into a metasystem (a system-of Systems-of-Systems), which—for some features—will have to be considered as a whole (Gestalt notion). At that level of aggregation, where the infrastructure is contemplated from the society standpoint, new principles can be hypothesized: ASAIA (as secure as infrastructure allow) and AEAIA (as efficient as infrastructure achieve).

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[1] The authors acknowledge the use of the term “Infranomics” in the context of Political Economy of Infrastructures by Ms. Rita Nangia in her blog, reachable at the web site http://www.infranomics.org/, as from 4th December 2009.

This Metasystem is composed of tangible and intangible elements:

- Technical components of the infrastructure supporting its functions (from the hardware, to the information, command and control parts);
- Stakeholders (comprising the operators, authorities, suppliers, end users, society at large);
- Resources (monetary [6], natural, human, technical, information);
- Mindframe (mentality, mood, cultural traits, etc.); and
- Constraint set (legal context [7–10], standards, international rules [11], etc.).

The new generation of infrastructures will be constructed upon the existing ones, however the services, architecture, business models and attributes of those newly developed systems will signify a qualitative leap forward, and not just more of the same. This leap results in the Metasystem. The technical components of the Metasystem have very different life-cycles varying from months to decades. At the same time, the decisions about the Metasystem components are taken by a multiplicity of actors, with each one of them following her own interests and concerns. Many of these components already are cross-border deployed.

Infranomics is the body of disciplines supporting the analysis and decision-making regarding the Metasystem (see Fig. 1). Infranomics is the set of theories, assumptions, models, methods, and associated scientific and technical tools required for studying the conception, design, development, implementation, operation, administration, maintenance, service supply, and resilience of the Metasystem. Because none of the currently existing disciplines provides a complete solution, Infranomics will be the Discipline-of-Disciplines grouping all needed knowledge.

Infranomics might manifest through *inter alia* the following acts:

- Analyzing how stakeholders interact, coordinate their functions, establish legal regimes and normative rules, set the economics of their services, handle normal and abnormal situations;
- Analyzing how infrastructural systems work and how they can fail (e.g. blackouts), their impact onto the resilience of society, taking into consideration all technical and organizational elements and external factors;

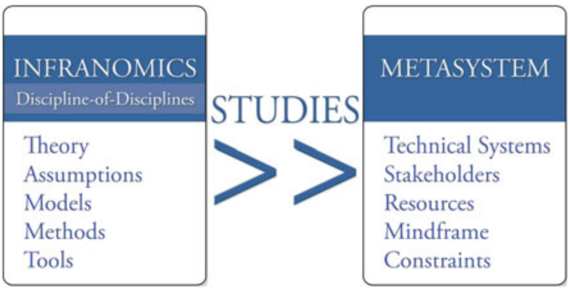


Fig. 1 Infranomics and metasystem

- Analyzing how infrastructures evolve with the introduction of new technologies, how vulnerable they are in different security scenarios, and how their adequacy and performance might degrade over time;
- Developing theories and methodologies for the modeling, simulation, assessment, critical analysis, and empirical investigation of infrastructures and their dependability;
- Assess infrastructures as a whole in the interaction among the political, legal and economic governance of societies, and mainly with respect to cross-border and multi-jurisdictional settings.

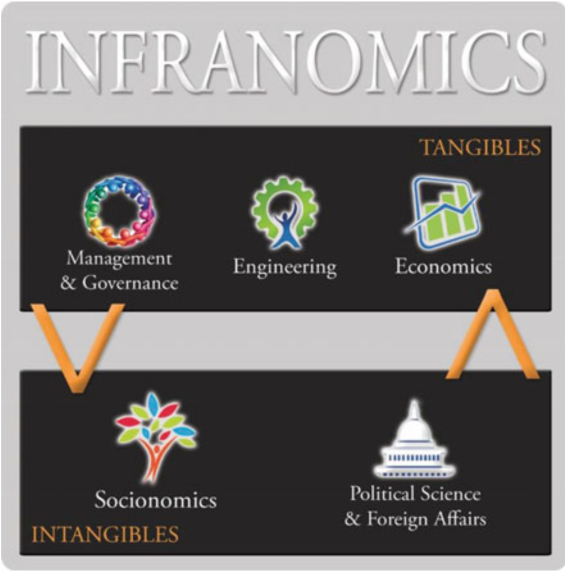
One of the key objectives of Infranomics should be to support decision making in view of achieving a set of goals, at the corporate, regional, national and international levels. For this aim, Infranomics should integrate the engineering, economic, political and social sciences, considering the inter-relationships among infrastructures and stakeholders, in a multi-national, multi-jurisdictional context. The five main components of Infranomics (see Fig. 2) are:

- management and governance
- engineering
- socionomics
- economics
- political science and foreign affairs

Fig. 2 Infranomics disciplines

Box 1 *Tangibles and Intangibles*

The main reason for the Infranomics discipline is the need to consider in a concurrent and harmonized way the necessary integration of tangible and intangible attributes of infrastructures. These tangibles and intangibles (see figure below) can be seen as two vectors, whose composition defines the field of Infranomics studies.



Tangibles: quantifiable assets of the infrastructure (including physical and logical elements), economic performability, technical attributes (reliability, maintainability, vulnerability, etc.), environmental conditions and requirements, resources and their attributes (e.g. scarceness, price, affordability), attributes of the end user service (e.g. quality, price, affordability).

Intangibles: qualitative elements which shape the definition and use of the infrastructure. E.g.: mood (of users, society, stakeholders), values and ethical positions, training of personnel, perception and acceptance of risk, awareness of vulnerabilities, policies of the business actors, strategic national and industrial objectives, geopolitical objectives, etc.

Box 2 Infranomics is applied to all aspects, agents, components and factors, endogenous and exogenous, relevant throughout the lifecycle of infrastructures: management and governance arrangements, financial analysis of investments and accidents, technological evolution and training of personnel and customers, health and environmental effects, crime and malicious/antagonist agents, etc.

Some comments can be added regarding some sub-disciplines:

- *Positive Infranomics*: what are the infrastructures, which are their structural, functional and behavioral elements, and how they are managed, regulated, etc.

- *Normative Infranomics*: which could be the most appropriate ways and means for managing the infrastructures and their systems in different circumstances.
- *Theoretical Infranomics*: the development of the concepts and models that describe the relations, activities, layers, interactions, cost and prices, etc.
- *Empirical Infranomics*: the experimental demonstration and validation of theories, comprising the methods and tools for designing, running and analyzing the results of experiments, and mainly with respect to the failure of the infrastructural systems.

Management involves the organization and coordination of the activities of enterprises in accordance with certain policies and in achievement of clearly defined objectives. Management comprises the planning, organization, leading and controlling of an enterprise or effort for the purpose of accomplishing a goal. Governance refers in this context to the regulation of interdependent relations in the absence of an overarching political authority, and to the use of institutions, structures of authority and even collaboration to allocate resources and coordinate or control activity in society or the economy [12].

Engineering embraces all aspects of the infrastructure life-cycle, from the conception to the decommissioning, passing through the design, development, operation and maintenance of the installations. This includes the analyses of aspects such as risk, vulnerability, technical performability, environmental compatibility, sustainability, resilience, etc.

Economics deals with irreversible resource allocation of financial and material resources, resulting in a monetary value for the owners, operators, suppliers and users of the infrastructure and their services.

Socionomics deals with the social mood that drives financial, macro-economic and political behavior regarding infrastructure. Socionomics is a theory of human social behavior describing the causal relationship between social mood and social action". In the web site they defend it as dedicated to "social prediction".

Political Science is view as an academic discipline concerned with the empirical study of government and politics. Political scientists have investigated the nature of states, the functions performed by governments, voter behavior, political parties. In a complementary way Foreign Affairs deal with matters that are connected with other countries.

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Part I
Infrastructure and Sustainability

Sustainable Procurement for Port Infrastructure Projects

Emile Broesterhuizen, Tiedo Vellinga, Poonam Taneja and Linda Docters van Leeuwen

Abstract There is a growing number of ports with sustainable policies. At the moment most of these policies are focused on clean transport. This study handles ports themselves by implementing sustainable criteria for the procurement of infrastructure projects. The aim is to get a balance between People, Planet and Profit. This means that those sustainable criteria have to be compared with the investment costs. A solution of this problem is given by setting a procurement model based on the so called concordance analysis, in combination with criteria which are based on the 3P theory and Life Cycle Analysis. Furthermore, the position of both client and contractor are taken into account by giving recommendations about contracting forms. As part of the research interviews were done with stakeholders as governments, port authorities and contractors. These interviews formed a basis for the obtained model.

Keywords Sustainable port development · Infrastructure projects · Procurement · Life cycle analysis · Value management · Sustainable management · Contract forms · Concordance analysis

E. Broesterhuizen (✉)
E.F.M. Broesterhuizen, Uilebomen 36, 2511 VP The Hague, The Netherlands
e-mail: e.broester@gmail.com

T. Vellinga · P. Taneja
Civil Engineering, Delft University of Technology, P.O. Box 5015, 2600 GA Delft, The Netherlands

L. Docters van Leeuwen
Iter Fidelis B.V., Computerweg 2, 3542 DR Utrecht, The Netherlands

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Introduction

While in other industries sustainable management is of the order of the day, sustainability is still in many ports' infancy. It is not only the legislator which forces ports to sustainable management, but also the society as a whole. More and more economic experts are convinced about the lower costs on the long term as a result of sustainability.

The port of Los Angeles was one of the pioneers of ports on this field by starting in 2006 the San Pedro Bay Ports Clean Air Action Program (CAAP): it was the most ambitious program in the world for cleaner ports. It led to emission reductions of 50–75 % in five years time for DPM, $PM_{2.5}$, PM_{10}, NO_x and SO_x (see Fig. 1). After this success more and more initiatives followed, like the World Ports Climate Initiative (WPCI) in 2008: a cooperation network of 55 ports in the world originated from the International Association of Ports and Harbors (IAPH) for reduction of CO_2 emissions.

By far, most attention is focused on cleaner transport and shipping. This chapter, a summary of the study of Broesterhuizen [3],[1] handles ports themselves by introducing a procurement model that contains sustainable criteria for the design, realization, use, demolition and recycling of infrastructure projects. Sustainability in procurement is inevitable to make the port's infrastructure more sustainable. Not only the project itself is investigated by setting criteria, but also the relation between client and contractor. The scope of the study concerns ports with transshipment as main function.

The study is divided into four phases: Analysis, Synthesis, Simulation and Evaluation. In the Analysis insight is gained in the current and future situation around sustainable procurement and sustainability in ports. The procurement model is formed in the Synthesis and applied on different projects from the field. One of these projects is described and analyzed in this chapter. The Evaluation gives a feedback to the main research question reading how sustainability criteria can be implemented in the procurement process for port infrastructure.

Analysis

In this phase different topics are studied about procurement in general, the role of sustainable criteria in the procurement process, the commercial (dis)advantage of sustainable management and the visions and policies around sustainable port development. As a part of this analysis several parties[2] are interviewed about their views and policies.

[1] Paragraphs 2.1–3.1 were part of the introduction to this study, published in a discussion paper: Broesterhuizen et al. [4].

[2] 2 large contracting companies, 2 port authorities, the government and a NGO.

PRIMARY POLLUTANTS DEFINED

DPM = Diesel Particulate Matter
NOx = Oxides of Nitrogen
SOx = Oxides of Sulfur
$PM_{2.5}$ = Particulate Matter less than 2.5 microns in diameter
PM_{10} = Particulate Matter less than 10 microns in diameter
CO_2 = Carbon Dioxide (A Green House Gas contributor)

OVERALL EMISSIONS REDUCTIONS CY 2005-2010

Pollutant	CY 2005-2010	
	%	tons
DPM	69%	617
$PM_{2.5}$	70%	579
PM_{10}	69%	678
NOx	50%	8,180
SOx	75%	3,978

Fig. 1 Emission reductions port of Los Angeles [8]

Procurement Process

European ports are bounded to European laws and these ports are obliged to European public procurement above a certain contract sum and many port infrastructure projects sums exceed this value. When it is a matter of public European procurement Port Authorities have the choice for procurement with a selection based on the lowest price or the most economically advantageous tender. The last criterion is a criterion which selects the alternative with the best price-quality ratio. This can be realized by setting criteria for a more sustainable alternative.

One of the goals of this study is to make a project as sustainable as possible. In the procurement phase of a project, it does not depend only from setting sustainable criteria. The choice for a type of contract is very important. Lately innovative contract forms, e.g. D&B and DBFM, are more popular. When using these types of contracts, contracting companies gain more freedom and influence in the design of the project. Therefore, more different kinds of alternatives are possible which helps the sustainability. Besides, these innovative contract forms involve the contractor in the project over a longer period of time. In practice these developments has led to the applying of Life Cycle Analysis (LCA) by contractors leading to a higher value of the project [9]. This is an important property of a sustainable project design: projects should not only be sustainable for a limited period of time, but also during their whole lifetime.

Economical Effects of Sustainable Management

In most industries (especially industries in consumer markets) sustainable purchasing and procurement is already integrated, more than the port sector. According to the study of Adams [1], many port authorities approach sustainability in a negative way: sustainability is seen as a necessity for reducing external effects (e.g. emissions), instead of the optimization of advantages like retaining and attracting clients while other industries make use of these advantages of sustainable management. According to MIT and the Boston Consulting Group [2] sustainable management has many commercial advantages which lead to a larger return for shareholders (see Fig. 2). Ports should make use of these advantages and sustainable procurement is one of the possibilities to realize this. Using sustainable policies ports will get a better image which lead to a license to operate and a license to grow.

Besides advantages, sustainable and innovative operational management can have disadvantages. Most of these disadvantages are dealing with uncertainties about the future due to the fact that in many cases sustainable investments are long term investments. A second disadvantage is the risks of investing in innovation. Private parties incline to make fewer investments in innovation due to the risk of spillovers of knowledge, investment risks and the differences in benefits between companies and the society in general.

Analysis of Actors

By making an analysis of the views and policies of the different actors (e.g. governments, port authorities, contractors, etc.) involved in sustainable port development insight is gained in the interests and the importance of the different topics. One of these actors is the Dutch government which set different themes that are important in sustainable port development [7]. These themes include: use of

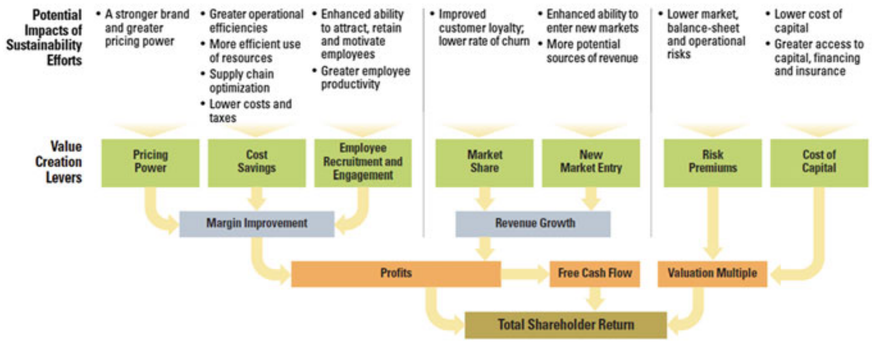

Fig. 2 Advantages of sustainable management [2]

space; mobility of the hinterland; development of nature; air quality; environmental management; energy, CO_2 emissions and waist flows; water quality. Research company CE Delft has set indicators based on these themes to measure the sustainability of the Dutch ports [6], which can be used for setting sustainability criteria. Based on the themes there is made an inventory of the different topics of attention from the actors. The conclusion is that most attention is going to environmental management (e.g. cooperation in knowledge, use of environmental management systems, ISO14001) and energy, CO_2 emissions and waist flows.

Interviews

As mentioned before, different parties from the procurement process were interviewed. Here, the most important conclusions are picked from the results. Due to the number of respondents, a statistical conclusion cannot be made but the results are very useful to get insight in different views and solutions. There was consensus in opinion about some topics, but there were many topics with disagreement too. This shows that more research has to be done about this subject. Most respondents were of opinion that especially the large companies in the building sector see the (commercial) advantages of sustainable management. Small companies still link sustainability with extra costs. There was agreement too about the proposition that sustainability should come from the contractor instead of the awarding authority. But the companies gave very different answers to the question if contractors are given enough space to make this possible. All respondents were of opinion that owners choose contracting forms which give too little space for innovation. Together with the opinion that sustainability should come from the contractor the conclusion can be made that contractors do not have enough space to realize sustainable projects.

There was disagreement too about the question if there should exist a general procurement model for the whole soil, road and hydraulic building sector instead of a model that is focused on the project itself. As advantage of such a model the ease of application is mentioned. A disadvantage could be the lack of freedom and the fact that every project is different.

It was very noticeable that most respondents didn't mention air quality as an important criterion for sustainability, while air quality is the number 1 topic in the several sustainable initiatives of international ports.

Synthesis

In this phase of the research the criteria of the procurement model are set. After the choice of the criteria an evaluation method is chosen with weight factors for the criteria. These choices are based on requirements as flexibility, adaptability, stability, transparency and user-friendliness.

Criteria

Before setting criteria, the question has to be answered which criteria will contribute to a more sustainable port infrastructure. To be able to answer this question a definition for a sustainable port is needed. In this study there is referred to the definition of the Dutch and Flemish environment organizations [5]: a port with an optimal balance between performance of business economics, utilizing the available capacity, limited use of space, minimal negative influence on the environment and a relation between port and hinterland. This is a very important definition for this study. To reach this 11 criteria are mentioned in the referred report. These criteria combined with the different indicators for sustainable ports set by CE Delft

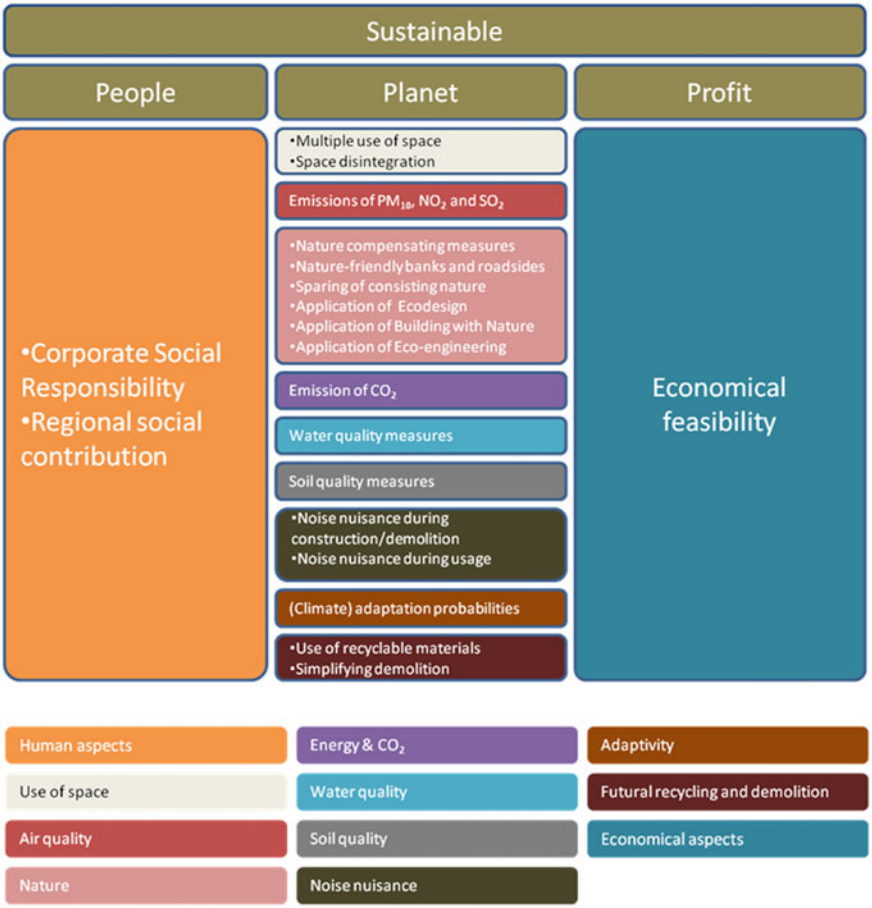

Fig. 3 Criteria framework: the *colors of the themes* in the *lower part* correspond with the colors of the different criteria

Table 1 Selection table for evaluation method: the total score is calculated by the sum of the individual performance scores in which −− is equal to −2 points, − is equal to −1 point, ± is equal to 0 points, + is equal to 1 point and ++ is equal to 2 points

Method	Applicable	Transparent	Flexible	Stable	Effective	User friendly	Total
CBA	−	+	++	+	++	++	7
CEA	−	+	++	+	++	++	7
Score card	++	++	++	−	−−	±	3
Weighted summation	++	+	±	±	−	+	3
Permutation method	++	++	−	±	+	−	4
Concordance analysis	++	+	−	±	++	±	5
Saaty method	++	−	±	−	±	+	1
Multidimensional scale method	++	−−	−−	±	++	−−	−2

and the People, Planet, Profit definition of sustainability led to different themes which are important when approaching sustainable port development. Then, the themes are translated to indicators for port infrastructure after analyzing the application of the themes on infrastructure. After setting the indicators for the sustainability of port infrastructure, criteria can be formulated. This has led criteria divided in 3 classes based on Life Cycle Analysis: People, Planet and Profit [3]. People contents the social criteria as corporate social responsibility, Planet consists the criteria for the environment, e.g. emissions and development of nature, and the Profit criterion will be formulated as the financial Net Present Value. A notable criterion is the adaptability of the work and is not included in traditional procurement criteria. This is understood to mean a flexible design which makes the construction works durable against changing circumstances in the future. For ports a very important changing circumstance is the climate change. Examples of a flexible design are floating quay walls and flexible designs for capacity expansions. The framework with the different criteria is shown in Fig. 3. The criteria are set in such a manner that the correlation between the criteria is minimized.

Selection of Evaluation Method

To evaluate alternatives based on these criteria, a suitable evaluation method is needed. Different kinds of evaluation methods are compared in Table 1 to each other based on applicability, transparency, flexibility, stability, effectiveness and user friendliness. These properties are chosen such to get an appropriate model for both the client and contractor and to optimize the sustainability of the project. The most common evaluation methods in civil engineering are compared in which a distinction is made between monetary evaluation methods [cost-benefit analysis (CBA), cost effectiveness analysis (CEA)], the score card method and Multicriteria Evaluation methods (MCE's; weighted summation, permutation method, concordance analysis, multidimensional scale method, Saaty method).

Cost-Benefit Analysis and Cost Effectiveness Analysis

In the CBA all effects are translated to costs using shadow prices. The preferred alternative is the alternative with the best balance. The advantage of this method is the amount of insight gained about the effects and all criteria can be compared to each other. The main disadvantage is that some criteria are difficult to translate in a monetary value.

In the CEA first a goal is set. Then it is analyzed which alternative can fulfill that goal against the lowest costs.

Weighted Summation

The weighted summation is the most common evaluation method in the civil engineering industry. It is based on the principle $P = W*E$ where P is the score, W the weight and E the effect. After standardization of the effects and multiplication with the weights of the effects score can be calculated. The advantage of this method is that it is very comprehensible. The disadvantage is that the weights are determined independently, allowing the case that the preferring alternative scores high on criteria with large weights while there are more criteria where it scores bad.

Concordance Analysis

The concordance analysis is a method where there the alternatives are first compared in pairs based on weighted scores. After that again a pairwise comparison is made between the alternatives but then without weights to inspect how bad the alternatives score to each other. The preferable alternative is the alternative that gives a good balance between scoring high on weighted criteria and scoring low without weights. The advantage of this method that the compensating effect of the weighted summation is removed.

Permutation Method

This method is based on the order of preference of the alternatives on all effects. Per criterion all orders of alternatives get a score. The order of preference with the best score on the end is the ultimate order of preference. Disadvantage of this method is that if there are a lot of alternatives, many calculations have to be done: when there are alternatives, already $5! = 120$ different orders of preference have to be evaluated.

Saaty-Method/Analytical Hierarchy Process Method

First the alternatives are compared pairwise on the criteria, making use of the Saaty scale: every time the better alternative get a score of 1 (equal score), 3, 5, 7 or 9 (by far better). This leads to the matrix A_J for criterion J. The eigenvectors of these matrices form the Option Performance Matrix (OPM). The same is done with the criteria: a score of 1 stands for equal important, 9 for by far more important. This leads to the Relative Value Vector (RVV). Then, the OPM is multiplied with the RVV resulting in the Value For Money Vector (VFM). This vector gives the total scores per alternative. The alternative with the highest score is the preferred alternative.

One of the advantages of this method is that it is giving insight in the importance of effects without the need of setting weights. A disadvantage is the mathematical nature, leading to less transparency.

Multidimensional Scaling Method

This method decreases the number of dimensions of a set of (correlated) criteria. These dimensions are not correlated to each other. Between these dimensions a point is determined in the dimension space. The alternative with the smallest distance to this point is the preferred alternative. This analysis is possible with a complex optimizing process which makes interpretation of results difficult.

Score Card Method

In this method it is indicated with colors how well an alternative scores on a list of criteria. With this method it is not needed to standardize scores or translate effects. Disadvantage is that it is difficult to make a quantitative comparison between alternatives.

The main advantages of monetary evaluation methods are their simplicity in their calculations but it is necessary to translate the different effects of the criteria to shadow prices, which can be dubious. The score card method is very transparent but a clear quantitative calculation is not possible. In contrast, MCE's are able to combine qualitative with quantitative data. Since the applicability of monetary evaluation methods is weak, a choice is made for the concordance method since this is the most practical method. In this method an alternative is evaluated based on weighted criteria how well the alternative scores in comparing with the other alternatives and how many times it scores worse on unweighted criteria. This leads to a balance between criteria which is important since sustainability is all about the balance between People, Planet and Profit.

Application of the Model

To ease the application of the model for both the contractor and client there is chosen for a model with qualitative criteria to avoid complex calculations and uncertainties. All measures by the contractor described in the tender are scored. In the case that there are no clear quantitative results available, this score is a grade between 1 and 10 during the tender stage, in which 10 is the best and 1 the worst. If there is a negotiation stage a grade between 1 and 3 will be given, since the selection process is progressed and a clearer distinction between the alternatives is needed. The score is based on how SMART[3] a measure is. If a clear quantitative effect is known as the investment costs, the effect can be used as a score.

After the scores are given to the alternatives all scores are standardized to 1 or (in case of negative score as investment costs) to −1.

The next step is to determine the concordance indices K_{ij}. A pairwise comparison is done between two alternatives *i* and *j*. The concordance index K_{ij} is simply the sum of the weights of the criteria of which alternative *i* scores better than alternative *j*. In Table 2 an overview is given of weights that can be used in this calculation. These weights are based on the current situation and can be changed by the client under the restriction that the sum of the weights is equal to 1. This step is repeated for all possible combinations resulting in a concordance matrix, see Table 3.

With this concordance matrix the net concordance dominance index can be calculated. For Alternative 1, this index is calculated as the sum of its concordance indices against the other alternatives minus the sum of the concordance indices of the other alternatives against Alternative 1, in general

$$K_i = \sum K_{ij} - \sum K_{ji}$$

This index is a measure for the scores on criteria with a large weight. From now on this index will be mentioned as the concordance. The higher the concordance, the higher the scores on the most important criteria.

After that, the discordance index D_{ij} is calculated as the absolute difference between the scores of alternatives *i* and *j* on the criteria for which *i* scores worse than *j*. This is repeated until the discordance matrix can be filled, see Table 4.

Now a discordance dominance is computed with the formula

$$D_i = \sum D_{ij} - \sum D_{ji}$$

This value will be named as discordance from now on. The higher the discordance, the worse the scores and it is a measure for bad scoring on all criteria.

The final step in the evaluation is to combine the concordance with the discordance. Since both indices have different meanings these indices cannot be summed. First the alternatives will be ranked based on concordance.

[3] Definition of SMART: Specific, Measurable, Acceptable, Realistic, Time restricted.

Table 2 Sustainability criteria with their weights

Main criterion	Criterion	Weight
People	Corporate social responsibility	0.11
	Regional social contribution	0.06
Planet	Use of space	0.03
	Emissions of PM_{10}, NO_2, SO_2	0.03
	Nature	0.06
	Emission of CO_2	0.06
	Water quality	0.03
	Soil quality	0.03
	Noise nuisance	0.01
	Adaptability	0.05
	Futural recycling and demolition	0.04
Profit	Nett present value	0.50

The sum of the weights is equal to 1 and the weights are based on the general situation for a large European port

Table 3 Concordance matrix

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Alternative 1	X	K_{12}	K_{13}	K_{14}	K_{15}
Alternative 2	K_{21}	X	K_{23}	K_{24}	K_{25}
Alternative 3	K_{31}	K_{32}	X	K_{34}	K_{35}
Alternative 4	K_{41}	K_{42}	K_{43}	X	K_{45}
Alternative 5	K_{51}	K_{52}	K_{53}	K_{54}	X

Table 4 Discordance matrix

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Alternative 1	X	D_{12}	D_{13}	D_{14}	D_{15}
Alternative 2	D_{21}	X	D_{23}	D_{24}	D_{25}
Alternative 3	D_{31}	D_{32}	X	D_{34}	D_{35}
Alternative 4	D_{41}	D_{42}	D_{43}	X	D_{45}
Alternative 5	D_{51}	D_{52}	D_{53}	D_{54}	X

The alternative with the highest ranking (that is with the highest concordance) gets 1 point, the second alternative 2 points, etcetera. Then the alternatives are ranked again, but this time based on their discordance. The alternative with the lowest discordance gets 1 point, the second 2 points and so on. Finally the ranking points are summed and the alternative with the lowest amount of points is the preferred alternative.

Simulation

In this part the developed procurement model is applied to a tender for a certain port infrastructure project. The outcomes will be evaluated and a comparison is made with the traditional method.

Example Project: Quay Wall

The example project consists of the design and realization of a quay wall with future expansion possibilities. The main components of the project are the design and construction of a mooring facility for oil tankers and the foundations for load arms and a rail with a crane.

After selection of 5 contractors the offers are evaluated using the model. In the original case, the offers were evaluated using a weighted summation method in which sustainability got a weighing percentage of 15 %. Within this percentage, sustainability was divided in 4 criteria:

- Avoiding transport during rush hours (33 %)
- Number of transports (17 %)
- Use of clean fuels (17 %)
- Recycling of material (33 %).

Therefore, these criteria are different from the model's criteria. Since the Net Present Values are not known, the investment costs are used as a measure for the economical feasibility. The negative value of the costs can be used directly as a score for this criterion. If the contractor does not take measures a neutral 5 is given as score, since the design does not necessarily leads to a more or less sustainable project. Furthermore, the tender is not yet in the final stage that means that improvements in the offers are possible.

The contractor of Alternative 1 took quite a lot measures within the criterion for the emissions of PM_{10}, NO_2 and SO_2. These measures differ in being SMART and there are a much transport movements leading to a considerably low mark (6). There is a limited amount of measures to limit CO_2 emissions and the contractor scores a 6 on this criterion and a low score for the economical feasibility since the investment costs are large.

The second alternative got the second place in the real situation. There was only a small amount of freight transport by trucks, in contrast to a large amount of commuter traffic. Thanks to a no-claims bonus system the measures scored higher on being SMART. This alternative got a high score on the criterion to limit the CO_2 emissions (9). There are a lot of measures to recycle material and the company is certificated with the highest award against CO_2 emission. There is much saving on use of steel and the contractor gave clear insight into the CO_2 emissions. On the profit criterion scores this alternative a second place.

The contracting company of the third alternative is the only contractor which is implementing the guidelines of ISO 26000, leading to a 9 as score on the criterion for Corporate Social Responsibility. Furthermore, it is the only alternative with possibilities for multiple use of space, protection of the soil quality and the application of nature friendly banks and roadsides. There are no clear measures about transport and there is much freight transport with trucks which is not enough compensated by the high score on commuter traffic. This leads to a 5 as score for the criterion against emissions of PM_{10}, NO_2 and SO_2. On the field of limitation of CO_2 emissions the total influence on the life cycle by the measures is small. Alternative 3 scores the third place on investment costs.

Alternative 4 takes initiatives to help the regional society. Some crafts are outsourced to the regional sheltered workshops. Alternative 4 scores an 8 when it comes to regional social contribution. The amount of freight transport by road is small, but the number of commuter transports is not known. The contractor scores bad for measures on clean fuels leading to a 5 for the criterion against emissions of PM_{10}, NO_2 and SO_2. This alternative is the most expensive alternative.

Alternative 5 was chosen by the client. It scored a 7 on Corporate Social Responsibility since the company is certificated on this field. There are a lot of actions against the emissions of PM_{10}, NO_2 and SO_2, rated with a 9. Like Alternative 2, this alternative is certificated with the highest award against CO_2 emission. Furthermore there is much saved on the amount of steel leading to less CO_2 emissions and the alternative is given a 9 for this criterion. Alternative 5 has the lowest investment costs.

The foregoing summarizes the contractors' most important actions described in their offers. The scores for all measures on all criteria are given in Table 5. Based on these scores the model can be filled in. According to the criteria of the model Alternative 5 is the most economically advantageous tender. Alternative 1 and Alternative 4 are sharing the last place as seen in Table 6.

In the real case, the contractor of Alternative 5 got the work and Alternative 2 scored the second place. The difference can be explained by taken other criteria into account, e.g. technical design. This makes it difficult to compare the outcomes, but they lay close together.

In the case of leaving the Profit criterion out, the outcome is different than the real case (that is, the ranking based on the sustainability criterion), see Table 7.

The large differences can be explained again to the differences in criteria. Alternative 3 scores high on criteria as Corporate Social Responsibility, use of space, water quality, soil quality, noise nuisance and adaptability. These are just the criteria which are not included in the real tender. This is more visible when the real outcome is compared to the analysis based on only the Planet criterion. This leads to an analysis with criteria which are more close to the real case, see Table 8.

The ranking of the concordance is almost the same as the ranking in the real case in Table 7. Looking to the concordance only is similar to the weighted summation method used by the client. By adding the discordance Alternative 3 gets a higher ranking, because this alternative has a better balance between more criteria what is important for a sustainable project, inspecting the very negative

Table 5 Scoring table; the scores on the profit criterion (investment costs) are given as ratios

Main criterion	Criterion	A1	A2	A3	A4	A5
People	Corporate social responsibility	5	5	9	5	7
	Regional social contribution	5	5	5	8	5
Planet	Use of space	5	5	7	5	5
	Emissions of PM_{10}, NO_2, SO_2	6	6	5	5	9
	Nature	5	5	6	5	5
	Emission of CO_2	6	9	6	7	9
	Water quality	5	7	8	5	5
	Soil quality	5	5	7	5	5
	Noise nuisance	5	5	9	5	8
	Adaptability	5	5	8	5	5
	Future recycling and demolition	5	7	5	6	6
Profit	Nett present value	−0.23921	−0.170607	−0.1883	−0.24504	−0.15684

Table 6 Ranking of alternatives

	Concordance	Discordance	Ranking
Alternative 1	−1.75	1.54	4
Alternative 2	1.04	0.33	3
Alternative 3	0.59	−1.80	2
Alternative 4	−2.33	0.82	4
Alternative 5	2.45	−0.89	1

Table 7 Ranking concordance analysis based on People and Planet criteria

	Concordance	Discordance	Ranking	Ranking real case
Alternative 1	−1.49	1.34	5	4
Alternative 2	0.10	0.40	3	1
Alternative 3	1.16	−1.80	1	2
Alternative 4	−0.67	0.60	4	5
Alternative 5	0.90	−0.54	2	2

Table 8 Ranking based on only Planet criterion

	Concordance	Discordance	Ranking	Ranking concordance
Alternative 1	−1.40	1.23	5	5
Alternative 2	0.97	0.03	1	1
Alternative 3	0.57	−1.46	1	3
Alternative 4	−0.99	1.06	4	4
Alternative 5	0.85	−0.86	1	2

discordance index. In the real case the client negotiated with the contractors of alternatives 2 and 5. According to this model, Alternative 3 should be given a chance too. This underlines the usefulness of the concordance analysis.

Evaluation and Conclusion

To incorporate sustainability as criterion in the procurement process it is necessary for the client to choose a contract form that is based on the most economically advantage tender where the winning alternative is the alternative with the best price to quality ratio. Sustainability is then a criterion for the quality. There are different kinds of contracting forms possible, where integrated contracting forms are preferable. The more the contractor is involved in the life cycle of the work, the more sustainable a design will be. Examples of integrated contracting forms are D&C or Design & Build contracting forms and DBFM(O) contracting forms.

Sustainability can be specified in criteria based on the 3P theory with the main criteria People, Planet and Profit. These main criteria can be divided in Corporate Social Responsibility, regional social contribution, multiple use of space, emissions of PM_{10}, NO_2 and SO_2, nature, CO_2 emission, water quality, soil quality, noise nuisance, adaptability, future recycling and demolition and Net Present Value. The request of the client has to be as clear as possible in such a way that the contractor knows exactly what the criteria are and how they are measured with which indicators.

The aim is to quantify criteria as much as possible, which is easier for implementing results by both the client as contractor. An analysis of the impact on the total Life Cycle (LCA) from realization to demolition is needed to get insight of the sustainability of the work. Based on these results an assessment can be performed.

The traditional method of weight summation does not take the balance between criteria into account. This balance is necessary for a sustainable project. The studied model gives a solution for this problem by including more criteria and by analyzing both the sustainable performance of the project and the underperformance. This gives more insight in the sustainability of the alternative and a better balance between the criteria. An example is the adaptability of a design which is not taken into account in current models.

The main problem with traditional methods is that scores on criteria with a heavy weight can compensate for scores with a lower weight. In this study there is shown that an alternative with the highest scores on the most weighty criteria is not automatically the preferred alternative.

Another advantage of the concordance analysis is the amount of extra information about the outcomes. When outcomes lay closely together, this information can help to decide which alternative is the most preferable. For example, when the concordance indices are almost equal, but there is a large difference in discordance, the choice can be made based on these discordance values. To make the method more reliable for determining the most economically advantageous tender other criteria can be added such as the technical design.

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Open Water Ports: Possibilities and Challenges for Container Terminals

Martijn P. C. de Jong, Otto M. Weiler and Jan-Joost Schouten

Abstract In this chapter, authors put forward a port layout design approach for an exposed container terminal. This is an unusual approach for this type of terminal because of the associated strict vessel motion criteria. Nevertheless, in view of increasingly bigger container ships that will respond less to environmental conditions, the proposed approach departs from traditional ideas on wave sheltering in ports. The chapter discusses associated advantages and disadvantages. Aside from potential economic benefits, advantages of such an approach could be smaller coastal impacts and larger sustainability. For the disadvantages we present possible directions in which we foresee that solutions could be found to overcome those (technical) limitations. After the remaining technical issues have been solved, and when the business plans of ports can facilitate this new approach, the concept of an open water port is expected to form a more sustainable alternative to traditional port layout design approaches.

Keywords Port layout design · Wave sheltering · Breakwaters · Innovative mooring techniques · Innovative container cranes · Minimising coastal impacts · Sustainability

Introduction

Traditionally, ports are designed using large and costly structures, e.g. rubble mound or caisson breakwaters, to provide shelter from ambient wave and current conditions. However, with ships getting bigger and bigger one can ask the question how much protection is still required. Should we invest heavily in protective

M. P. C. de Jong (✉) · O. M. Weiler · J.-J. Schouten
Deltares, Harbour, Coastal and Offshore Engineering Department,
PO Box 177, 2600 MH Delft, The Netherlands
e-mail: martijn.dejong@deltares.nl

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measures, or can we mitigate the motion response of vessels via new technical means of mooring and cargo transfer, or could container shipping companies accept higher downtimes?

In this chapter, authors propose an alternative port design approach that departs from the traditional ideas on sheltering and starts off with a (more) open port situation, located on a detached structure or land area close to shore. Similar concepts have been suggested a number of times in the past, e.g. by Bruun [1–3], Burdall and Williamson [4], and Tsinker [12]. Bruun [3] states for example:

> It is obvious that it may sometimes be difficult to justify the cost of … breakwaters and that it therefore may be necessary to find a less expensive alternative to reduce their length to a minimum. This raises the question as to whether in specific cases it will be possible to avoid the use of breakwaters altogether, in favour of an unprotected berth, and thus to construct only a pier.

However, these suggested concepts were not seen as a standard approach and since then they have mainly been applied for tanker terminals. Furthermore, they were mainly driven by economics and not by sustainability motivations.

Focus of this chapter is open water ports for container terminals, which is an uncommon concept, since such terminals involve the most stringent criteria on wave and current conditions. For certain other types of cargo the open water port principle is much more common. For decades the oil industry is using open water facilities for liquid cargo. Ongoing developments in that field include the Joint Industry Project HawaII (sHAllow WAter InItiative), which focuses on mooring LNG vessels in relatively exposed conditions in shallow water and the effect of low-frequency (infragravity) waves in particular [7]. Bruun [2, 3] refers to the classic example of the Port of Hadera in Israel, where coal for a power plant is delivered to shore from an open water mooring location (Fig. 1). Many ongoing open port developments and plans, e.g. bulk terminals in Australia, indicate that the concept of an open port has since then remained mostly limited to these specific cargo types.

The development of Yangshan, Shanghai's deep-water container port, can be considered an exceptional situation, in which a fairly open container terminal was constructed by connecting several natural islands, about 30 km off the main coast, via a reclamation. However, nearby islands shelter those container berths from incoming waves. Another recent example is the offshore container terminal of

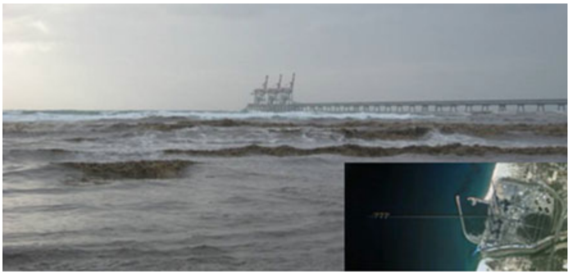

Fig. 1 Open water terminal at Hadera, Israel

Mumbai Port (Fig. 2), which is planned to become in operation in 2013. That terminal is in fact a good example of the open terminal concept as discussed in the remainder of this chapter. It has been built in the relatively sheltered waters along the Thane Creek, on the lee side of the Mumbai peninsula. Other similar developments have also focussed on relatively sheltered areas (bays etc.). The most recent example known to the authors of a plan to construct an open water offshore container terminal is near Venice, Italy (Fig. 3), but this scheme still includes large breakwaters to provide shelter from waves. In all, it can be concluded that so far the open port concept, particularly for container terminals and/or in more exposed conditions, has not really caught on.

Fig. 2 Artist impressions of the new offshore container terminal of Mumbai port (*Source* V. Dudhwadkar)

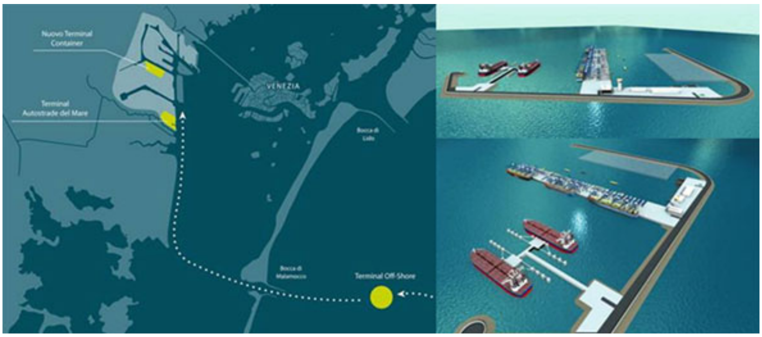

Fig. 3 Terminal plans of the Port of Venice (*Source* www.port.venice.it)

Since the time that the open port concept was first suggested (early eighties) the trend of increasing container vessel sizes has continued: from 250–300 m, 4,000 TEU, to around 400 m length, 15,000 TEU. Furthermore, significant developments have been made in innovative types of mooring equipment. Moreover, a clear trend in the last decades is the increased interest in sustainability and the increasingly common requirement for ports to become more ‘green’. In our view, these elements justify a renewed consideration of the unsheltered port concept, within a broader frame of reference, combining the benefits of an open port as identified earlier in literature with the increased attention to sustainability of port developments.

In this chapter we put forward the approach of an open nearshore container port for further discussion and consideration. The approach is presented including both the associated benefits, mainly focussing on sustainability, as well as the associated disadvantages, including the several technical challenges that still need to be overcome to ensure that an unsheltered port becomes a realistic design alternative on a regular basis. For the disadvantages we present possible directions in which we foresee that solutions could be found to overcome those limitations.

When the suggested approach proves to be feasible, then that would mean that new (nearshore) port designs will become less invasive, with reduced impacts on the surrounding (coastal) areas. Furthermore, such an open port situation could be designed such that less sedimentation occurs compared to more confined port layouts, which could lead to a reduction in dredging efforts (and associated fuel usage and plume dispersion) and less issues of accumulating pollutants. These types of advantages indicate that the alternative port design considered here could form a more sustainable option compared to traditional port design approaches.

Rationale Behind the Open Water Port Concept

Historically, ports started inside naturally sheltered locations along rivers or inside bays and estuaries. With increasing vessel sizes, ports moved towards deeper water along the coast. Often such locations did not provide sufficient shelter from waves and breakwaters were erected to provide calm conditions artificially. Several recent port extensions/developments go a step further and involve large land reclamations that protrude into sea, in which the basins are surrounded by the newly reclaimed land. This ensures that the required depths can be provided at reasonable costs and efforts. Furthermore, the reclaimed land facilitates the quayside operations very efficiently. Examples are the port developments in Dubai, such as Port Jebel Ali [9], and the large Maasvlakte 2 harbour extension of the Port of Rotterdam (see e.g. [5]). In those cases sheltering is provided by breakwaters and/or the (closed) outer contour of the surrounding land area.

At other locations in the world developments on such a large scale might not be feasible because of technical, ecological, and/or economical reasons. In search of even larger depths for increasingly larger (container) vessels, with lengths of about 400 m and draughts around 14.5 m, a logical next step would be to move out to open sea and develop berthing facilities there.

An open nearshore container terminal could be a basic detached reclamation behind which vessels are moored. Because of their large dimensions, it will be possible to (off)load container vessels in quite severe wave conditions, also without providing sheltering via additional large (breakwater) structures. The less confined geometry compared to traditional designs of port basins might even help reduce seiching in basins, particularly when low-frequency (infragravity) waves are present, which are well known for causing excessive motions of moored vessels (see e.g. [6, 13]).

The reclamation can be aligned with the dominant physical coastal processes as much as possible, particularly tidal currents and sediment transports. This will ensure that alongshore morphological processes are impacted as little as possible. Furthermore, the open port layout could be designed such that sedimentation can be kept to a minimum, possibly even up to the point where the tidal conditions ensure that settling sediments during slack tide are flushed out of the manoeuvring areas during other tidal stages. Also the influence on ecology could be minimised in this way, because the natural migration paths of sea animals are hindered as little as possible.

An open water port could require less building efforts than a traditional port design, although it will involve constructing a connection to shore. Such a connection could be a train bridge connection, or a road deck on piles (Fig. 2). That will involve additional costs compared to a traditional port design, which might (partly) counteract the savings of omitting breakwaters. Although of high relevance for the general feasibility of port planning, these economic aspects of an open water port are not the main topic of the present chapter. Here we discuss technical aspects of the open nearshore port design, limitations and benefits, the latter with a focus on sustainability aspects.

In order to have a sustainable development of a port, a port design should include a direction of growth which is aimed at meeting the present requirements while at the same time preserving the environment so that these needs can be met not only in the present, but also for future generations. This implies that future developments, although difficult to foresee completely, should also be considered in the initial port master plan as much as possible. An additional benefit of the nearshore open port design is that fewer complications are foreseen in terms of future port extension compared to the traditional port located inland. Although marine spatial planning is an issue, more directions of freedom for port expansion are available offshore, automatically resulting in less conflicting functions. This makes the open port design more ‘future proof’, allowing flexible adaptations to future developments.

Limitations and Mitigation

Identification of Most Critical Limitations

It is realistic to note that a number of technical challenges still need to be overcome in order for the open nearshore port to become a common and equivalent alternative to the traditional way of port designing. The main challenge for a design approach based on an open water port will be to keep the downtime of a container terminal at an acceptable level, i.e. comparable to terminals in traditional, sheltered ports. This can be achieved via different means, either by limiting the response of the vessel to waves or by adapting container cranes to deal with increased motions of the vessel. These aspects are considered in detail below. Other challenges include the transport of containers between the offshore terminal and the mainland, which should be possible under a wide range of wind conditions. In addition, the structure connecting the terminal to the mainland needs to be able to withstand severe wave conditions. Those elements are not considered further here, but do need to be taken into account when developing an open offshore port.

Mitigation via Reduction of Vessel Motion Response

Recently, PIANC published updated guidelines for maximum allowable motions of moored container vessels for efficient (off)loading [10]. They conclude that for large container vessels the requirements for surge motions are particularly critical because present-day container cranes cannot follow that motion efficiently. The working group report states that when surge motions are kept within prescribed limits, movements in other degrees of freedom are expected to be within acceptable limits as well.

In recent years innovative mooring systems have been developed that show potential to be very efficient at keeping vessels constrained at the berth, particularly for surge motions. A method where magnets are used to hold the ship at the quay has been developed at Delft University of Technology by Fiktorie [8]. Another new mooring technique is the Moormaster™ unit, which uses vacuum pads to keep the vessel at the berth. Performance analyses of such units showed that ship (surge) motions for a given sea state can be reduced significantly using such techniques (see e.g. [6]). A third system has recently been developed by the Boatmen Association in the Port of Rotterdam. This technique is called Shore-tension (see http://www.shoretension.com/). It consists of units positioned on the quay (Fig. 4) that ensure that the proper line tensions are maintained, leading to reduced (surge) motions of the moored vessel.

Although each of these systems has its own benefits and limitations, these ongoing developments indicate that on the response side of the vessel there is much to gain in efficiency compared to traditional mooring techniques, even more

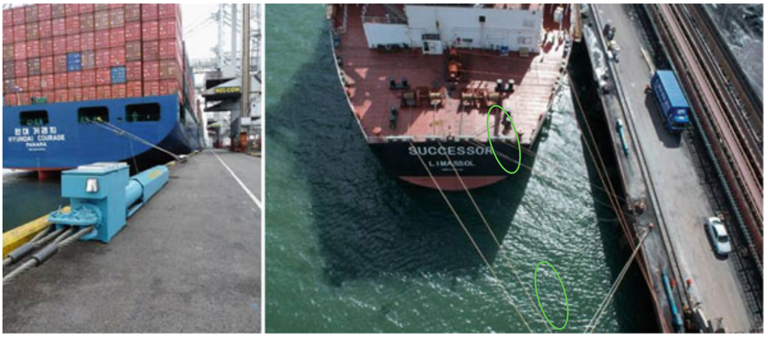

Fig. 4 Example of a recent development in mooring techniques: the Shoretension system (*Source* www.shoretension.com)

so than was the case when Bruun [1] first suggested the option of an open, exposed port. The increased capability of reducing the vessel response is expected to be exchangeable for the lower level of sheltering provided by an open port, even for container vessels.

Mitigation via Increased Container Crane Capabilities

The criteria reported by PIANC [10] have been developed based on the present state of technical developments, taking for example capabilities of twist-lock pins and spreader flaps into account. Nowadays, gantry crane spreaders may also have the capability to compensate for vessel surge motions to some level, but in practice these are not always used to their full extent. This can be related to either the level of experience of a crane operator, to the complexity of the methods, or to the time it takes to apply these methods compared to just wait for the next window of opportunity to place the container on the ship. On the other hand, ongoing innovations by container crane designers and builders are expected to lead to smarter cranes with practical surge compensation capabilities in the future. A somewhat extreme, but very interesting innovation in this field is the recent development by the Office of Naval Research (ONR) of the Large Vessel Interface Lift On/Lift Off (LVI Lo/Lo) Crane (Fig. 5) for ship-to-ship container transfer at sea [11]. This development shows that using information on vessel motions, and enabling the crane to compensate for those motions, will greatly enhance container crane capabilities.

The LVI Lo/Lo system has been developed for ship-to-ship cargo transfer operations in up to Bft 4 sea states. Vessel motions inside a port, even under less sheltered conditions, will be much smaller than at open sea. Therefore port container cranes will probably not require the same level of complexity (and costs). Nevertheless, the operational reliability of such a system in a high throughput

Fig. 5 The large vessel interface lift on/lift off (LVI Lo/Lo) crane for ship-to-ship container transfer at sea (*Source* ONR, USA)

situation inside a port will require ample attention. Overall, it is expected that even when only specific elements of elaborate crane innovations are adopted for container gantry cranes that the capabilities of those cranes will already be greatly enhanced, further contributing to the feasibility of an open nearshore port design.

Benefits, with Focus on Sustainability

Coastal (Morphology) Processes in a Traditional Port Design

The main sustainability benefit of an open port design will be the smaller impact on coastal (morphology) processes. In this section first coastal processes and related impacts are considered for a traditional port design including breakwaters, before discussing the advantages that the open port design could provide (Coastal (Morphology) Processes in an Open Port Approach). These advantages will mainly be related to reducing or avoiding the coastal impacts associated with those traditional port designs.

No severe erosion or sedimentation will occur as long as a coastal system is stable. In case of sandy coastlines, wave and current conditions generate longshore sediment transport along the coast. The magnitude of this transport spatially differs in cross-shore direction, which is determined by the local hydrodynamic conditions. In general these hydrodynamic conditions are dominated by the nearshore wave climate. The magnitude of the longshore transport has its maximum in the surf zone, i.e. the area between the breaker line and the coastline, and reduces further offshore (Fig. 6). The sediment transport will be proportional to the current velocity.

The longshore sediment transport will be blocked when reclamations and/or breakwaters are constructed and therefore this can significantly affect the coastal stability. This will result in accretion at the updrift side of the port and in erosion at the leeward side of those structures.

The process of accretion will move the coastline, actually the whole cross-shore profile, in offshore direction until sediment is no longer completely trapped by the updrift breakwater. From that moment on a part of the longshore sediment will move around the tip of the breakwater and enter the navigation channel and port basins. Depending on the local hydrodynamics and bearing capacity of the port basins and navigation channel, the sediment can become trapped inside the port.

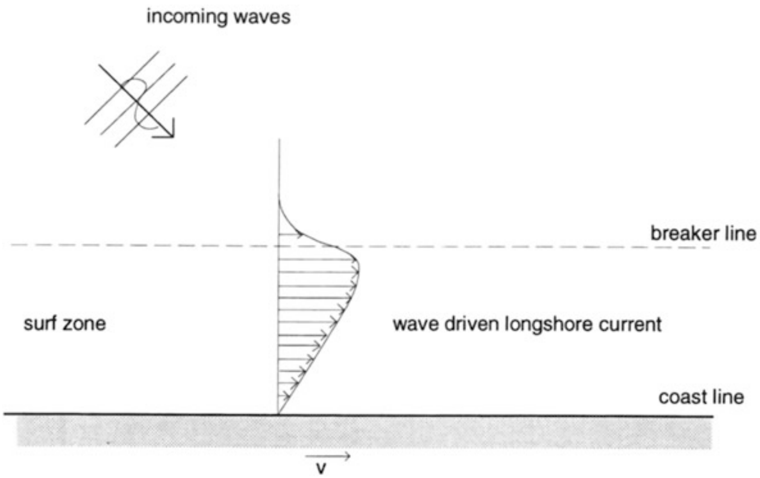

Fig. 6 Wave driven longshore current, most dominant in the surf zone

Fig. 7 Port of IJmuiden, sediment transport is directed in northern direction (i.e. towards the *top left* of the image). Accretion occurs at the south side of the breakwaters (*Source* RWS)

Fig. 8 Port of Carrara, Italy (*Source* Google Earth). Sediment transport is directed in south-eastern direction. Sand accumulation occurs at the north-western side of the port. The groins on the eastern, downdrift side of the port cover the area with erosion problems

The examples of these types of coastal problems are numerous. A classical example is the Port of IJmuiden, The Netherlands can be seen in Fig. 7. When reaching this point in coastal development, the nautical depth of the navigational channel can no longer be guaranteed as well as the depth of the port basins. Maintenance dredging costs may increase significantly. Not only maintaining the nautical depth is a problem, in terms of costs, energy or hindrance to navigation activities, also the dredged material itself can form an issue. The dredged material could be contaminated and require special storage or specific cleaning methods.

Erosion will occur at the downdrift side. An example is the coastal impact of the Port of Carrara, Italy, which is shown in Fig. 8. In response to the construction of the port, the coastal area southeast of the port started to show erosion. A series of coastal protection schemes were constructed in order to maintain the initial coastline position. Most often, hard coastal structures, here a combination of groins and detached breakwaters, are designed to maintain the position of the coastline. However, this automatically results in a shift of erosion further downdrift. The extent of this shift is limited only by locations where the natural local longshore sediment transport is reduced to zero or alters its direction. The example in Fig. 8 shows that the extent of the coastal impacts of a traditional port design can easily be a number of times larger than the horizontal dimensions of the port itself.

A possible solution to overcome the negative effect of blocking longshore sediment transport due to a port is to apply a sand bypass system. Such a system involves the installation of pumping stations at the updrift side of the port breakwaters, where the accretion occurs. The pumped sand is placed at the downdrift side of the port. Such a system aims at preventing sediment from being transported towards the entrance channel and the port basins and additionally, erosion is prevented at the downdrift side of the port. In order to be efficient, the pumps will have to be operational on a daily basis, like at the Nerang River entrance in Queensland, Australia, where the sand bypassing system is operational since 1986. Operating such a system will have a number of drawbacks. The first issue is the environmental impact of bringing sediment into suspension at the disposal area. Secondly, a large amount of energy is required for the pump systems on a daily basis.

Another option is to regularly apply coastal sand nourishments in eroding areas. A drawback of such an approach is that it can have an adverse effect on the marine environment and particularly on the benthic communities (bottom-dwelling sea life). Dredging is widely considered as an activity that is stressful to the environment and many studies have described its impacts (see e.g. [14]). In some countries this has resulted in policies that restrict dredging operations. As there is a strong relation between the local sea bed characteristics and the associated faunal community, changes in the geomorphological structure and hydrodynamic conditions due to dredging and nourishment activities are expected to result over time and in space in adaptations in the faunal composition. A result could be the alteration of the marine species diversity and of the productivity of an area, including commercial fish species.

It is obvious that none of the presented mitigating measures for coastal stability result in a truly sustainable strategy and this speaks for considering alternative port designs.

Coastal (Morphology) Processes in an Open Port Approach

Following the understanding that the longshore sediment transport is most significant in the nearshore zone, the location of a port design further offshore in open and deeper waters avoids blocking the longshore sediment transport and therefore reduces accretion and erosion issues associated with traditional port designs. This requires an 'open' structure as connection to the mainland, like a jetty. In that way the longshore currents and the related longshore sediment transport remain largely undisturbed. To achieve such a situation, the reclamation needs to be located seaward of the surf zone, i.e. beyond the region with the highest sediment transport rates (Fig. 5). This requires that the reclamation is constructed at a distance from shore of at least several hundreds of meters, depending on the local average wave and tidal conditions.

The construction of the reclamation for the port infrastructure will to some extent influence the local wave conditions. This means that also in an open port design approach the coastline will be influenced. This might result in e.g. the initial stages of salient formation. Nevertheless, the coastal impact of an open port design is expected to be minor compared to the accretion and erosion that could be caused by port breakwaters.

In addition to coastal impacts, sedimentation of the harbour basins can be a major concern when considering maintenance costs as well as environmental impacts. The dredged material will have to be disposed at an appropriate dump location. This either offshore, or in case of contaminated sediment, at a special confined disposal facility. The advantage of the proposed open port design is that the use of relative large water depths offshore and the local current conditions could result in much less or possibly no dredging activities of the port basins. This not only limits the dredging during the construction phase but also for the following operational (maintenance) phase of the port basins.

Discussion and Outlook

Most of the separate elements and viewpoints presented here are not new on their own. However, social developments like increased focus on sustainability combined with technical innovations in the last decade, e.g. on advanced mooring techniques, mean that the combination of these elements merits renewed consideration within a larger framework. Therefore the open-water port concept is presented here as a starting point for further discussion and consideration. Particularly the benefits on sustainability and minimisation of (coastal) impacts should form important incentives to elaborate on the option of open port layouts for future port developments.

We suggest altering the design approach that is most commonly applied nowadays. Instead of a priori assuming that a fully tranquil basin is required and designing a port to match that criterion, we propose to start with reviewing the level of shelter that is required and continue from there. This requires that all parties involved should come together early in the design, including future terminal managers/users, to set up an overall port layout plan that is a balance between providing wave sheltering and measures to limit or mitigate the response of a vessel. Only in that way the benefits of an open nearshore port design can be used to its fullest potential.

The same applies for the coastal impacts of a scheme, which are often studied when the port design is almost fully completed and the resulting coastal impacts are seen as given, almost unavoidable, side effects. By first studying the local coastal system, including morphological processes, the port design can be made such that it takes those processes into account from the start and could even make use of them.

Although not the focus of the present chapter, it is relevant to mention that developing the open port concept for container terminals is expected to also involve adapting the business cases for such terminals. This will include the (re)distribution of costs, e.g. will the port bear the investment costs of the advanced mooring facilities and/or can the lower construction costs of the port geometry result in lower lease fees for terminal operators? Only in that way ports based on this alternative design approach can compete with ports that offer traditional mooring facilities.

In the end we expect that full acceptance of an open port approach will take a number of successful pilot projects by port developers that see the long term benefits of this alternative design approach and are willing and able to take up this challenge.

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Role of Flexibility in Sustainable Port Development

Poonam Taneja, Tiedo Vellinga and Robin Ros

Abstract Sustainability has become a high profile objective in all aspects of our lives, including the development of our infrastructures. Flexibility can enhance sustainability endeavors, yet its contribution is not clear to most. In this chapter, authors investigate the role of flexibility in sustainable port development in order to promote its incorporation in port projects. We establish that the greatest payoffs from flexibility are achieved through initiating new life cycle for a capital-intensive port infrastructure, though reuse of the elements and materials also contributes to flexibility. Reuse concurrently optimizes use of natural resources, limits waste and pollution in the environment, conserves energy, and thus limits the overall negative ecological impact. It also results in significantly lowers lifecycle costs. Thus, flexibility helps achieve (long-term) financial viability in face of economic uncertainty, while reducing environmental and social impacts. Therefore, flexibility considerations are important during design, procurement, and contracting of engineering projects. The best way to redirect the choice of decision-makers towards flexibility is to make visible its long-term benefits, and its contribution to sustainability. We discuss some evaluation methods and propose that the quantitative methods are more likely make a case for flexibility.

Keywords Flexibility · Sustainability · Sustainable port development · Reusability · Long-term planning

P. Taneja (✉)
Poonam Taneja, Delft University of Technology, Faculty of Civil Engineering,
P.O. Box 5048, 2600 GA Delft, The Netherlands
e-mail: p.taneja@tudelft.nl

P. Taneja · T. Vellinga · R. Ros
Delft University of Technology, Faculty of Civil Engineering, P.O. Box 5015,
2600 GA Delft, The Netherlands

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Introduction

The global concerns over availability of natural resources, the growing pollution, global warming, climate change, and an increasing awareness are the major drivers for sustainability in the modern world today. It is believed that sustainability represents a multi-dimensional way to improve the quality of life for everyone. Sustainable development touches all aspects of our lives including the places we work and live, the natural recreational pleasures we enjoy and the natural resources that support all life. Much attention is being devoted to how the practice of sustainable development, in contrast to the traditional linear approaches to decision-making, could be helpful in evaluating policy choices or business decisions [1, 2].

Sustainable development of infrastructures, which are the skeleton of our economy, is also a focus of considerable attention. The decision-makers involved in infrastructure projects must select among different project and project alternatives, which, in varying degrees, contribute to sustainability. Till recently, the evaluation has mostly been based on an economic criteria but nowadays various sustainability criteria are being included in the process. Many claim that flexibility in infrastructures enhances sustainability attributes through addressing uncertainty [3, 4]. Though flexibility is often among the selection criteria during project evaluation, it is not assigned a significant weight, mainly because its contribution to sustainability is not clear to most.

In this chapter, authors investigate the role of flexibility in sustainable port development. Our objective is to promote its incorporation during design and planning of port infrastructures. We think that by making clear its contribution in enhancing sustainability endeavors, we can redirect the choice of planners and decision-makers towards flexibility.

Our research approach is to first investigate what sustainability and flexibility represent in the context of ports. Next, we seek a link to flexibility—what dimensions of sustainability does it influence and in what manner? Finally we ask ourselves how we can direct the focus towards flexibility in practice, i.e., during design, procurement, and contracting of civil engineering projects.

Sustainable Port Development

Port Development Project

Infrastructures represent the basic services and facilities necessary for an economy to function [5]. Port infrastructures are an essential component of the international trade and goods movement. Currently, a global increase in trade and cargo throughput, overlapping port hinterlands and increasing competition, combined with the ageing and inadequate infrastructure in most ports worldwide, are driving forces for new port investments.

A port development project can mean an entirely new port, or an expansion and upgrading of the existing facilities. The Chairman of American Association of Port Authorities notes [6]: "Ports hold a unique role in transportation, logistics and infrastructure development. Sustainability involves the simultaneous pursuit of economic prosperity, environmental quality and social responsibility. Ports recognize that their activities may impact environment and natural resources and that they have responsibilities as members of communities in which they operate."

Any development project has economic, environmental, and social impacts. A port development project can involve reclaiming land (thereby disturbing the ecosystem) or sometime even causing displacement of the urban population. The vessel traffic and development activities translate into air quality, water quality, and noise issues; environmental management issues; and often accessibility issues for the adjacent areas. One can see why 'sustainable' and 'development' are seen to be oxymorons. Another contradiction is that while principles of sustainability advocate production close to centers of consumption, this results in reduced transport and international trade, on which ports (and related economies) are dependent. Having said this, we will attempt to operationalize the concept of sustainability and the idea it promotes.

Sustainable Development

Sustainable development of infrastructures requires that carrying out activities that offer economic benefits in the present, may not negatively affecting social and environmental choices that are available to people in the future. Ports contribute to economic benefits through cargo handling, and produce additional indirect benefits in the form of trade enhancement, second order increases in production volumes, and collateral increases in trade-related services, and to the social dimension of sustainability through lowered transportation costs and job creation [7]. Sustainable development of port includes *designing, building, and operating* port infrastructures in ways that does not diminish the social, economic, and ecological processes required to maintain human equity, diversity, and the functionality of natural systems.[1] The three aspects are discussed here.

The planning and design of new port infrastructures, or the adaptation and reuse of existing infrastructure, should be consistent with the principles of urban sustainability and global sustainable development. This encompasses the following considerations (as we will see later flexibility contributes directly to most of these):

- an efficient (intensive) use of space
- efficient use of resources and increased productivity of assets
- attention for accessibility of the port

[1] http://www.civ.utoronto.ca/sir/default.htm.

- minimizing energy consumption
- greater consideration of cost recovery of port infrastructure investments
- reducing lifecycle costs (the taxpayers money can be put to alternative uses)
- designing infrastructure and its elements for reuse, e.g., recyclable, maintainable
- material selection for sustainability e.g., quality, durability and energy conservation
- as far as possible future-proof (with regard to technological developments, global climate change, sea level rise etc.).

Sustainability during construction and operations generally means measures related to resource and energy efficiency during material selection and construction, as well as consideration during selection of equipment, logistic concepts, and operations. It involves monitoring air and water quality, implementing mitigating actions, ensuring health, safety and security, and efficient use of resources (water, space etc.). In the long run, the ultimate desire is to achieve a situation whereby the ports operations become environmentally self-servicing and responsible [8].

Flexibility in Port Development

Defining Flexibility

Sustainability and flexibility are multi-dimensional concepts and various definitions exist in literature. They have an inherent relationship to each other as well as with the concepts of risk and uncertainty. Moses [9] in his framing paper over 'Foundational issues in Engineering systems' explores the relationship between robustness, uncertainty, flexibility, safety, and sustainability. Dovers and Handmer [10] study the relationship between sustainability, risk, and uncertainty. In order to investigate the relationship between sustainability and flexibility, we first examine some definitions.

Sanchez and Wilmsmeijer [11] define flexibility, in generic terms, as the ability of a system or organization to change or react with little penalty in time, effort, cost, or performance. Bettis and Hitt [12] define flexibility as the ability to rapidly sense the change in the environment, conceptualize a response to that change, and reconfigure resources to execute that change. According to Dovers [13], sustainability is the ability of a human, natural or mixed system to withstand or adapt to endogenous or exogenous change indefinitely. Sustainable development is therefore a pathway of deliberate change and improvement which maintains or enhances this attribute of the system, while answering the needs of the present population.

Thus while both definitions refer to system change in response to external forces, sustainability adds new dimensions by mentioning 'future' and 'long-term'. Flexibility implies 'long term' through its reference to uncertainty. Both refer to resource utilization. Flexibility enables functionality under uncertain conditions and emerging requirements while sustainability adds economic, social and environmental dimensions to the system.

Flexibility Attributes and Sustainability

Scholtes [14]: The most important uncertainty management concept for large projects is that of flexibility. Managers should integrate flexible reaction capacity in the project, so that new schemes can be developed during the course of the project if a wholly unforeseeable event occurs. Predicting the uncertain future is difficult, but to the extent one can use past events as a guide to designing flexible alternatives or options into a system, the cost of adapting to similar events in the future will be greatly reduced [9].

The word flexibility in the context of ports can have many associations, e.g., flexible port layout, flexible infrastructures, flexible operations, flexible management, etc. We discuss here, how each of these aspects contributes to sustainability. In each case, the goal of flexibility is the same—to reduce vulnerability and cope with uncertainty.

- Flexible infrastructures conjure up the images of mobile, upgradable, downgradable, modular, multi-functional, multi-user structures. What is common to all of these is the ability to adapt, i.e. be remodelled to meet changing demands.
- A flexible Master Plan layout permits reconfiguration of a space for a new or changed use.
- Flexible operations can refer to flexible use of resources (labour, equipment, etc.) and flexible operating procedures, in response to changing scale or type of operations.
- A flexible management is willing to alter its approach in response to unanticipated change with regards to planning, decision-making, policies, and actions.

A flexible layout allows future expansion, and permits re-configuration without expensive modifications. Flexibility in infrastructure helps to prolong the useful lifetime of an infrastructure through allowing adaptation and thus promoting reusability. Reuse concurrently optimizes use of natural resources, limits waste and pollution in the environment, thereby reducing the overall ecological impact. It also results in significantly lowers lifecycle costs (despite the costs associated with incorporation of flexibility and subsequent adaptations) and conserves energy resources. The savings can be invested in improving social equity or the environment. In this manner flexibility helps achieve (long-term) financial viability in face of economic uncertainty, while reducing environmental and social impacts. A sustainable product is often referred to as a product whose economic benefits that outweigh its tangible and intangible costs so as to provide financial capital for continued development [3]—as we have seen, flexibility makes this possible.

The greatest payoffs are achieved through the reuse of the capital intensive infrastructure whereby a new life cycle is initiated. This type of reuse is the highest form of waste reduction. However, reuse as components or raw materials integrates the structure into a life cycle of another structure and also contributes to sustainability. Recovery from products to obtain raw materials or reusable components is an important means of reducing disposal volume and cost while contributing to environmental sustainability.

It is useful to note here that attributes such as interoperability, interchangeability, compatibility, scalability, evolvability, and mobility facilitate adaptation and reuse. In addition, maintainability and durability promote reuse of an infrastructure. A structure that is easy to dismantle or assemble facilitates reuse of its elements. Recyclability promotes reuse of material. Flexibility is often aimed at improving efficiency, productivity, and reducing engineering effort and costs. These contribute to sustainability endeavours as well. Even though adaptation incurs costs, a payoff occurs in the form of lowered ecological impact. Greden [3] suggests that a flexible design will have a different risk-reward profile than an inflexible system, and thus may be more attractive to investors. Flexible designs will help to advance sustainability goals by specifically addressing future uncertainty at the design stage.

While flexible designs create many benefits in the system, flexible (uncertainty absorbing contracts) with the terminal operators and contractors, reduce the future risk for a Port Authority. Flexible utilization of resources during operation, sometimes geared to changing scales (in response to change in demand) and at other times to changing cargo, serves to intensify use of resources, thereby contributing to sustainability. An adaptive management willing to periodically re-examine its assumptions, and adopt new strategies and procedures in the face of new developments, can steer a firm to cope with change. Flexibility during decision-making allows time for uncertainty to clear up.

To sum up in words of Greden [3]: Flexibility's contribution to sustainability goals lies in reducing waste and/or positioning a product/design/or system with sustainability benefits to hedge financial risk and, on the upside, to take advantage of evolving opportunities.

Flexibility and Sustainability as a Design Approach

The traditional approaches and frameworks tend to emphasize near term solutions to infrastructure planning, which means that there is inadequate attention for sustainability [15]. Flexibility, on the other hand requires a holistic, long-term systems approach. Through aspiring for flexibility, we include a long-term perspective, which automatically encompasses uncertainty considerations and embraces issues that might be important in the future. Designing for flexibility fundamentally embodies a life cycle approach to design, whereby life cycle costs and long-term performance have to be considered. This also applies to sustainability that needs a systems approach: accepting and designing approaches that suit the axiomatic proposition that the sustainability problem is a whole-system problem [10].

Designing for flexibility and sustainability requires that projects and decisions be made with the long term benefits in mind. It requires that environmental and social impacts of the proposed outcome or result be a part of the decision-making process. Flexibility and sustainability considerations are required at the beginning of a project. For instance, the cost of recycling and disposability can be significantly affected by decisions related to materials and designs. They require a systematic approach to the integrated design that considers from the very outset all elements of the product life cycle, from conception to disposal, including cost, schedule, quality and user requirements.

According to Greden [3], flexibility, as a design goal and operational mandate, can make a major impact on the sustainable attributes of an infrastructure. Applying her definition of a sustainable product, a sustainable port exhibits a positive economic, environmental, health, and safety performance record, thereby providing people and the earth, including all of its ecosystems and life forms, with the capacity to thrive in future generations.

Opting for Flexibility and Sustainability

Standard Practices

A port project goes through various stages: preliminary design, feasibility study, detailed design, tendering and construction, exploitation, and adaptation or decay. Evaluation and selection takes place at the feasibility stage and the tender stage.

Feasibility stage: Engineers from various disciplines carry out the technical design, and a business case is set up to examine the financial viability of a project. The Net Present Value and the Internal Rate of Return are the most commonly used financial criteria. Uncertainty is only reflected in a higher discount factor or a shorter payback time. It seems self-evident, in present times, to take uncertainty, flexibility and sustainability aspects related to a port into account during the evaluation. This is however not standard practice, and can lead to misguided decisions. Worthwhile projects may not pass the (financial) feasibility criteria for screening projects and result in missed opportunities for the port, along with lost benefits for the society [16].

In the present practice, the indirect and societal impacts of a port development project are stated separately in the business case, while remaining outside the profitability calculations. This involves a risk that societal impacts are represented less prominently than financial items so that the business case is not balanced. In marginal cases, an attempt is made to include the societal costs and benefits in a port development business case. But it is difficult to justify this to the port management, as it does not form a part of the standard procedure of project evaluation. As a result, the commercial criterion mostly governs.

Tender stage: Next, the selected alternative is put on the market in a tender in order to select a contractor to carry out the construction. The selection is based on the EMVI criteria[2] (or the lowest bid). But an evaluation based purely on costs, and the constraint on the tenderer not to offer alternative designs but base his bid on a reference design, does not propagate innovation. In an alternative method, the landlord port authority sets out a design and construct contract, where the total bid including the design and the construction has to be evaluated. The decision is based on the cost of the project, and not on its value. The added value of an innovative flexible concept is to increase utilization, productivity and consequently increase income and minimize risks. This cannot be revealed through a cost estimation.

People, Planet and Profit are used to succinctly describe the triple bottom lines and the goal of sustainability. How to include the people, profit and planet criteria in such an evaluation procedures, is a challenge for all.

Incorporating Flexibility Criteria in Evaluation

In this section, we discuss how sustainability is implemented in the tendering procedure for infrastructural projects, and examine how we can best implement flexibility.

Sustainability has become a high profile objective. Decision-makers in governments and businesses must choose among different project alternatives which, in varying degrees, contribute to sustainability. They also have to account for their choices to a large audience or a broad range of stakeholders [17]. The organisation for economic cooperation and development (OECD) has drawn up recommendations for corporate social responsibility, which includes principles and standards of good practice consistent with applicable laws for multinational enterprises.[3]

Sustainability criteria being considered during evaluation are: the extent of occupied space, reduced land value due to division of land, additional traffic generated due to the construction, deterioration of existing nature, emissions in air and in surface and ground water, nature compensation measures, creation of nature-friendly banks and slopes, implementation of an environmental management system, attention for energy demand, measures concerning disposal of waste materials, measures against noise during demolition, construction and operations, reuse of material, attention for ecological constraints, e.g. amount of earth filling, soil quality etc. In the Netherlands, the 5 % rule (or social return agreement) is applicable whereby 5 % of the building sum is set towards employing long time unemployed or trainees.

[2] Economisch meest voordelige inschrijving.

[3] http://www.oecdguidelines.nl/guidelines/general-humanrights/.

Flexibility in decision-making, design and operations, enhances the value of a project, but cannot be included in the project evaluation with standard methods. Though efficient use of space and reuse of material are among the many evaluation criteria, flexibility in its highest form (reuse of infrastructure) is not included. Its contribution to sustainability is not clear to most, i.e., what does flexibility cost and what value will it create for the system?

Not only are the (positive) economic impacts of reusability difficult to estimate, the benefits of reduced environmental impacts are also difficult to quantify. The multi-dimensional nature of flexibility, and the likelihood that the flexibility may not be utilized and therefore result in a waste of resources, adds to the problem. Flexible innovative concepts carry with them considerable risks which are difficult to foresee. So how we can redirect the decision-makers to opt for innovative flexible solutions over the numerous alternatives?

The lack of suitable analytical and evaluation techniques has been a barrier against investments in flexibility in the past. New techniques have evolved, but their use is not widespread due to their black-box approach. We need to find ways to make visible and transparent the long-term benefits of flexibility such as optimum use of resources, lower lifecycle costs, better long-term performance, and minimization or compensation of negative environmental impacts. In case of a traditional tendering procedure this needs to be done at the feasibility stage, while in case of a design and construct contract, this is possible during the tender evaluation.

In this chapter, the authors limit themselves to investigating how we can include reuse or an extended economic lifetime in our evaluation.

Some Plausible Methods

Method 1: A Variation on the Traditional Approach

This is a variation on the traditional method which combines a qualitative and quantitative approach. The NPV is evaluated based on the tangible costs and benefits for each alternative. The intangible costs and benefits for each alternative are also listed. Flexibility criteria related to reuse can be added to this, and a qualitative evaluation carried out for each alternative. The criteria follow from the Delftse Ladder [18]. These can be assigned weights based on expert opinion and included in the evaluation. This method can be applied at the feasibility stage, or at the tender stage, using costs instead of revenues.

- Is the infrastructure reusable for another use without adaptation (is it robust against increased loads, bigger ships, another function)?
- If yes, how long (5–10 years, 10–15 years, 15–20 years)?
- Is the infrastructure reusable for another function with adaptation?
- If yes, how long (5–10 years, 10–15 years, 15–20 years)?

- What will the adaptation cost (as a percentage of capital costs: 0–10, 10–20, 20–30 %)?
- Are there reusable elements/components?
- Is the structure modular?
- Are the elements easy to dismantle, transport, and assemble?
- Are there reusable/recyclable materials?

The last two are the most commonly applied sustainability criteria. The many uncertain parameters and the qualitative nature of the method means that the evaluation is subjective. Therefore a fair comparison of alternatives may be specially difficult if the alternatives are similar. Willcocks [19] suggests that managers should enter alternative estimates of intangible benefits (e.g. minimum and maximum values) into the NPV model to explore the project's sensitivity to the delivery of these intangibles. Another shortcoming is that it is impossible to link the synthesized rating to business plans or to cash flow projections [20].

Method 2: Use of Scenarios

In this method, the port owner or Authority defines the technical lifetime of the infrastructure (say 50 or 100 years) and sketches a discrete number of alternative scenarios. Each scenario encompasses functional requirements for the infrastructure, a period of use, and the expected throughput. A design is made corresponding to each scenario and its NPV calculated. In this way, a range of NPV's is obtained which provides more information for decision support. These scenarios are merely plausible descriptions of the future, and the results are indicative, but adequate for the purpose of comparing alternatives. A range of NPV's also provides an indication of the risk and the selection will depend on the risk attitude of the manager. If most of the design parameters are a given, the flexibility in design (robust, upgradable, multifunctional, multi-user infrastructure) will be reflected in the NPV values. Many oppose the use of scenarios as being guess work.

Method 3: Expected Value Method

This is a variation of Method 2. A stochastic business case is set up at the feasibility stage. It can vary all uncertain inputs (future costs, revenues, and timing of investments) simultaneously, and is of great value in infrastructure planning and appraisal. It can also capture the complicated nature of contractual arrangements and payment mechanisms, incorporate the probability of an increase in throughput and include available flexible options in a project. It results in a range and distribution of the possible NPV outcomes and the likelihood of their occurrence. A probabilistic estimation of risks for all the projects in the portfolio provides an organization with a more realistic risk map that can influence their risk attitude, and allow them to timely steer their policies.

Discussion

Methods 2 and 3 can both be applied to take into account the flexibility attributes of an infrastructure [21, 22].

None of the above methods include indirect, i.e. social and environmental benefits of reuse. More research is required in order to monetize these in order to come up with a comprehensive evaluation model.

Conclusions

A global increase in trade, increasing competition, and inadequate infrastructure are the driving forces for new port investments worldwide. Ports recognize that their activities impact environment and natural resources, and seek a balanced approach for sustainable development. Sustainability has become a high profile objective. Flexibility can play a role in enhancing sustainability, yet its contribution is not clear to most. In this chapter we investigate the role of flexibility in sustainable port development in order to promote its incorporation in port infrastructures.

The greatest payoffs from flexibility are achieved through initiating new life cycle for a capital intensive port infrastructure, and to a lesser extent through reuse of elements and materials. Reuse concurrently optimizes use of natural resources, limits waste and pollution in the environment, conserves energy, and reduces limits overall ecological impact. It also results in significantly lowers lifecycle costs (despite the costs associated with incorporation of flexibility and subsequent adaptations). Thus flexibility helps achieve long-term financial viability in face of economic uncertainty, while helping environmental and social problems. We need to focus on flexibility in practice, i.e., during design, procurement, and contracting of civil engineering projects.

That flexibility may or may not be utilized in the future, acts as a big deterrent while making the decision to incorporate it. In order redirect the choice of decision-makers towards flexibility, the best way is to make visible the long-term benefits and thus its contribution to sustainability. We discuss three plausible methods which can include the costs and benefits of reuse during evaluation. (Reuse is facilitated by the flexibility attributes in a system, such as multi-functionality, scalability, modularity, and mobility, etc. which means added costs). We think that the quantitative methods are more likely make a case for flexibility. More research is required in order to monetize the other indirect and direct impacts of flexibility, to come up with a comprehensive evaluation model.

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Part II
Asset Management

An Integrated Approach to Strategic Asset Management

Kerry Brown, Martin Laue, Javier Tafur, Muhammad Nateque Mahmood, Pascal Scherrer and Robyn Keast

Abstract This chapter focuses on identifying and analysing the elements of Strategic Management for infrastructure and engineering assets and asks: what are the considerations and implications for adopting and implementing an integrated strategic asset management framework? We contend that corporate governance, policy, objectives and strategy as well as interagency collaboration should be considered as elements in a 'staged approach' to understanding how assets are managed within organisations. This will allow for a more comprehensive framework for engineering asset management that considers social and contextual elements. Asset governance details the policies and processes needed to acquire, utilise, maintain and account for an organisation's assets. It stems from corporate governance principles and defines the management context in which engineering asset management is implemented. This will be examined to determine the appropriate relationship between organisational strategic management and strategic asset management to further the theoretical engagement with the maturity of strategy, policy and governance for infrastructure and engineered assets. The chapter draws on a document analysis of corporate reports and policy recommendations in terms of infrastructure

K. Brown (✉) · M. N. Mahmood · P. Scherrer
School of Tourism and Hospitality Management, Southern Cross University,
School of Business, Gold Coast Campus, Locked Mail Bag 4 Coolangatta,
Gold Coast, QLD 4225, Australia
e-mail: kerry.brown@scu.edu.au

M. Laue · M. N. Mahmood
Cooperative Research Centre for Infrastructure and Engineering Asset Management
(CIEAM), Level 7, O Block, QUT Gardens Point campus, 2 George Street,
Brisbane, QLD 4000, Australia

J. Tafur
Department of Industrial Engineering and Business Administration,
Universidad Politecnica de Madrid, Av Ramiro de Maeztu, 7 28040 Madrid, Spain

R. Keast
School of Business, Southern Cross University, Gold Coast Campus, Locked Bag 4,
Coolangatta, Gold Coast, QLD 4225, Australia

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and engineered assets. The chapter concludes that incorporating an integrated asset management framework can promote a more robust conceptualisation of public assets and how they combine to provide a comprehensive system of service outcomes.

Keywords Integrated strategic asset management · Service delivery planning · Knowledge management · Organisational management

Introduction

Managing assets has become more complex and demanding than ever before due to increasing resource scarcity, degrading environment, climate change, and Humphrey [1], asset management is based on three main pillars: management, engineering and information, which together form a foundation for efficient and/or sustainable use. The degree of functionality of any asset is dependent on how well it is planned, designed, operated, maintained, and disposed in the context of these three core areas. As a counter to these challenging tasks, instead of managing assets through a whole-of-life cycle approach by individual agencies/organisations, there has been a shift towards a more integrated or collective approach involving multi-agencies/organisations. Such an approach allows organisations to access additional knowledge, expertise and resources to create collaborative advantage. This approach is not business as usual and necessarily requires a shift in the way in which infrastructure projects are developed, delivered and managed. Therefore, in this chapter, authors developed a more comprehensive framework for asset management in order to fit in a multi-agency environment, new contextual considerations and contemporary approaches to managing built assets.

New Issues in Asset Management

Previous asset management models while useful in their context are no longer sufficient or adequate to meet the changing nature and challenges of contemporary society. This chapter incorporates and extends a previous framework for asset management [2–4]. Drawn from (literature and workshops) a number of additional elements which are contended to be important for inclusion to be considered:

Environmental: Greater appreciation of the interaction between built assets and the natural environment.

Sustainability: Ensures that the social, economic and environmental needs of a community are met and kept healthy for future generations [5].

Resilience: Increased emphasis on the asset, environment and the community to respond to and recover from external impacts.

Whole of life asset management: Requires that decisions and actions across the entire lifecycle of the asset from design to disposal be considered.

Increased community demands: information and communication technology (ICT) advances have led to higher citizen expectations for immediate and localised services. Closer alignment of policies, resources and projects will deliver better quality, more efficient and timely built assets.

Information management: Information needs and capabilities are more demanding and complex.

Expanded governance arrangements: Assets are now owned, governed and operated by an expanded set of decision-makers. Alongside conventional governance forms, there is now an array of hybrid models such as public–private partnerships, alliance and relational contracts. More innovative and variable governance approaches are required for these different models to manage the unique risks and opportunities associated with them.

Integrated Strategic Asset Management Framework

The following framework pulls together the expanded elements and reflects the increasingly complex and interconnected processes which government and its agencies need to take into account when delivering services. The framework demonstrates that ISAM as shown in Fig. 1, is cumulative and each component is interdependent.

A logical progression through each component is required for maximum service delivery outcomes. Whilst this ISAM framework focuses on the public sector, it is equally applicable to any organisation or sector. The development of the ISAM framework is based on the current literature review including journals, conference papers and reports from different government and private organisations, and also from opinions/feedback of experts in the field of asset management. The following sections provide details regarding parts of the proposed framework.

Environmental Factors

This section provides additional information related to environmental factors affecting asset management, in particular it focuses on risk management and sustainability management.

Risks arise as a result of two main areas: a limited, or lack of, knowledge, experience or information and uncertainty (particularly about the future); or as a result of relationship changes between the parties involved in an undertaking [4]. The aim of Risk Management is to achieve more reliable planning, greater financial certainty and improved decision making and management outcomes. Risk Management should be applied on all governmental (Government and

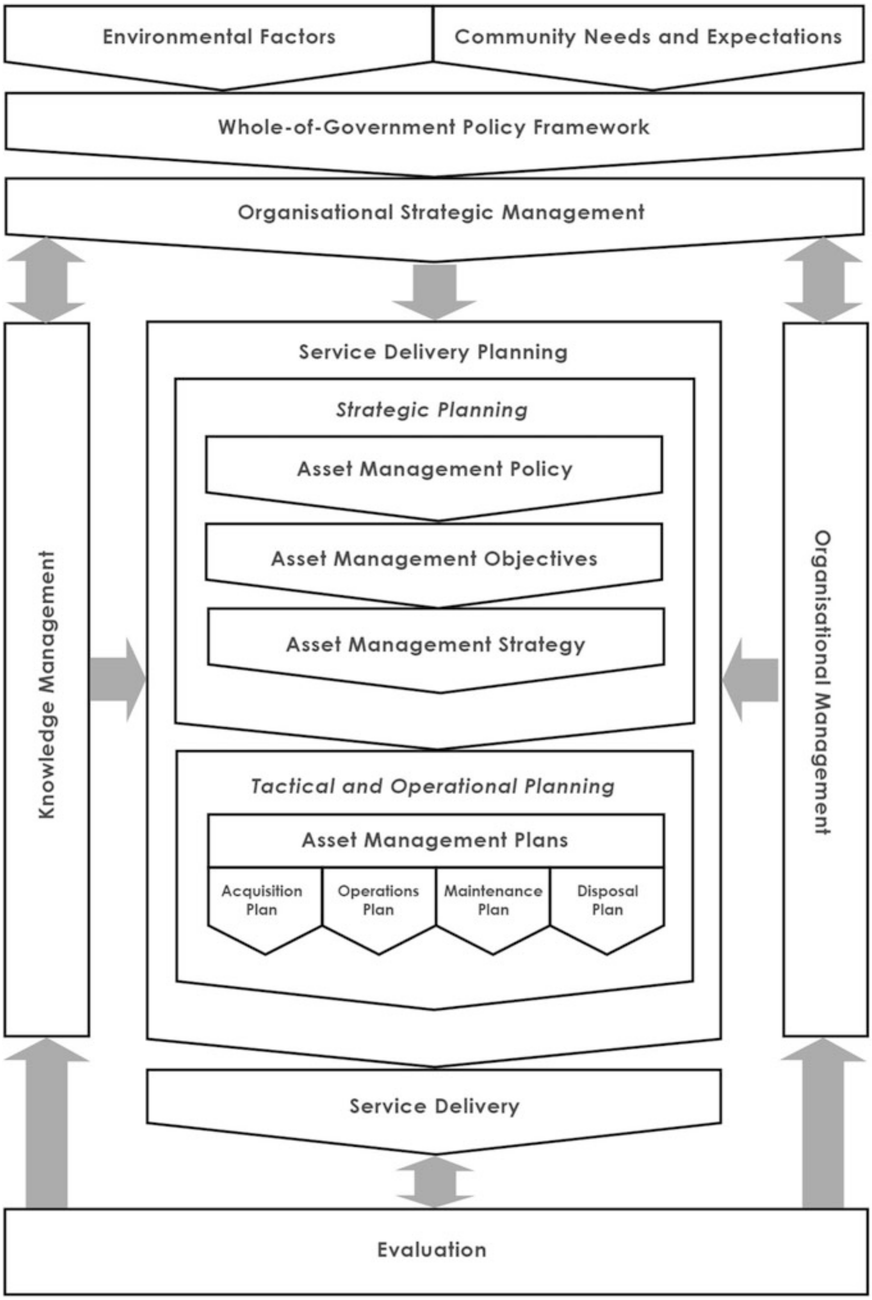

Fig. 1 Integrated strategic asset management framework

Agency) and organisational (Strategic Management and Asset Management) levels. It provides planners and managers with a structured way of identifying and analysing potential risks, and assists in devising and implementing appropriate strategies to help mitigate risks, considering their likely impact. Strategies can include risk prevention, risk transfer, impact mitigation or risk acceptance. A range of strategies can be used within a single project for a number of anticipated individual risks.

Sustainability Management is the ability to meet present needs without limiting the ability of future generations to meet their own needs [6]. Sustainability Management has a significant impact on policy development and strategy considerations. As a result it is vital that private and public organisations take Sustainability Management issues into consideration when developing policies and strategies. A core concept in Sustainability Management is the notion that there is interdependency between human communities and economies—in other words the way in which humans manage the environment is linked with the level of community cohesion and its economic performance.

Community Needs and Expectations

This section outlines Community Needs and Expectations. In particular, it provides a framework for understanding the requirements of the community and suggests that a range of stakeholder engagement strategies may assist Asset Managers in effective stakeholder management practices.

In the context of public sector, Asset Management 'demand' refers to community and government needs and expectations. It also encompasses the ambitions and aspirations of other sectional groups. As the driving force for supply, community/government needs and expectations, and sectional groups' aspirations and ambitions are all key inputs into the Asset Management process [4].

However, demand can outstrip supply in the case of government services—often as a result of limited financial resources. In consequence, managing demand is critical to ensure priorities are appropriately identified and met so as to ensure maximum community benefit. Demand Management helps to achieve this; in essence it involves active intervention in the market to influence demand for services, including assets [2].

Stakeholder Management is the process of interpreting the expectations of external and internal individuals or groups, who have an interest in asset management activities or will be effected by its outputs and the process of interacting with them. The objective of Stakeholder Management is the creation of a positive relationship with different stakeholders and comprises stakeholder identification, stakeholder classification, strategy development, stakeholder engagement, and of the maintenance of relationships [7].

Whole-of-Government Policy Framework

Limited resources mean governments have to exercise sound financial, social and environmental management and make prudent decisions to best prioritise services to meet community needs and expectations. This service delivery approach is achieved through a whole-of-government model, which is comprised of legislation, policies, plans, service delivery strategies and standards, capital and recurrent budgets and, government institutions; and partnerships including with working groups, community based organisations and private providers. This framework is designed to guide a coherent service intervention model and assist effective and accountable service delivery across all levels of government as well as within the private and community sectors.

Organisational Strategic Management

Organisational Strategic Management gives effect to whole-of-government policy through service delivery. The organisation is responsible for delivering the service; therefore it needs to determine how this should occur and what is required. Organisational Strategic Management involves an understanding of governance, corporate policy, corporate objectives, corporate strategy and interagency collaboration. Asset Management Strategic Planning should be aligned with and stem from the Organisational Strategic Management objectives to ensure smooth and effective management of company's assets and service delivery. The main components of organisational strategic management are Governance, Corporate Policy, Vision and Vision Statement, Mission and Mission Statement and Values.

Governance: Alles et al. [8] define governance as "the laws, policies, and procedures that ensure organisations run in the interest of owners and resources are allocated, managed, and redeployed to maximize productivity and value". Governance helps to determine the correct management processes, organisational structures and incentives are employed to ensure managerial attitudes and behaviours align with key stakeholder interests [9] as well as to determine the appropriate reporting and disclosures that ensure transparency and accountability [10]. For this ISAM framework, the Governance can also be specified as Corporate Governance.

The framework by which companies are directed and managed is referred to as Corporate Governance. Corporate Governance encompasses how an organisation's objectives are set and realised, how risk is monitored and measured, and how its performance is optimised. Good corporate governance encourages organisations to create value through innovation, entrepreneurism, development and exploration; provides accountability; and ensures there are control systems in place appropriate to the level of risk.

A subset of corporate governance, Asset Governance details the policies and processes needed to acquire, utilise, maintain and account for an organisation's assets. As such, asset governance can be considered to be an asset management approach that encompasses asset ownership and the management of distributed systems in a competitive and deregulated market [11–15].

Asset governance advocates transparent and accountable asset management policies. It outlines aims to define principles to manage assets effectively in distributed networks, a context where the development, stewardship and operation of assets may be open to competition [16]. Central to good asset governance is the clear definition and differentiation of roles and responsibilities, particularly those of the asset owner, asset governor and service providers. As such, asset governance provides for a micro level mechanism to manage the separation of powers in asset management that typifies network management [17], and facilitates effective asset management in a distributed system. Regulatory compliance, supply business satisfaction, risk-based, data supported, continuous improvement, pragmatic, and income maximisation and generation are all key asset governance principles.

Asset governance stems from the organisation's overarching corporate governance principles; as a result it defines the management context in which engineering asset management is implemented [18].

Corporate Policy: To constitute the fundamental purpose of an organisation, its intentions and ideals for a future direction, it is necessary to develop and state a Vision, a Mission and organisational Values (summarised in the Corporate Policy). These factors are needed within an organisation to have a common goal, in which the employees can believe, and to which they can work towards. These factors are also needed to inform the public about the organisation's goals and intentions.

Vision and Vision Statement: The Vision encapsulates an organisation's future direction and business constitution and describes an ideal to be strived. It acts as a guide for what the organisation is striving to achieve and become. A strategic Vision focuses on the organisation's future [19]. The Vision is formalised and documented in the Vision Statement. Many organisations today develop a Vision Statement that answers the question "What do we want to become?" [20]. Whereas the focus of the Corporate Vision is on the future direction, the organisation's Mission tends to focus on the present, answering "What is our business and what are we trying to accomplish on behalf of our customers?" [19]. It comprises the organisation's reason for existence, its fundamental purpose and includes its character and values [21].

Mission and Mission Statement: The Mission is formalised and documented in the Mission Statement. The Mission Statement encompasses the organisation's activities and current business constitution [19] answering "What is our business?" [21].

Values: Underpinning business activities are an organisation's values—guidelines that regulate the behaviour of staff and management as they endeavour to achieve the organisation's Vision [21]. The organisation's values can be assessed based on the Corporate Objectives, Corporate Strategy and Interagency Collaboartion.

Corporate Objectives are developed by organisations in order to articulate what the organisation hopes to achieve in the future. They act as a guide for all organisational activities and projects in order to ensure the organisation's long-term success and viability, and must be flexible in order to respond to the internal and external environment. Corporate Objectives are a culmination of a range of strategic analyses and are derived from the organisation's mission, capabilities and resources; PEST and SWOT analyses; community demands; government objectives; and desired outcomes.

According to Viljoen and Dann [21], "Corporate Strategy refers to the management of the entire organisation and concerns how the Mission is activated to achieve the Corporate Objectives". In particular, Corporate Strategy encapsulates how an organisation's activities align with its mission and values to ensure its long-term prosperity. Strategies are future-focused, requiring top management decisions and organisational resources. Strategies affect the long-term prosperity of an organisation and are multi-functional and multi-divisional, and must take into account the internal and external environment. Given their impact, choosing appropriate strategies is critical and all options should be carefully identified and considered before a preferred option is chosen [20]. In developing Corporate Strategy, risk management should be applied in order to ensure that corporate objectives are met, risk consequences do not adversely impact any stakeholders and the best strategic planning strategies are chosen [4].

Interagency collaboration involves representatives from various agencies coming together to identify and work toward a common goal. Collaboration is defined as "…a process to reach goals that cannot be achieved acting singly (or, at a minimum, cannot be reached as efficiently). As a process, collaboration is a means to an end, not an end in itself" [22]. During interagency collaboration, problems and solutions are shared across agencies with the common method for achieving set objectives being consensus building using an action-planning format. Another characteristic of interagency collaboration is the merging of resources including funding sources, training and personnel, as well as program philosophy [23]. In order to achieve the intended group outcome, group members agree to disagree in order to focus on the collaboration target at hand.

Service Delivery Strategic Planning

Service delivery is indicated by the Level of Service (LOS) provided by an asset. A Service Delivery Strategy translates the broad aims of an organisation into specific service outcomes. It clearly outlines the plans to deliver services and the overall strategy that will be adopted to satisfy community needs and obtain value for money. There are multiple vehicles to deliver a service, ranging from non-asset solutions including contracted services supplied by external parties, the re-use of existing assets to the provision of a new asset. Service delivery strategic planning can be described under the following three headings.

Asset Management Policy: An Asset Management Policy is the translation of the Corporate Strategy for the process area of Asset Management; as such it is based on the Corporate Policy and Corporate Objectives. It has to be consistent with the Government Policy Framework and the Government Objectives, and has to help to satisfy the Community Demands. An Asset Management Policy is the overall basis of all Asset Management decisions and activities and, like the Corporate Policy, it includes a Vision and a Vision Statement, a Mission and a Mission Statement, and Principles for the area of Asset Management.

Asset Management Objectives: Asset Management Objectives are indicators for the implementation of the Asset Management Policy and the achievement of the Asset Management Strategy. They are derived from the Government Objectives and Corporate Objectives and on a functional level they can relate to the required performance or condition of an asset. Asset Management Objectives should detail how each objective will be measured over a period of time in order to evaluate the organisation's performance—without this, objectives will only be a 'wish list'. According to Viljoen and Dann [21] objectives should include: the attribute to be measured (e.g. share of market, or customers/clients serviced), the scale on which the attribute is to be measured, referred to as a 'yard stick' (e.g. percentage points), a goal (level of the attribute desired), a specified period of time to achieve the goal.

Asset Management Strategy: The Asset Management Strategy (Agency's Service Delivery Strategy) follows the specifications of the Asset Management Policy and sets out activities, which help to achieve the Asset Management Objectives. In essence it also supports the Corporate Strategy and the achievement of the Corporate Objectives. How an agency's Asset Management responds to Community Demands is guided by the Asset Management Strategy which outlines the development of an asset portfolio, risk management strategies and asset performance measures. According to the New South Wales Treasury [4], the Asset Management Strategy identifies any requirements needed ('gaps') to support services and outlines the organisation's response to these by identifying appropriate acquisitions (planned capital investment), maintenance and disposal (such as replacement and/or upgrading).

Service Delivery Tactical and Operational Planning

Service Delivery Tactical and Operational Planning are also known as Asset Management Planning, which specifies how assets have to be managed to fulfil the Asset Management Strategy to achieve the Asset Management Objectives. In order to do so, Asset Management Plans set out a framework for an organisation to allocate appropriate resources and make strategic decisions to support service delivery through the whole asset management life cycle. Asset Management Plans should be comprised of four plans (acquisition plan, operations plan, maintenance plan and disposal plan) and they are described as follows:

Acquisition Plan: An Acquisition Plan is the primary document outlining the acquisition of all major assets. It also links program delivery needs to the required assets. The Asset Management Strategy facilitates asset acquisition decisions, while business plans are used to consider various alternatives such as non-asset solutions and the use of other assets within the existing asset portfolio.

There are a number of ways to acquire assets: purchasing, construction, development, finance lease. For significant acquisitions, (those that are complex and/or involve significant cost), detailed plans are prepared. These plans can include: a statement of need and acquisition rationale, staff roles and responsibilities required to manage the acquisition, required acquisition activities such as contract management and other technical, legislative and management considerations, timeframes and the key decision points throughout the acquisition plan, capital outflows amounts and timing, anticipated life-cycle *costs, monitoring and other control processes to ensure the intended acquisition outcome* [24].

Operations Plan: The operational aspects of an asset based on its life-cycle are detailed in the Operations Plan. Operations Plans detail the program and asset manager roles and responsibilities, and assign responsibility for asset performance and life-cycle cost accounting including: asset performance measures, asset condition, physical security and safeguarding, depreciation, finance costs, operating costs for example energy and cleaning costs, specialist staff costs required to operate an asset, operational training costs, maintenance costs, major disposal costs for example, make good, demolition or restoration [24, 25].

Maintenance Plan: Research shows that poor maintenance can result in a loss of functionality; a shorter than anticipated useful life; reduced utilisation; or even result in a threat to human safety or a breach in legislative requirements. As such it is a critical function in the overall life-cycle of an asset [24]. Maintenance has a dual purpose: refurbishment (restoring an asset to a required benchmark enabling its useful life) and enhancement (increasing an asset's service potential). Maintenance planning is key—particularly for major maintenance activities requiring critical assets to be taken off-line. Maintenance involves a range of activities and can be broken down into planned and unplanned operations and recurrent maintenance, and major and minor capital works.

Disposal Plan: The Disposal Plan leads into the planning process for new or replacement assets and is a useful management tool in assessing why assets may not have performed as intended. As such it should be an integrated part of the Asset Management Strategy. A number of reasons for disposing an asset can be identified including: end of useful life; surplus to requirements; under-utilised; not fit for purpose; unserviceable; the need for the service provided by the asset has disappeared; does not meet legislative requirements. The Australian National Audit Office [24] identifies a number of considerations when planning significant asset disposal: rationale for disposal, the proper costing and evaluation of disposal alternatives, engagement of experts to assist in professional valuation and disposal, due diligence reviews to ensure there is sufficient transparency and accountability for asset disposals including compliance with legislative requirements, proper approval authority, both within and outside the entity where required.

Service Delivery

Service delivery comprises the actual provision and maintenance of services, in accordance with the strategic and tactical plans, and the operational management. Service delivery activities would generally comprise the creation, maintenance, renewal/upgrading and disposal of the assets but may also include operational activities. For example a building comprising an aquatic centre would require ongoing expenditure on maintenance and upgrade of facilities as well as expenditure on operating activities such as staff, chemicals and utilities. For optimal service delivery clear assignment of responsibility and accountability should be established for each asset and its related operations. This includes the identification of assets, the capture of information and the assessment of performance against the agreed level of service.

Evaluation

Evaluation is the measuring, reporting and reviewing of asset performance against asset management, organisational and government objectives. Contemporary evaluation now incorporates not only the evaluation of the asset but also the evaluation of the impact of the asset on the environment and society. The following information is provided in relation to the Evaluation function: Asset Performance Measurement, Review, Audit and Report.

Asset Performance Measurement: In addition to ensuring that an organisation's actions, objectives and strategies align, "the goal of a performance measurement system is to communicate and implement strategy" [26]. As a result, performance measurement systems and frameworks need to reflect efforts to measure how activities and processes: contribute separately and jointly to meet Asset Management and Corporate Objectives; link operations to strategic goals; ensure a customer focus; drive future activities and needs; and enhance performance [27]. Performance measurement should provide meaningful measures of activities, processes and achievements as well as facilitate stakeholder feedback [28]. Asset Performance Management identifies and registers all assets required to deliver the stated service and determines how effectively and efficiently these assets support the service requirements. A number of performance measures exist to assess asset performance: Financial Performance, Function, Utilisation and Physical [29].

Many asset owner organisations now adopt Key Performance Indicators (KPIs) to measure performance, identifying what the organisation sets out to achieve in terms of service levels and sets KPIs for those services. Recording and analysing KPIs significantly contributes to achieving Corporate and Asset Management Objectives. In essence, KPIs identify how well services are provided, and how much time is taken to address and correct performance gaps between intended and actual performance. As defined by AAMCoG [29], "Key Performance Indicators are those critical performance measures which ultimately determine assets serviceability and stakeholder value" and can be: process-based (e.g. statutory compliance), activity-based (e.g. dollars spent) and, outcome-based (e.g. goals achieved, service success).

KPIs are particularly useful when they link to policy concerns or outcomes. KPIs fall into a number of categories, such as: quantitative (the amount of a product or service), qualitative (structured perceptions or structured feedback), cost efficiency (the unit cost of achieving a specified amount of service), cost effectiveness (the unit cost of achieving a specified amount of service to a designated level of quality), timeliness/responsiveness (the time taken to perform a service, or the number of transactions or products within a time cycle), and work team productivity (the output of a workforce unit or group) [30].

Management Reporting: Reports can be distinguished by progress reports, benefit reports, and financial reports. Regular progress reports should be provided to senior agency decision-makers, Ministers and Cabinet, covering: important milestones, including whether delivery is proceeding on time and meeting budget; whether project start-up was achieved in line with the endorsed costs and schedule; any serious emerging problems that are likely to affect service benefits articulated in the business case, and for which support for potential responses may be needed (such as additional maintenance to address unexpectedly high usage rates, or negative variations in the performance of contractors) [3].

Benefit reports inform future decision-making, strategic asset investment planning, business case development, and Asset Management and are required as part of an agency's senior decision maker's Asset Management responsibilities. The Benefit Report should be provided at appropriate intervals throughout a major asset's life-cycle and should: clearly state the extent to which value for money from the asset is being achieved compared to the predicted results, highlight any lessons learned to be later incorporated into planning for similar assets, or in business cases relating to the asset later in its life (e.g. to clarify whether an asset should be refurbished or should be subject to disposal). After disposal, senior decision makers should be advised on the total value for money and service delivery benefits gained from the investment.

Financial reporting (also referred to as 'close the books') is the process of reconciling, consolidating and generating financial reports/statements periodically to meet regulatory requirements and the information needs of internal and external stakeholders [31, 32]. According to the Australian National Audit Office [31] financial reporting activity can include: ensuring validity and consistency in the organisation's charts of accounts;, completing journal entries; consolidating data from outlying business units; running trial balances; correcting errors; reconciling and analysing accounts; calculating taxes; preparing and distributing reports; supervising closing tasks; and reviewing key accounts and reports.

Review: As outlined by the Queensland Department of Environment and Resource Management [33], reviews allow organisations to adopt a strategic view of: performance in relation to service levels; operation, maintenance and renewals;

future demands/flows; and other factors impacting on its future service levels and standards; and whether the strategies, actions and financial projections are optimal.

There are two categories of reviews: Post Implementation Review (assesses how well the project outcomes aligned with the actual needs the project aimed to meet) and Post Completion Review (a method of systematically and rigorously comparing actual project performance with the original project objectives). Reviews are normally carried out internally by the service provider; however external consultants may be employed. Regardless of whether the review is carried out internally or by an external contractor, key service provider personnel, such as field staff, must be involved in the review process. Reviews should be seen as a predecessor to regular audits.

Audit: "An audit is a systematic, independent and documented process for obtaining evidence and evaluating it objectively to determine the extent to which the audit criteria, the standards and obligations in a service provider's policies, procedures or requirements, have been fulfilled" [4]. Audits form part of the regulatory framework, verifying that service provider information is accurate and reliable. Audits also provide evidence to customers and stakeholders that services comply with regulatory requirements. In addition to benefiting the agency, audits also benefit service providers, identifying improvement opportunities and providing incentives to achieve compliance.

The auditing process relies on a number of key principles to ensure that relevant and appropriate conclusions are reached. They also enable independent auditors to reach similar conclusions in similar circumstances. These principles ensure audits provide effective and reliable support to management policies and controls, by providing information on which an organisation can assess and act upon to improve service performance.

Knowledge Management

This section focuses on knowledge management practices, which can assist in increasing asset productivity. In particular, it provides valuable insights related to the development and maintenance of asset information repositories, such as asset registers and offers suggestions for improving the acquisition, sharing and integration of tacit knowledge. Knowledge management is a systemic and organisationally specified process for acquiring, organising, and communicating both tacit and explicit knowledge so that others can use that knowledge to become more effective and productive [34, 35]. According to Leng and Stepherdson [36], there are different benefits of Knowledge Management as Table 1 shows.

One way to ensure effective, asset related, knowledge management is through the application of data and information management systems, which have become essential for most business operations, providing quality and timely data for decision makers. Information systems now cover a range of Asset Management

Table 1 Benefits associated with knowledge management

Benefits of knowledge management	Description of benefits
Effectiveness	Better access to expertise and past learning experiences can lead to improved decision making
Responsiveness	An integrated knowledge of customers' preferences and needs can improve an organisation's responses
Efficiency	The reuse and transfer of knowledge can enhance the productivity of knowledge workers
Flexibility	Knowledge enables organisations to be more flexible and responsive to rapid changes in the market as a result of better insights on customer and competitor trends
Innovation	Knowledge assists in the successful designing of new products, services and processes faster and with greater frequency

areas such as asset registration; process scheduling and control; materials, maintenance, risk, reliability, and safety management; and condition monitoring [37].

Asset Registers house information relating to various aspects of an asset portfolio, allowing it to be cross-referenced and retrieved as needed. Assets that have service potential and/or the capacity to provide economic benefits through their use in service delivery should be recorded in an asset register. Asset Registers come in many forms and can be electronic (e.g. computer) or paper-based (e.g. card file). Data can relate to one or more categories including: service delivery functions; physical properties; technical data; financial information (e.g. asset valuation and expenditure); property title details, key operational data, maintenance data and, performance records. Asset Registers should be integrated into the agency's management information system. While agencies have different needs a consistent approach can be adopted.

Asset Data Management concerns the capture, management and utilisation (data acquisition, data analysis, and information use) of asset data. The resulting translated data is essential to improve asset reliability, safety, availability, utilisation and an increased return on investment.

Organisational Management

Organisational management is the process of planning, organising, leading and controlling the efforts of organisation members and resources to achieve organisational goals. From the asset management perspective, organisational management involves support for strategic asset management through effective leadership. It may also involve shaping and auditing organisational competencies and skills, adopting change management strategies, and promoting asset management culture to ensure optimal asset management outcomes.

Leadership: Leadership quality directly impacts the successful implementation of any Corporate or Asset Management Strategy. Leadership involves supervising activities, giving orders and motivating subordinates in a way that meets the corporate and asset management objectives. These leadership functions can be classified as one of three main management functions: planning, organising and leading. The main activities as identified by Luffman et al. [38] are: planning (investing, evaluating, decision-making and controlling); organising (organising the structure, staffing, communicating, co-ordinating, negotiating, representing); and leading (supervising, giving orders and motivating).

A Strategic Asset Manager is responsible for a range of activities carried out over an asset's life-cycle, including: planning, designing, developing, operating, maintaining, rehabilitating, retiring and disposing different types of physical assets technically and economically, as well as in a socially responsible and sustainable way. They must consider the short- and long-term life-cycle to satisfy the needs of not only today's generations but future generations and focus on the bigger picture as well as more micro operational issues.

Change Management: In a change management context, change is a broad occurrence involving the growth and/or development of one or more public service elements, such as: service design; organisational structure; organisational culture; the management or administration of the organisation; and the skills needed to manage and deliver the service. Planned change management involves systematically scanning the environment and determining ways in which an organisation must adapt or change. Planned change involves four stages:

1. Setting goals and defining the 'desired future state';
2. Diagnosing the present condition in relation to these goals and setting the desired future state;
3. Defining the transitional activities and commitments needed to achieve the desired future state; and
4. Developing strategies and an action plan to manage the transition and reach the desired future state [39].

To develop effective change strategies, agencies must set clear corporate objectives, adopt appropriate communication strategies and linkages across the agency and possess high-quality leadership and management. According to Osborne and Brown [40], "Emergent change management is the reaction to change that is thrust upon an organisation by changes in its environment that are outside of its control". To respond to emergent change, managers must be enablers of organisational learning, specifically learning and developing by trial and error, and must create an environment where staff can also learn from their experiences.

Organisational Competencies and Skills: Competence refers to the knowledge and skills a person possesses or is required to posses in order to perform a work activity. Organisations need to constantly audit their current skill sets to identify gaps and the resources required. McGeoch et al. [41] stress the importance of asset management related training to ensure qualified personnel, who are clear about their role and accountable for their performance. Within a work context, required knowledge and skills include the areas of: organisation, process, work task and working environment; and can be categorised as professional, social, or methodical competence.

Asset Management Culture: Osborne and Brown [40] defined Organisational Culture as "the shared ideas, customs, assumptions, expectations, traditions, values and understandings that determine the way employees will behave." An organisational ethos that promotes optimal asset management outcomes often requires significant and deliberate cultural change. Pushing cultural boundaries may be necessary to embed a sustainable asset management culture.

Conclusion

Integrated strategic asset management has never been more crucial or challenging. Modern societies rely on a well connected system of purposeful and functional assets to maximise their wellbeing. Economic modelling demonstrates that developing and replacing existing and often aging public assets is an increasingly expensive process; drawing on already constrained budgets. Coupled with this economic imperative is a growing appreciation of the importance of embedding a consideration of the sustainability of the environment in which assets are located. Together these elements call for a more holistic conceptualisation of infrastructure and engineering assets and how these different elements combine to provide a comprehensive system of service outcomes. The ISAM framework has been developed from the benchmarks in industry, international best practice and leading edge research.

This chapter explores a contemporary set of practices to assist those responsible for the delivery and management of assets. Rapid advances in knowledge and technologies mean that asset management practice, and therefore this ISAM framework, will be subject to continued evolution and change.

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Integrated Strategic Asset Management: Frameworks and Dimensions

Martin Laue, Kerry Brown, Pascal Scherrer and Robyn Keast

Abstract Comprehensive asset management should be embedded in organisations through the temporal, organisational and spatial dimensions. We examine how an integrated approach to asset management might consider the whole range of interrelations and interactions of these dimensions. Asset management should take into account the operational and the strategic management of the asset (time dimension) as well as organisational, technology and information and human factors management (organisational dimension). Furthermore, the inclusion of management topics arising from interaction between assets, stakeholders and clients, ecological environments, industry, and government is critical (spatial dimension). We argue that a strategic standpoint for asset management establishes a framework that includes governance, policy, tactical and operational aspects that are brought into a comprehensive integrated approach. Prior frameworks have identified the various elements that need to be considered. However, they have not addressed their operationalisation and neglected governance and broader contextual factors in building an asset management model. We present an integrated asset management approach to developing a capability maturity model which addresses all three outlined dimensions. To do so it is necessary to define asset management process areas, capability and maturity levels, and capability and maturity indicators for each process area.

M. Laue · K. Brown · P. Scherrer · R. Keast
School of Tourism and Hospitality Management, Southern Cross University,
School of Business, Southern Cross University, Gold Coast Campus,
Locked Mail Bag 4, Coolangatta, Qld 4225, Australia

M. Laue · K. Brown
Cooperative Research Centre for Infrastructure and Engineering Asset Management (CIEAM), Level 7, O Block, QUT Gardens Point Campus, 2 George Street, Brisbane, Qld 4000, Australia

K. Brown (✉)
School of Tourism and Hospitality Management, Southern Cross University,
PO Box 157, Lismore, NSW 2480, Australia
e-mail: kerry.brown@scu.edu.au

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Introduction

Effective and efficient asset management should be core business of any organisation with significant infrastructure assets. As such, it is not surprising that a plethora of models have been developed to support organisations in managing their assets and providing a gauge of how well they are so doing. An increasing focus in recent years on monitoring and evaluation and benchmarking has further contributed to the development of maturity models, in attempts to encourage organisations to continually review and improve their management of assets. However, current models exhibit a distinct weakness in that they focus primarily on the operational and technical level and neglect the levels of strategy, policy and governance as well as the social dimensions. In this paper we build on conceptualisation that asset management is embedded in organisations through the temporal, organisational, and spatial dimensions to characterise asset management in a comprehensive way. We describe the findings arising from a research project funded by the Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM) with the aim to develop an integrated asset management capability maturity model. Our research question examines how an integrated approach to asset management might consider the whole range of interrelations and interactions of these dimensions.

Dimensions of Asset Management

Asset management is 'the process of organising, planning and controlling the acquisition, care, refurbishment, and disposal of infrastructure and engineering assets. It is a systematic, structured process covering the whole life of physical assets' [5]. Based on this definition of asset management we examine the different dimensions in which asset management is embedded to obtain a holistic view. Amadi-Echendu et al. [1] highlight five different dimensions (spatial, time, measurement, statistical, and organisational) to describe the generality of asset management. From our point of view and as outlined in the following sections, the time, organisational, and spatial dimensions are sufficient to characterise asset management in a comprehensive way. Integrated Asset Management then describes the integration of these dimensions, while An Integrated Asset Management Capability Maturity Model will focus on the development of a capability maturity model.

The Time Dimension of Asset Management

The first dimension in asset management considered in this research is time. The dimension of time can have two different characteristics. The first characteristic relates to the different stages of the asset lifecycle (acquisition, care, refurbishment, and disposal) as derived from the CIEAM definition of asset management. The second characteristic deals with the planning horizon which is adopted in the asset management process. This research will focus mainly on the latter aspect. The planning horizon in asset management extends from an operational point of view (short term) across a tactical one (middle term) to a strategic perspective (long term). Historically, the focus of asset management has been primarily on operational elements such as maintenance actions. Consequently, attention to a strategic perspective such as policy and governance arrangements that determine, regulate, and facilitate the operational activities has been lacking [11]. Non- or mis-alignment of operational activities with a strategic perspective can lead to sub-optimal asset performance [9]. Thus, it is important to consider both the *operational* and the *strategic* perspectives (we merge the tactical and the strategic aspects into the strategic) together. Figure 1 shows the two time dimensions of asset management: (1) strategic asset management and (2) operational asset management.

The Organisational Dimension of Asset Management

The second dimension in asset management considered in this research is the organisational dimension. Asset management processes consist of different tasks. CIEAM's definition of asset management, describes the tasks of organising, planning and controlling. Each of these tasks are characterised by their elements:

- an object of the task (in our case the asset);
- an operation of the object (in our case for instance the controlling of the asset);
- an agent;
- work equipment and information; and
- working conditions (based on Hacker [7]).

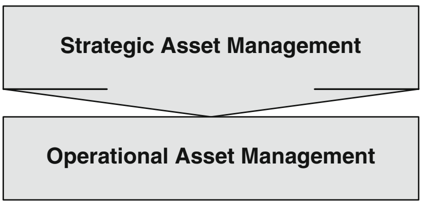

Fig. 1 Time dimension of asset management

To achieve comprehensive asset management, the management of *human factors* (agents) and the management of *technology* (work equipment) *and information* need to be considered. These two management areas, expressed by a consistent knowledge base in the field of technology and information management and effective human resource development in the field of human factors management, are probably the most pressing challenges facing asset management [1].

Working conditions consist of elements relating to the themes of workplace, work environment, time, and organisation. The management of these themes relates to higher level organisational processes which can be summarised as *organisational management* and in the context of asset management includes themes like corporate governance and innovation management. As Fig. 2 shows, a holistic asset management approach should consider technological and informational subjects, individual and social issues and organisational topics.

In this way the organisational dimension of asset management includes: (1) technology and information management, (2) human factors management, and (3) organisational management.

The Spatial Dimension of Asset Management

The third dimension in asset management we consider is the spatial dimension. This aspect relates to the degree of consideration of environmental factors in the asset management process. This dimension ranges from a perspective which encompasses only management processes relating to the asset itself and the nearest environment such as performance and condition monitoring, to a perspective which includes the broad interaction between the asset and environmental factors. We propose to cluster relevant environmental factors in four groups: (1) stakeholders and clients, (2) ecological environment, (3) industrial sector, and (4) government. Figure 3 indicates the different management themes which arise from the interaction between the asset (management) and these four environmental factor groups.

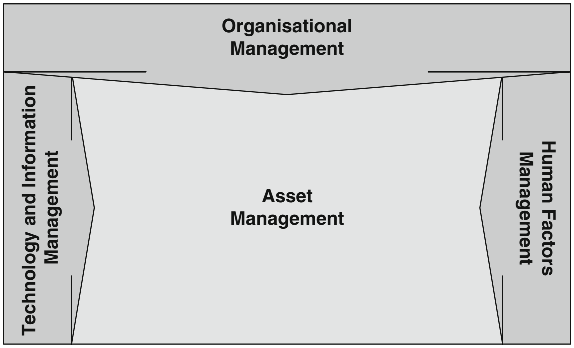

Fig. 2 Organisational dimension of asset management

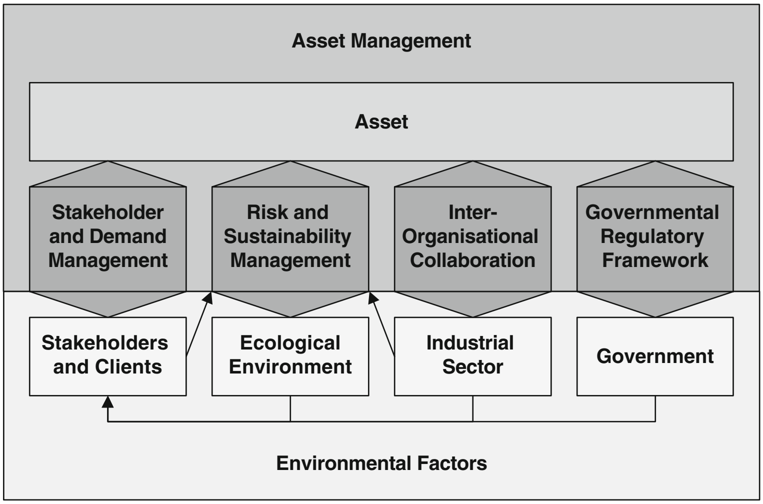

Fig. 3 Spatial dimension of asset management

The interaction between the asset (management) and environmental factors can be diverse. For example, legislation (environmental factor) may influence asset management at different stages of the asset lifecycle. Assets may also influence environmental factors, such as in the example of sustainability management where the interactions of assets with the ecological system are considered. There are also interactions where the asset management of an organisation influences and gets influenced by the asset management of another organization, such as in the process of collaboration. Thus the spatial dimension of asset management includes: (1) the management of the asset itself and the nearest environment; and (2) the management of the interaction of the asset with environmental factors (stakeholder and demand management, risk and sustainability management, inter-organisational collaboration, and governmental regulatory framework).

Integrated Asset Management

Integrated asset management not only combines the different dimensions of asset management into a greater whole, but also considers the whole range of interrelations and interactions between these different dimensions. Before we look at an integrated asset management approach, we want to describe the relation of the asset and organisational internal and external factors.

The Asset and Organisational Internal and External Factors

The three dimensions of asset management also reflect the relations between the asset and organisational internal and external factors. The time dimension reflects the core of asset management which is described in the spatial dimension as the management of the asset itself and its nearest environment. The organisational dimension reflects internal organisational factors and processes and their interrelations with the asset and also with the organisational external environment. The spatial dimension describes organisational external factors and topics which arise from the interactions with the asset and with the organisational internal environment. The interrelations and interactions of the asset, organisational internal factors, and the organisational external environment are visualised in Fig. 4 which is based on the Human-Technology-Organisation—approach [6].

The Human-Technology-Organisation approach postulates that humans, technology and organisation are interdependent and together influence the task or process (in our case the management of the asset). It is necessary for the integration of asset management to investigate 'heavily in the merger of new technical solutions, management processes and the human factors' [12] and simultaneously and equally address all three factors in the management of the asset.

However, not only the organisational internal factors need to be considered. The organisational external factors should also be addressed. The concept of sustainability management delivers significant insight in these relations. Sustainability management in asset management is the ability to manage assets in such a way to

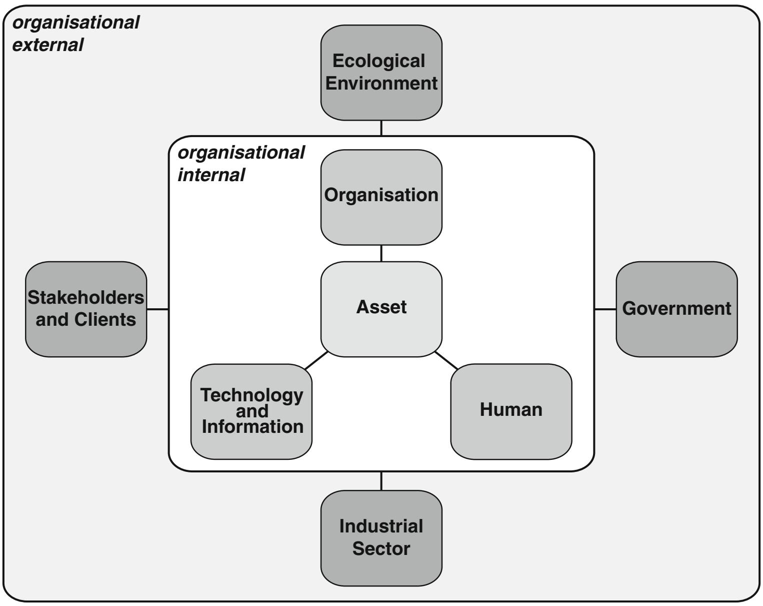

Fig. 4 The asset and organisational internal and external factors

meet present needs without limiting the ability of future generations to meet their own needs [3].

Based on the concept of the three pillars of sustainability, economic factors (like financial interests of stakeholders) are embedded in the society and can't exist without it. The economy and society (for instance expressed by cultural interest in the conversation of heritage assets) are again constrained by the ecological environment and also cannot exist without them [10]. Therefore holistic asset management has to address organisational external factors as well as organisational internal factors.

An Integrated Asset Management Approach

An integrated asset management approach which wants to be comprehensive has to consider the whole range of interrelations and interactions of the time, the organisational and the spatial dimension. It has to address the operational management of the asset as well as the strategic management of the asset. It further has to consider the encompassing organisational management, technology and information management, and human factors management. And finally, it has to include the different management themes which arise from the interaction between the asset, the stakeholders and clients, the ecological environment, the industrial sector and the government. Figure 5 shows the combination of the whole range of all three dimensions of asset management in an integrated asset management approach.

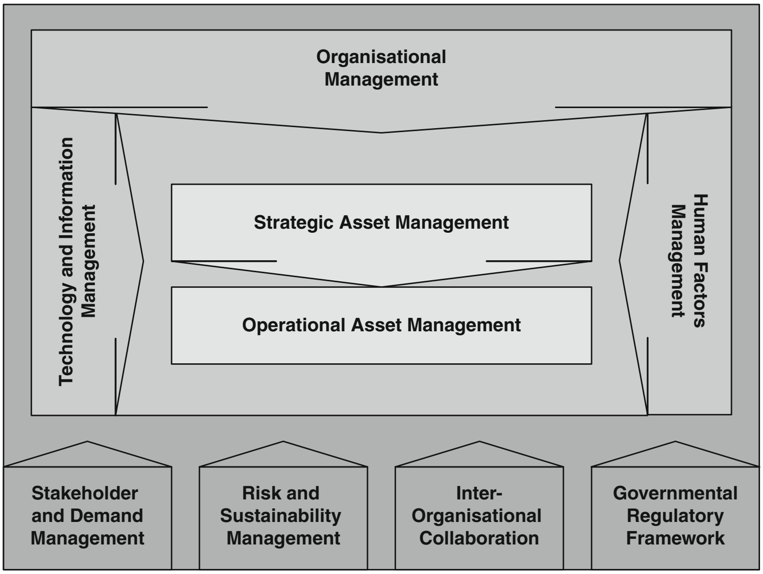

Fig. 5 Integrated asset management

Table 1 Process areas of integrated asset management

Dimensions	Management areas	Process areas
Time	Strategic asset management	Asset governance
		Asset management policy
		Asset management strategy
		Asset management plans
		Asset performance measurement
		Management reporting
		Review, audit
	Operational asset management	Operational management of planning, design, creation, acquisition
		Operations management
		Maintenance management
		Incident management
		Facility management
		Performance and condition monitoring
		Continual improvement
		Operational management of renewal, refurbishment, shutdown, disposal
Organisational	Organisational management	Corporate governance
		Corporate policy
		Corporate strategy
		strategic management (strategic analysis techniques)
		Innovation management
		Financial management (accounting techniques)
	Technology and information management	Data management
		Document management, asset register
		Information systems
		Knowledge management
	Human factors management	Competence management
		Leadership
		Communication
		Organisational culture
		Change management
Spatial	Stakeholder and demand management	Stakeholder management
		Demand management
	Risk and sustainability management	Risk management
		Sustainability management, social procurement
	Inter-organisational collaboration	Collaboration (cross-organisation, cross-government)
		Contract management, private provision
	Governmental regulatory framework	Government policy framework
		Legislation

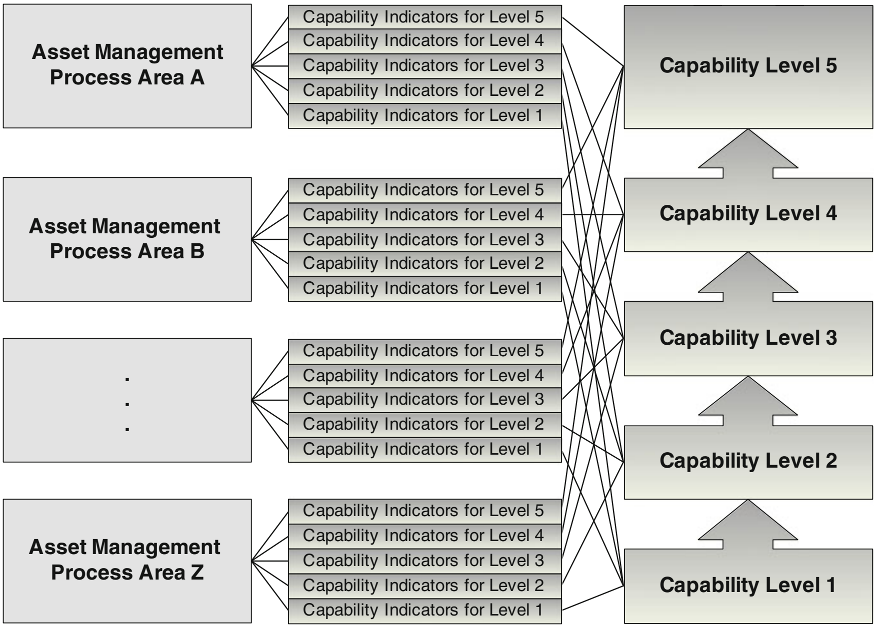

Fig. 6 Continuous representation of an asset management capability maturity model

Topics of Integrated Asset Management

The integrated asset management approach was first adopted in a modified version by the Australian Asset Management Collaborative Group (AAMCoG) in the development of the 'Guide to Integrated Strategic Asset Management' [2]. The industry-oriented guide was developed in cooperation with the Cooperative Research Centre for Infrastructure and Engineering Asset Management (CIEAM) and the Australasian Procurement and Construction Council (APCC). The guide is backed by an extensive research document (summarising the relevant bodies of knowledge) with detailed supporting information on the topics of the guide. The guide addresses an important gap in existing asset management models by introducing governance and strategic topics as well as human, social and organisational issues into asset management [8]. Table 1 describes the process areas grouped by management areas and listed against the three dimensions of the integrated asset management approach. These process areas were developed in cooperation with members of AAMCoG, CIEAM and the APCC during the development of the guide.

Fig. 7 Staged representation of an asset management capability maturity model

An Integrated Asset Management Capability Maturity Model

A capability maturity model is an approach to appraise and improve processes in organisations through the description of an evolutionary path from immature processes to mature processes. Two different representations are used to achieve this; the continuous and the staged representation. The continuous representation uses capability levels to improve processes of an individual process area or a group of process areas. The staged representation uses maturity levels which represent a pre-defined set of process areas and so describe a path for improvement for the entire organisation [4]. The following sections describe the integrated asset

Table 2 Combination of continuous and staged representation

Maturity level	Asset management process area	Capability level to fulfil
1		
2	A	2
	B	2
3	C	3
	D	3
4	E	3
	F	3
5	G	3
	H	3

management capability maturity model under development through the CIEAM program 'AMCaMM' (Asset Management Capability Maturity Model).

Development of an Asset Management Capability Maturity Model

The first step in the development of a capability maturity model for (integrated) asset management is the definition of asset management process areas. The second step is to define capability and maturity levels. The third step is to define the capability indicators for each capability level for each process area (continuous representation) and the maturity indicators for each process area (staged representation). With the assumption of five capability and five maturity levels, Fig. 6 illustrates the continuous representation of an asset management capability maturity model and Fig. 7 presents the staged representation of an asset management capability maturity model.

To combine the continuous and the staged representation it is necessary to define the capability levels of the process areas of the continuous representation which have to be fulfilled to get to the next maturity level of the staged representation. Table 2 illustrates this relationship.

Appearance of an Asset Management Capability Maturity Model

In regard to the first step, the definition of asset management process areas, the areas described in Table 1 provide a basis for further discussions. The segmentation and

Table 3 Levels of maturity and capability

Level	Name	Description
1	Performing	The processes are performed in an unscheduled way and are not documented, analysed, standardised, integrated, or optimised
2	Analysing	The purpose of the processes, input and requested output, the necessary workflow and information, other process agents and their roles, and required work equipment are documented and analysed
3	Standardising	Process-elements such as input and output, workflow, information, roles, work equipment, and process conditions are clearly stated and are standardised. These standardised processes provide consistency for all process areas
4	Integrating	The different processes are integrated in an overall approach and comprehensive organisation functions are implemented
5	Optimising	The processes and their elements are continually improved through analysing, standardising, integrating, and optimising

classification as well as the suitability for a capability maturity model of the different process areas should be discussed.

In relation to step two, the definition of capability and maturity levels, we examined different capability maturity models, especially in the field of asset management (physical asset management, information technology asset management, information asset management, intellectual asset management, and general management). In these models the levels of the capability and maturity levels range from zero to six. Three models use a range of six levels, 13 models a range of five levels, and three models a range of four levels. As a result, it is proposed to develop a range of five levels as described in Table 3. The definition of capability and maturity indicators will then inform the development of indicators in step three.

In summary, we argue that a strategic standpoint for asset management establishes a framework that includes governance, policy, tactical and operational aspects that are brought into a comprehensive integrated approach. Prior research and frameworks have identified the various elements that need to be considered, however, these models have not addressed how to operationalise the various levels and have neglected governance and broader contextual and social factors in building an asset management model. This research establishes a coherent framework as a possible alternative to start to develop integrated asset management from a strategic point of view. Based on our integrated asset management approach we present a possible approach to developing a capability maturity model which addresses all three dimensions. For the further development of such a capability maturity model it is necessary to define asset management process areas, capability and maturity levels, and capability and maturity indicators for each process area.

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Real Estate Portfolio Decision Making

Monique H. Arkesteijn and Ruud Binnekamp

Abstract Corporate or public organizations often own a real estate portfolio which has been acquired to serve certain organizational goals. However, some buildings in the portfolio might no longer serve these goals and could be sold or, conversely, buildings that could serve goals can be acquired. Choosing the combination of interventions that meets these different goals best is a multi-criteria group decision-making problem. Multiple Criteria Decision Analysis (MCDA) methodologies enable the aggregation of the performance rating of alternatives on different criteria into an overall performance rating. Given that criteria are properties by which to measure the portfolio's performance MCDA approaches should help to find the intervention that meets different goals best. A survey on such approaches showed that they (1) use preference scales to which mathematical operations do not apply or (2) do not have a well-defined procedure for selecting the most preferred portfolio. In this chapter, a design methodology using preference scales to which mathematical operations are applicable has been converted into a portfolio design methodology so that it (1) allows all decision-makers to iteratively enter their criteria and preferences and (2) orders all possible portfolios based on the overall preference rating. It has been evaluated based on a case simulation with data from a Dutch municipality.

Keywords Corporate and public real estate management · Portfolio level · Multi criteria decision making · Preference measurement

M. H. Arkesteijn (✉) · R. Binnekamp
Faculty of Architecture and The Built Environment, Department Real Estate & Housing, Delft University of Technology, P.O. Box 5043, 2600 GA Delft, The Netherlands
e-mail: m.h.arkesteijn@tudelft.nl

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Introduction

In this chapter we show that "… the conditions that must be satisfied in order to enable the application of linear algebra and calculus, …" [4, p. 10] are not satisfied in certain models in the field of corporate and public real estate management. Barzilai [4, p. 10] "established that there is only one model for strong measurement of subjective variables" and developed an evaluation methodology called Preference Function Modeling (PFM) [3] which Binnekamp [5] transformed into a design methodology called Preference-Based Design (PBD). This methodology is applied to cases at a building and area level, but has not been applied at a portfolio level. This chapter describes how this methodology has been converted into a Preference-Based Portfolio Design (PBPD) methodology.

This chapter describes (Sect. 2) foundational errors and solutions in decision theory and (Sect. 3) evaluates whether these errors are made in real estate portfolio decision making. In (Sect. 4) the PBDB methodology is discussed. The chapter ends (Sect. 5) with conclusions, discussions and recommendations.

Decision Theory Foundational Errors and Solutions

In the domain of architecture we face the problem of multiple stakeholders having to choose the design that best fits their interests as a group. The scientific foundation of selection (choice) is preference measurement. ″The construction of the mathematical foundations of any scientific discipline requires the identification of the conditions that must be satisfied in order to enable the application of the mathematical operations of linear algebra and calculus″ [4, p. 1]. In addition, the mathematical foundations of social science disciplines, including economic theory, require the application of mathematical operations to non-physical variables. "*Value* (or utility, or preference) is not a physical property of the objects being valued, that is, value is a subjective (or psychological, or personal) property" [4, p. 4].

″The construction of a model for preference measurement is addressed by Von Neumann and Morgenstern″ ([20] in Barzilai [4, p. 2]). ″Elaborating upon Von Neumann and Morgenstern's concepts, Stevens ([15], see Barzilai [4, p. 4]) proposed a uniqueness-based classification of "scale type" and research interest turned from the issues of the possibility of measurement of psychological variables and the applicability of mathematical operations on scale values to the construction of "interval" scales, i.e. scales that are unique up to an additive constant and a positive multiplicative constant″. There is no proof in literature that these scales devised by Stevens (or any model based on Von Neumann and Morgenstern's concepts) allow mathematical operations Barzilai [4, p. 5].

In reconstructing the foundations of (preference) measurement, Barzilai [4, p. 5] classifies measurement scales by the mathematical operations that are enabled on scale values. He defines *proper* scales as scales to which the operations of addition and multiplication (including subtraction and division) are applicable [4, pp. 8–9]. Those proper scales that also enable order and the application of the limit operation of calculus are termed *strong* scales [4, p. 10]. All other scales, including Stevens "interval" scales are termed *weak*.

In other words, to evaluate the mathematical foundation of any methodology involving preference measurement, we initially only need to look at the scales used for measuring preference. If the operations of addition and multiplication are applied where they are not applicable, the numbers generated are meaningless. Barzilai [2, 3] developed a new theory of (preference) measurement based on measurement scales to which linear algebra and calculus are applicable. Based on this theory, a practical methodology for constructing proper preference scales, PFM, and the Tetra software tool that implements it, have been developed.

In its current form however, PFM is an evaluation methodology, helping decision makers to choose the most preferred design alternative from a set of already existing alternatives. In the domain of architecture a design methodology is needed, where the design alternatives are not known a priori. The following Preference-Based Design (PBD) procedure proposed by Binnekamp [5, p. 121] offers such a design methodology:

Step 1. Specify the decision variable(s) the decision maker is interested in.
Step 2. Rate the decision maker's preferences for each decision variable as follows:

(a) For each decision variable establish (synthetic) reference alternatives which define the endpoints of a cubic Bezier curve:

(i) Define a 'bottom' reference alternative, the alternative associated with the value for the decision variable that is least preferred, rated at 0. This defines the origin endpoint of the curve, (x0, y0).
(ii) Define a 'top' reference alternative, the alternative associated with the value for the decision variable that is most preferred, rated at 100. This defines the destination endpoint of the curve, (x3, y3).

(b) Rate the preference for alternatives associated with the other decision variable values relative to these reference alternatives by manipulating the two control points (x1, y1) and (x2, y2).

Step 3. To each decision variable assign decision maker's weight.
Step 4. Determine the design constraints.
Step 5. Combine decision variable values to generate design alternatives and use the design constraints to test their feasibility.
Step 6. Use the PFM algorithm to yield an overall preference scale of all feasible alternatives.

Within the PDB procedure design alternatives are defined as combinations of decision variable values. These alternatives are defined as follows. For each decision variable a Bezier curve is defined to relate decision variable values to preference ratings. Each curve is then divided into a number of segments yielding a number of points on each curve. Combinations of points on each curve thus represent design alternatives. The x-coordinates of these points represent decision variable values. Design constraints, relating to decision variable values, are used to test design alternatives on feasibility. The y-coordinates represent preference ratings associated with decision variable values. These are used to determine the overall preference rating for combinations of decision variable values that pass the feasibility test.

This PBD methodology [5] is successfully applied to cases at a building and area level, but, as of now, has not been applied at a portfolio level.

Evaluating Approaches to Real Estate Portfolio Decision Making

Real estate decision making on a portfolio level is addressed in real estate management (REM). De Jonge et al. [8, p. 10] distinguish various specialisations in REM, like: *portfolio management*, also referred to as REM by investors; *corporate real estate management* (CREM): REM (steered) by private organisations or businesses and *public real estate management* (PREM): REM by public parties. This research focuses on CREM and PREM, especially on PREM for municipalities.

De Jonge [7, p. 15] has positioned CREM in terms of a match between business i.e. the demand side and real estate i.e. the supply side, connecting the strategic and operational level. CREM has the objective to optimally attune corporate accommodation to organisational performance, adding value to corporate objectives and indirectly generating income [7, p. 10]. Heywood [10, p. 1] shows that this alignment is "a long-standing issue".

Van der Schaaf [18, p. 5] stated that "public real estate portfolios have very specific characteristics and there is clear evidence of political influence on the quality and location of the buildings included in them". This has a strong influence on how such properties are managed. She defined PREM within governments as "the management of a government's real estate portfolio by aligning the portfolio and services to (1) the needs of the users, (2) the financial policy set by the Treasury and (3) the political goals that governments want to achieve" [18, p. 6].

Municipalities own 42 million square meter gross floor area size in The Netherlands, which almost equals the size of the Dutch office market [19]. The book value of this portfolio is estimated at 15–20 billion euro by Teuben et al. [17, p. 11], with an estimated market value of 30–37 billion euro. Tazelaar and Schonau [16, p. 6] indicated that the professionalization of PREM for municipalities in The Netherlands currently is important because of three reasons: (1) the need for more efficient use of municipal real estate; (2) the increasing demand for public accountability; and (3) the quality of municipal services.

In the strategic alignment within CREM and PREM "adding value" and "optimally attuning" are central concepts. The specific interest of this chapter is in how preference is measured in these models and how the stakeholders interests are integrated, i.e. how a strategy is selected, i.e. how an optimal solution is determined.

Consider the following example of such a selection process: a municipality acquired a substantial number of buildings within its city to serve societal goals. However, some buildings (might) no longer serve societal goals and could be sold or, conversely, buildings that could serve societal goals can be acquired. More than one decision maker decides which intervention to select. Choosing the intervention that meets the different goals best is in essence a multi-criteria group decision making problem. Multiple Criteria Decision Analysis (MCDA) methodologies enable the aggregation of the performance rating of alternatives on different criteria into an overall performance rating. Alternatives are rated on preference on each criterion. Given that criteria are properties by which to measure the portfolio's performance on a goal we can expect that MCDA approaches help to find the combination of interventions that aligns the portfolio to the organisational objectives.

For these MCDA models within corporate and public real estate management the work of Barzilai [4] and Binnekamp [5] is relevant because Barzilai [4, p. 2] focuses on measuring preference (synonymous to value and utility) and found errors at the foundations of utility theory. Most CREM models use an algorithm-based approach according to Heywood [10, p. 6] which he defines as a series of defined steps, meaning that mathematical operations are not necessarily used. In order to determine whether these models are based on mathematically sound foundations CREM and PREM models are evaluated. Firstly it is determined if mathematical operations are used and secondly, for the methods using mathematical operations, if strong, proper or weak scales have been used. As can be concluded from Table 1 in three of the four models that *use* mathematical operations weak scales were used, which means that the conditions are *not* satisfied in order for the operations of addition and multiplication to be applicable to scale values.

For the three models that do *not use* mathematical operations it can be deferred from the models or case descriptions that mathematical operations are performed when evaluating the performance and/or selecting a strategy. However, in their texts it is not explicitly shown how the preferences were measured and how the overall performance rating was determined. Brackertz and Kenley [6, p. 62] for instance use employee satisfaction and a customer satisfaction ratio as

Table 1 Evaluation of CREM and PREM models

Domain	Authors	Use of mathematical operations	Scales used
CREM	Nourse et al. [11], Roulac [13, p. 149]	Yes	Not indicated
CREM	Edwards and Ellison [9]	No	N.A.
CREM	Osgood [12]	No	N.A.
CREM	Scheffer et al. [14, p.193, 195]	Yes	Weak[a]
PREM	Brackertz and Kenly [6, p. 62]	Yes	Weak
PREM	Wilson et al. [21]	No	N.A.
PREM	Van der Schaaf [18, p. 140]	Yes	Weak

[a] In this model preference is measured indirectly

performance measures. Nourse and Roulac [11] indicate that they use linear programming but do not specify how. Binnekamp [5, pp. 2, 59–61] also found a major problem relating to the use of LP for solving group decision making problems; LP can only produce single-criterion design solutions, which fully satisfy no more than one of a single decision maker's interests. Edwards and Ellison [9, pp. 27–28] indicate that their framework is a heuristic tool and as such should be used to order information and to facilitate understanding of property problems. The selection and implementation of strategies are brought together in general in the framework and addressed through the case studies. In some case studies they refer to 'overall performance rating'.

We conclude that, as yet, no methodology for designing a portfolio exists which incorporates proper preference measurement. We therefore propose the following preference-based portfolio design methodology.

Preference-Based Portfolio Design

It is necessary to convert the PBD procedure in two ways in order to be able to use it on portfolio level. Firstly it is important to note that in the PBD procedure [5, p. 121] each combination of decision variable values defines no more than one alternative. However, with respect to the problem of real estate portfolio decision making, one combination of decision variable values could define more than one alternative. For instance, consider a portfolio consisting of 3 buildings; building A, B and C. Assume that we are interested in the percentage of buildings that serve societal goals. Also assume that building A is the only building within the portfolio serving societal goals. This means that removing building B or C would both result in a portfolio having 50 % of buildings serving societal goals. Conversely, setting this decision variable to 50 would define two alternatives (portfolio with building A and B and the portfolio with buildings A and C), not just one.

To resolve this problem all possible portfolios need to be generated using the number of buildings in the current portfolio and the number of allowed interventions. Given i interventions and j buildings a total of i to the power of j combinations are possible. In this experiment the portfolio consists of 15 buildings and 3 interventions (remove, keep, renovate) are considered. A building can be removed from the portfolio for instance if it is demolished or sold. The total number of possible portfolios is the number of interventions to the power of the number of buildings ($3^{15} = 14{,}348{,}907$).

Secondly, approaching the generation of portfolios this way means that the performance of each portfolio is determined a posteriori. Going back to the previous example, removing building B is an example of a generated portfolio. Only after this portfolio has been generated it is possible to determine the number of buildings that serve societal goals with respect to the total number of buildings within that particular portfolio consisting of buildings A and C.

However, within the original PBD procedure, the Bezier curve was divided in segments yielding a number of points on each curve. The x-coordinates of these points represented the performance of the alternative with respect to that design variable a priori.

As a result, it is no longer useful to divide the curve in segments to generate a set of points. Instead, the preference rating needs to be a function of the design variable value. This means that it is not possible to use a Bezier curve because this is a parametric equation. Instead, the decision maker needs to define 3 points relating decision variable values to preference ratings. The Lagrange curve defined by these points can then be found by means of curve fitting.

The above changes mean that steps 2 and 5 of the original PBD procedure needs to be changed as follows:

Step 2. Rate the decision maker's preferences for each decision variable as follows:

(a) Establish (synthetic) reference alternatives which define 2 points of a Lagrange curve:

(i) Define a 'bottom' reference alternative, the alternative associated with the value for the decision variable that is least preferred, rated at 0. This defines the first point of the curve, (x_0, y_0).

(ii) Define a 'top' reference alternative, the alternative associated with the value for the decision variable that is most preferred, rated at 100. This defines the second point of the curve, (x_1, y_1).

(b) Rate the preference for an alternative associated with an intermediate decision variable value relative to the reference alternatives. This defines the third point of the curve (x_2, y_2).

Step 5. Generate all design alternatives (using the number of buildings and allowed interventions). Then use the design constraints to test their feasibility.

In order to evaluate this converted PBPD procedure a case simulation is generated based on the prototype Public Real Estate system under construction [1] for the municipality of Rotterdam.

Step 1: Specifying the decision variable(s)

The following six decision variables for the specified stakeholders within this municipality are used. (1) Policymaker: the percentage of buildings within the (new) portfolio serving societal goals. (2) Policymaker: the percentage of buildings within the (new) portfolio having an overall preference rating of 40 or more on the criterion 'user satisfaction'.[1] (3) Technical manager: the percentage of buildings within the (new) portfolio having an overall preference rating of 40 or more on the

[1] Note that within this procedure preference is rated at an object level and portfolio level. For example, 'user satisfaction' and 'technical state' are rated on an object level. The percentage of buildings within the (new) portfolio having an overall preference rating of 40 or more on the criterion 'user satisfaction' is rated on a portfolio level.

criterion 'technical state'. (4) Asset manager: The percentage of buildings within the (new) portfolio for which the rent covers the cost. (5) Users: The gross floor area of the (new) portfolio and (6) Policymakers: The additional yearly rent due to renovation.

Step 2: the decision maker's preferences for each decision variable

Table 2 shows for each decision variable value the 3 points that relate decision variable values to preference ratings. These 3 points define a Lagrange curve (example for decision variable 1 is given in Fig. 1).

Step 3: Assigning decision maker's weight to each decision variable

Table 3 shows for each decision variable value the weight assigned by the associated decision maker.

Step 4: Determining the design constraints

For this experiment no design constraints are used.

Step 5: Generating all design alternatives

In this experiment the portfolio consists of 15 buildings and 3 interventions (remove, keep, and renovate) are considered. Of each building information relating

Table 2 Decision variables and associated decision maker's preference ratings

Decision variable	x0, y0	x1, y1	x2, y2
1. Percentage of buildings serving societal goals	40, 0	80, 50	100, 100
2. Percentage of buildings scoring ≥40 on user satisfaction	0, 0	50, 70	100, 100
3. Percentage of buildings scoring ≥40 on technical state	20, 0	50, 60	100, 100
4. Percentage of buildings for which rent covers costs	0, 0	50, 60	100, 100
5. Gross floor area	1,794, 0	1709, 100	1,628, 0
6. Additional yearly rent due to renovation interventions	0, 100	30k, 40	60k, 0

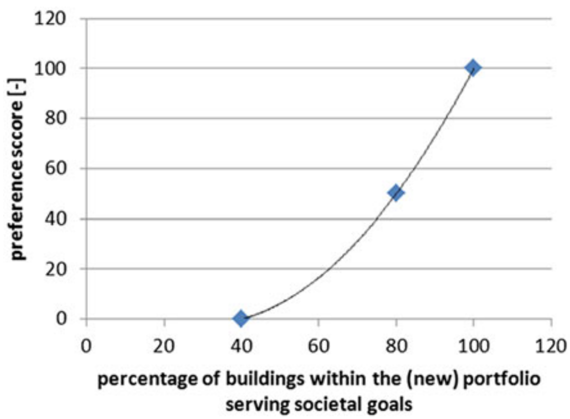

Fig. 1 Lagrange curve relating preference rating to the percentage of buildings within the portfolio serving societal goals

Table 3 Decision variables and assigned decision maker's weights

Decision variable	Weight
1. Percentage of buildings serving societal goals	10
2. Percentage of buildings scoring ≥40 on user satisfaction	10
3. Percentage of buildings scoring ≥40 on technical state	10
4. Percentage of buildings for which rent covers costs	10
5. Gross floor area	40
6. Additional yearly rent due to renovation interventions	20

Table 4 Top 10 of portfolios sorted on overall preference rating

Portfolio	Bulding Numbers															Rating
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
9388514	1	2	2	1	2	2	2	2	2	1	2	1	2	0	2	75.6
9388502	1	2	2	1	2	2	2	2	2	1	2	1	0	2	2	75.6
9387773	1	2	2	1	2	2	2	2	1	1	2	1	0	2	2	75.5
9387785	1	2	2	1	2	2	2	2	1	1	2	1	2	0	2	75.5
9033491	1	2	1	2	2	2	2	2	1	1	2	1	2	0	2	75.4
9033479	1	2	1	2	2	2	2	2	1	1	2	1	0	2	2	75.4
8857073	1	2	1	1	2	2	2	2	2	1	2	1	2	0	2	75.2
8857061	1	2	1	1	2	2	2	2	2	1	2	1	0	2	2	75.2
8856344	1	2	1	1	2	2	2	2	1	1	2	1	2	0	2	75.1
8856332	1	2	1	1	2	2	2	2	1	1	2	1	0	2	2	75.1
Current	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	17.7

0 = remove, 1 = keep, 2 = renovate

to each decision variable is known. No design constraints are used, this means all design alternatives are considered feasible.

Step 6: Using the PFM algorithm to yield an overall preference scale

Table 4 shows the top 10 of portfolios ordered on associated preference ratings. It also shows the overall preference rating of the current portfolio (keep all buildings). In this case, without strict financial limitations, the highest rated portfolio shows a possible overall performance improvement of 57.9.

Conclusions, Recommendations and Discussions

We conclude that, as yet, no methodology for designing a portfolio exists which incorporates proper preference measurement. We recommend that more than seven models will be evaluated. The proposed PBPD procedure can be used at portfolio level because the two before mentioned limitations are removed.

However, the use of the Lagrange curves which oscillate between their roots (knots) could create a problem because they can take negative preference values. This problem is dealt with by directly visually feeding back the Lagrange curve defined by the points.

In this experiment the total number of possible portfolios is the number of interventions to the power of the number of buildings ($3^{15} = 14{,}348{,}907$). If a portfolio consist of more buildings and more interventions will be considered, as is usually the case, the computer time needed to generate and evaluate all possible portfolios can become too much which asks for the need for a search algorithm.

Despite these limitations, we see the proposed PBPD procedure and associated model as a proof of concept for applying it in practice. Currently work is being carried out to find the search algorithm. The next step will be to evaluate the PBPD procedure in practice.

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Part III
Safety, Renewable Energy and Management

Design for Safety: A New Service for Alarming and Informing the Population in Case of Emergency

Helena M. Jagtman

Abstract In case of emergencies, the population in danger should be alarmed so individuals can take action to get or remain out of danger. The means available for alarming the population are limited. Many countries have outdoor sirens. Their operability however is restricted since sirens have only one implicit instruction. In 2012 a new citizens' alarming and informing system was introduced using cell broadcast in The Netherlands. This chapter discusses the field of citizens' alarming and the type of technologies available to communicate to the population. This framework is relevant for understanding how one should asses a new technology from a safety point of view. One of the challenges for the new alarming service is the composition of a short text message to alarm the population via their mobile phone, which is complete, relevant and correct for situation. This new field is recently being explored. We explain amongst others how the not yet known disaster is dominant for the message content and explain how a message can be composed. Results from workshops with experts from the emergency rescue services are discussed. We rounds off arguing dilemmas in order to get to effective citizens' alarming via the new service.

Keywords Cell broadcast · Emergency warning system · Alarm message content

What is Citizens' Alarming?

In case of a treat or incident governments have a responsible to alarm and inform the population (see bottom of Fig. 1). *Alarming* should notify the population in the affected area about the danger *with* the intention to change behaviour resulting in

H. M. Jagtman (✉)
Safety Science Group, Faculty of Technology Policy and Management,
Delft University of Technology, 5015 2600 GA Delft, The Netherlands
e-mail: h.m.jagtman@tudelft.nl

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the population getting to a safe location or act safely in order to limit damage to people and properties. Notification of the population can be done either with or without special alarming technology as for example outdoor sirens, sound trucks, helicopters or door-to-door notification by fire fighters and policemen. The decision to use alarming technologies depends on the need to quicken the notification in order to limit damage. This is for example the case if direct action of the people present in the affected area is required to get or stay safe. Many countries for this purpose have outdoor sirens [5] or make use of sound trucks. The population can also be warned without the need to speed up the notification. The means to notify people in such cases are for example the national or regional news, daily current affaire programs or newspapers. *Informing* is aimed at keeping the population who are or feel threatened updated about the situation. Informing different from alarming does not require (immediate) reaction for the population. The government informs the population via public meetings and via the media. Some examples of these channels used for citizens' alarming and their relation (see colour coding) to alarming and informing about the threat or the incident "A" are shown in the upper part of Fig. 1.

Not all technologies shown in Fig. 1 are governmental controlled. Apart from the government also private parties and individuals communicate about a treat or incident. Current affairs programs decide themselves what they broadcast from official statements or public meetings. Moreover, the programs decide which persons and experts they invite to comment on the events. Also companies communicate in case of an incident to their own employees, visitors and customers. The population will also pass on a notification among themselves. Even for people-to-people communication various technologies are used. It could be passed on face-to-face, via telephone or internet to known and also unknown people. Finally certain threats are noticed by individuals in the vicinity or the source via their senses, for example via vision or smell. In the section "Disaster Communication: Illustration Fire of a Chemical Storage Facility" the contribution of these channels are shown for one particular case.

Risk Versus Disaster Communication

Alarming and informing relate to an incident. From emergency preparedness we also know communication about hazards. In this case it concerns risk communication which is aimed at educating the public about how they should respond if they will be in danger in some unknown future situation (see blue box in Fig. 1). Each Dutch municipality is obligated to instruct and prepare their residence for emergency cases. Risk communication educates the population about the general actions which are required for hazards in their municipality, region, state or country. The general instruction in case of release of dangerous substances is to go insight and lock all doors, windows and everything which can serve as ventilation. However, if one is outdoors alternative actions are required. Disaster communication differs from risk

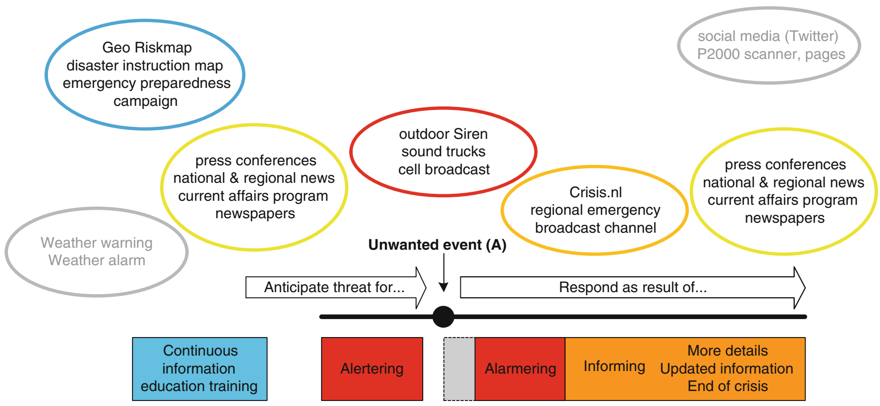

Fig. 1 Examples of channels for alarming and informing the population

communication amongst others because in case of an incident the instructions relevant for the situation should be communicated rather than the general instructions. Moreover risk communication does not involve time pressure nor should the population take action to get or remain safe.

Another type of Risk communication is the use of risk or hazard maps which show hazardous locations to the public. In The Netherlands the risk map includes natural (e.g. flooding) and man-made hazards (e.g. chemical installations). Risk maps are used in multiple other European countries to communicate about risks. These maps more often relate to geographically locate of natural hazards than man-made hazards [3].

Disaster Communication: Illustration Fire of a Chemical Storage Facility

The contribution of multiple means to alarm and inform the population is illustrated for a fire at Chemie-Pack in Moerdijk in the south of The Netherlands. This facility caught fire on January 5th 2011. The fire brigade was alarmed about the fire at 14:26 h [33]. The fire caused a heavy dark toxic cloud which headed north and later northeast. At 15:18 h the siren was sounded for the first time in the area north of the site [26]. Additionally from 16:30 h sound trucks were used to instruct the population to get or stay inside and close their doors and windows [26]. Via a questionnaire 462 people gave us insight in how and at what time people were first notified about the fire at this facility [14]. The respondents were divided into three groups:

- AREA1: alarming with speed up notification via sirens and sound trucks. The people present in this area needed to go insight and close doors, windows and other ventilation immediately in order to prevent inhalation of a too high concentration of toxics.

- AREA2: alarming without speeding up the notification via the regional disaster channel, a special website for incidents (crisis.nl) and other national media. Citizens present in this area were alarmed about the toxic cloud which was predicted to get in their direction in the course of the evening and night.
- AREA3: informing via various regular media (television, radio, internet and press conferences) to provide updates about the latest developments for all those who feel threatened or are interested in the situation.

Figure 2 shows what share of the three areas were aware of the fire per time slot. In AREA1 where people had to take immediate action 68 % of the respondents were notified at 16 h. For areas 2 and 3 this was respectively 40 and 29 %. At 17 h 89 % in area 1 had been notified. Not before 19 h the share of people who knew about the fire in AREA2 was about the same as in AREA1.

Table 1 shows via which channels the people in the three areas were notified. Be aware that the contribution of a channel cannot be compared between the areas: since visual observation was only possible in AREA1 and parts of AREA2 and the special alarm channels to speed up notification were only used in AREA1. These latter channels notified 27 % of the people present in AREA1. These people and those who saw the smoke and were thus notified via visual observation were the first to hear from the fire. These channels had an indirect effect as well, since people who were notified by the alarming channels told others about the fire. Most people in AREA1 (almost 45 %) were notified via another person. This was also the case in AREA2 were 47 % heard about the fire via somebody else. While in AREA1 15 % of those alarmed by another person were notified by a stranger, hardly anybody in AREA2 or 3 heard from an unknown person. Thus in the area with acute danger the people present were united and helped one another. Those in

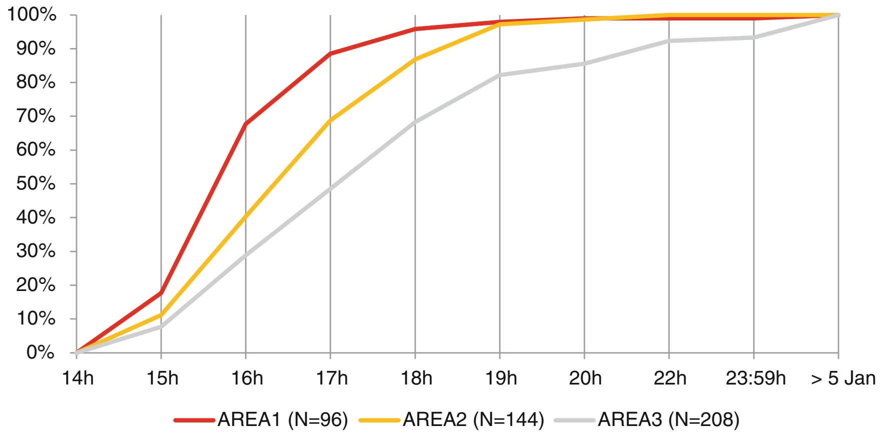

Fig. 2 Share of the people present per area who were notified about the fire at Chemie-Pack

Table 1 Channels via which people were notified about the fire at Chemie-Pack

Type of channel	Communication channel	AREA1 (N = 96) (%)	AREA2 (N = 144) (%)	AREA3 (n = 208) (%)
Visual observation		9	4	0
Alarming	Siren	24	0	0
	Sound truck	2	0	0
	SMS-alert	1	1	1
Informing	Local broadcast company	6	7	4
	National radio/TV	6	18	35
	Internet	5	22	28
Person	Via a known person	38	44	24
	Via a stranger	7	1	1
	Announcement to multiple people	0	3	1
Other		1	1	6

AREA2 who were not notified by another person mostly heard about this fire from information channels. Information channels notified two-third of the people present in AREA3.

Problems with Conventional Alarming Technologies

Alarming technologies such as the outdoor siren system haven limitations due to design and operational specifications. In The Netherlands, for example, sirens can only be used if the required action is to go inside, shut doors and windows and turn off the ventilation system. This is the instruction about what to do in case of the siren, which is educated to the population as part of the governmental risk communication program. Instruction of only one required action via sirens limits the type of threats and incidents for which use of this alarming technology is an option. There are however other disaster scenarios for which other required actions, such as for example stay outside, leave/evacuate or do not use, could be relevant to communicate quickly to the public. The population cannot be notified in any situation where one of these is the required action to get or stay safe. Such situations could be, for example, some explosion dangers, wildfires and certain floods or flood threats. Apart from limitations in the type of risks the system design has its limitations. The specifications require outdoor audibility and exclude the obligations to place sirens in remote areas where the number of inhabitants is limited [20]. As a result the siren is not always heard indoors and at certain locations (especial rural locations). Moreover, hearing-impaired and deaf people will never be alarmed directly via the outdoor siren. They need aid from others to get notified.

Besides limitations due to design and operations specifications, the sirens in The Netherlands are being criticised both when the system is used but especially when it was not used to alarm the population in the past. On March 5th 2012 at 0:30 h the siren was sounded to alarm the population in Heerhugowaard (North of Amsterdam) about a fire in a greenhouse [35]. However, people could not get any further information since the calamity broadcast channel did not provide any news on radio, television or internet until half an hour after sounding the sirens. It took the municipality even an hour to provide information via their website. As described in the previous section a chemical storage facility caught fire in January 2011. Although the population of the area north of the waterways were alarmed via the sirens the citizens of Moerdijk were not. Moerdijk residential area is situated leeward of the wind and therefore situated in the areas that needed speedup via alarming channels. This was however late explained to these residents. In addition the communication during the acute phase of this fire was later criticised on its internal focus [33]. The public was informed about measurement results of the concentration of dangerous goods in the toxic cloud without proper explanation of the meaning of these results. Although most governmental information was not incorrect, it was different interpreted by the media causing confusion amongst the public.

Mobile Phone Technologies

Meanwhile mobile phone technologies have become part of everyday life. Several private initiatives of safety and security services via mobile networks are available. Internationally known and also available in The Netherlands is Amber-Alert a service sending alerts in case of missing children. Examples in The Netherlands are: Burgernet; a service asking the population for information in safety or security related (police) problems via SMS which are sent to subscribers, SMS-Alert; which is similar to Burgernet. These services not only use SMS but also other traditional and new media platforms. All these services require subscription and sent messages based on the zip code of the household. Messages via these services are received, regardless of the actual location at the moment a message was sent. Depending on their presence at the moment of the occasion for which the authorities ask assistance, the message could be relevant or not to the receiver. This does not bring the population in danger, because messages from these services do not require an action. For citizens' alarming however messages should be sent to people who are—at the moment of the incident—present in the area in danger. For every individual the area in danger is not necessarily one's place of residence. It could moreover be a location that one is visiting seldom, for example for a holiday, business trip or a conference. Another drawback is the delivery performance of SMS which is based on best-effort basis without any guarantee how long it takes for a message to be delivered [29].

An alternative mobile phone technology which broadcast messages to a geographical area is cell broadcast [30]. Cell broadcast like SMS is part of standards for GSM, CDMA, UMTS (3G) and LTE (4G). Cell broadcast messages are sent point-to-area to all mobile phones connected to the network in a specified area [11]. Anyone also people rarely visiting an area in which a cell broadcast message is sent can receive it. A mobile phone will only display a cell broadcast message if the device is tuned in order to receive messages. Tuning one's mobile phone means that the owner needs to define the channel or channels from which messages are desired. Currently some new bought devices are sold with cell broadcast channels predefined. Messages can only be receive real time [1], therefore a mobile phone should be switched on and have network connect to one of the broadcasting cells at the moment of broadcasting. To increase the change that messages are received, the broadcast can be repeated. The mobile phone technology does not suffer from network congestion as SMS does in case multiple bulk messages are sent at the same time. Cell broadcast will dispatch messages one-way, thus unconfirmed. As a result the sender cannot be informed to whom nor to how many mobile phones the message is delivered. This makes the services anonymous, which reduces privacy issues in comparison to a service for which subscription is required. It is possible to receive confirmation of the actual broadcast success or failure from the network [27]. Due to it functionality, without confirmation of delivery, there is no guarantee that each mobile phone connected to the network in the area in danger will receive a message. This is not a necessity for effective alarming, however it should be known to anyone involved how this technology operates.

Citizens' Alarming Via the Mobile Phone

Figure 3 shows the four processes which should function to be able to effectively alarm the population.

The orange line shows the decision making of rescue services about the necessity of alarming the population, about the area to be warned and about the alarm text message. The red line shows the technological chain to broadcast a message from a mobile phone network. The blue line showing the alarm message text which needs to be received on the mobile phone, needs to be notified, read and understood by the people. The green line finally shows the response of the population which should be in line with the action given in the alarm message text. Each of the four lines are related to different stakeholders who are responsible for correct functioning of their part in the alarm chain. The orange line is the domain of fire, policy and rescue services together with other authorities responsible for alarming the population. If they do not consider cell broadcast no messages will be sent during an incident. The red line is the domain of the operators of mobile phone networks, only users of the networks involved in an alarming services using cell broadcast can receive these messages. The blue line relates to multiple parties: manufacturers of mobile phones to implement cell broadcast (according to standard) on the devices and users of mobile phones who need to realize under which circumstances they can or cannot receive a message. Finally the green involves the population who based on a received message determine if the act accordingly or not.

NL-Alert: Cell Broadcast for Citizens' Alarming in the Netherlands

Discussion about new technologies for public warning started over a decennium ago. The 1999 policy document on Disaster management [22] proposed to explore the possibilities of mobile phone technologies to warn the population. In 2005 and 2006 the first large-scale trials with population have taken place. The Safety Science Group has evaluated the public warning trials [12, 32]. The evaluation included five themes: technology (understand the technological alarm chain from network to mobile phone), potential effectiveness (proportion of the respondents who were reached and responded properly to cell broadcast messages), message design (the content of alarming messages), acceptability (including user friendliness) and responsibility of stakeholders involved in the alarming chain. The evaluation of the trials showed that an alarming service using cell broadcast can function as long as all stakeholders involved acknowledge all linkages of the alarm chain [12]. Important is not only to implement and control the technological chain, but also to set up a working procedure for emergency services (when and how to use NL-Alert) and citizens to create awareness about what is needed from them to be alarmed on their mobile phones.

In 2008 the Dutch government decided to introduce cell broadcast for citizens' alarming (Kamerstukken II 2007–2008, 29 668 nr 24). The next step, in 2009, was to sign agreement with relevant partners for the availably of the technological infrastructure (orange and red lines in Fig. 3). These include all owners of mobile network in The Netherlands and in addition an intermediate stakeholder (a broker) between the operators and emergency control rooms where a message will be

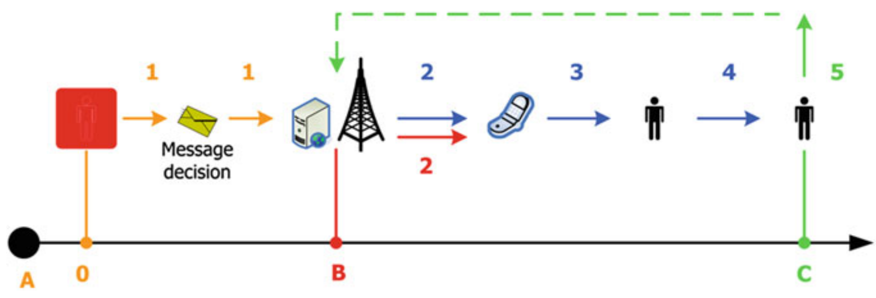

Fig. 3 Operation alarming chain when using mobile phone technology for citizens' alarm [17]

created and dispatched. In 2010 the Parliament was informed about the progress of implementation of the alarming service using cell broadcast and announced NL-Alert to become the name of the service (Kamerstukken II 2009–2010, 29 668 nr 30). Late 2011 it was announced that the system will be operable in stages starting from 2012 (Kamerstukken II 2010–2011, 29 668, nr 36).

November 8th 2012 the Dutch Minister of Safety and Justice launched NL-Alert nationwide in The Netherlands (Kamerstukken II 2012–2013, 29 517, nr 68). This moment marked the start of the campaign "NL-Alert: direct information in case of an emergency" (in Dutch, NL-Alert: direct informatie in een noodsituatie). The campaign should make the population aware that they need to check their mobile phone settings and if required change these in order to receive any alarm message. Unique about the new Dutch alarm system, apart from the agreements with all involved Dutch mobile network owners, is that NL-Alert provides incident-related contextual alarm messages. Any NL-Alert will notify the population about the danger and in the same massage provide guides about the required action(s) to get or stay safe. A NL-Alert as such contributes to increasing emergency self-reliant behaviour of the population in danger [32]. This sets demands on defining the content of the alarm related to the incident for which it has to notify the population.

Until mid-February 2013 NL-Alert was used in four occasions. In three cases local alarm messages were sent to warn the population about a fire causing heavy smoke. The fourth occasion was not incident-related. On February 4th 2013 at noon a control message was sent. This messages was the result of many reactions from the population who wondered how they could check if they had correctly changed the settings of their mobile phones. At this Monday an NL-Alert was broadcasted together with the siren, which is monthly tested in The Netherlands. NL-Alert control messages will be sent nationwide twice a year in May and November together with the monthly siren [23]. Since emergencies fortunately occur seldom the change of being present in the neighbourhood of an incident for which an NL-Alert is broadcasted is limited. The yearly tested therefore function as reminder about the service for the population. People can check twice a year that they can (still) receive a message. Rescue personnel are also made aware of this service as one of the means to alarm and inform the population. Employees of the emergency control room can practice the procedures to dispatch a message at these control messages occasions.

Cell Broadcast in Other Countries

In multiple countries the use of cell broadcast to notify the population became recently available or are considered. Most of these initiatives relate to early warnings for natural hazards. These often include mixture of different technologies to deliver a message to the population. Examples of such initiatives are shown in Table 2.

Table 2 Example of mobile phone warning systems

Country	Aim of the service	Development stage	References
Japan (Area mail)	Earthquake and Tsunami warning	In use since 2007	[31]
Chile	Emergency alert system (focus Tsunami warning)	2010 licence agreement, currently in five networks testing and expanding of the system	Galvez [10]
Israel (National message)	Earthquake and missile warning	Demonstrated 2010 civil defence drill "Turning Point 4"	eVigilo [8]
South Korea	Alert, warning, response and recovery information for social, natural and man-made disasters	Life in 2009. Still updating law and regulation and expanding the service	Choi [4]
Sri Lanka (Disaster and emergency warning network)	First alert to emergency personnel and public alerts only when a threat is adequately verified	Launched in January 2009 after testing	[30]
US (Wireless emergency alert/CMAS)	All hazard warring system using various technologies, include presidential warning, imminent threats and amber alerts.	In use since June 2012	Moore [24] and FEMA [9]

An important difference is that most initiatives make use of predefined messages that are automatically generated. The automatic warning systems also include other alarming and informing channels. Not all services provide an action related to the warning. This relates especially to the natural hazard warnings systems. For a number of these initiatives not all mobile network operators are involved, meaning that the service cannot directly alarm all people with mobile network connection. Moreover, in some of these systems, different from the Dutch case, the operators and manufactures bear responsibility for tuning the mobile phone. This is the case for example in the USA. As a result, a customer can check if a mobile phone is CMAS-compatible via a sign on the box in which the mobile is sold/delivered.

Systems View on Composing Alarm Messages

Since NL-Alert aims to notify the population and simultaneously provide guidance for the required action, challenging apart from realizing the technological chain, is to be able to define the content of the alarm message related to an incident. In contrast to risk communication, in everyday non-emergency circumstances, the communicated preparation action(s) will not be sufficient for alarming about one specific incident. From these general messages "in case of an incident X do Y" the population cannot discover if incident type X is affecting them at that moment.

Systems View on Content of Alarm Messages

The content of an alarm message depend on the type of incident, the moment of alarming or informing the population and the required action. For an alarm message the incident or more specific the hazard source is the starting point. Mileti and Sorensen [21] classify 14 different disaster types into three main sources: natural (geological or climatological), technology and social disasters. Countries prepare for various hazard sources which differ based on the chosen level of detail. Regarding natural disasters the classifications also differ because certain incidents, e.g. volcanic eruptions or tsunamis are not relevant for all countries [6].

The relation between type of incident, moment of alarming and action is shown in Fig. 4. Depending on the type of disaster certain moments to alarming will be more or less relevant. Alert messages are in particular possible in crisis where the moment and location of a hazard release can be predicted. Early Warning Systems such as the Japanese Area mail and the Israeli missile warning are examples of possible alerts. Another alert example are treats for a BLEVE, which is an explosion with liquid gasses involved. Other incidents, such as a tunnel fire, cannot be foreseen. An 'alert' message sent in case of a critical threat asking to take precautionary measures as soon as possible to prevent getting affected in such cases is irrelevant. The relevant moments of alarming relates to the aim of a message: notify and alarm to limit personal losses or inform about the course of events. The alarming and alerting messages include first actions to be taken quickly to get or stay safe.

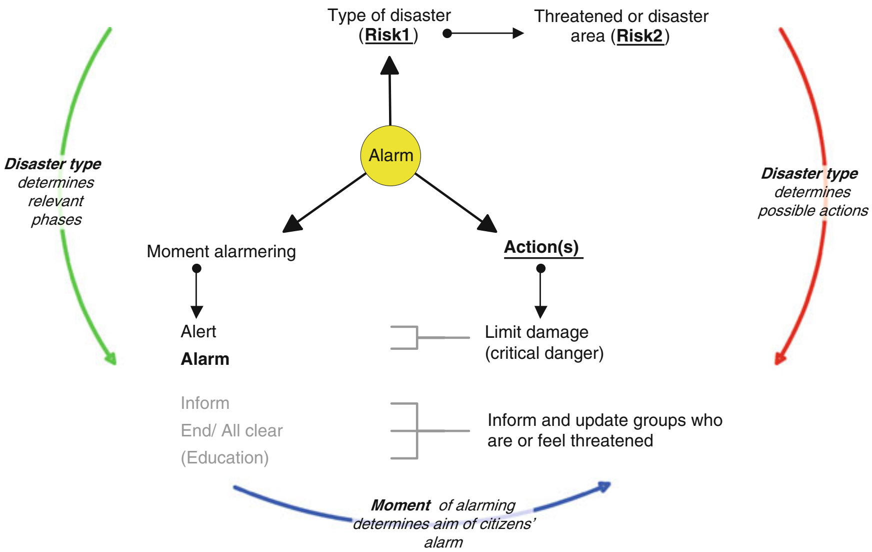

Fig. 4 Relationships between incident (disaster type), moment of alarm (type of message) and action [14]

The incident circumstances and the moment of alarming determine relevant required actions. The incident circumstances include both the hazard source and the area which is potentially affected by this source. This in particular distinguishes an alarming service from all risk communication precaution measures. In case of a real incident the required action due to area specific circumstances could differ from the general most suitable action. For example, if in a fire with smoke heavy release a domino-effect (the first incident initiates another incident) cannot be excluded, instructing the population to leave the area would possibly be preferred above shelter inside. If such a fire would occur near a forest or dune environment with hardly any buildings, shelter may also not be the preferred option.

The informing messages may but does not necessarily include a reminder to continue an action, such as keep windows closed, since the people in the area are still in danger. Depending on the functionality of the area in danger, the message should consider multiple different groups. If an incident has effect on an area around a city centre, the people present include for example residents of the neighbourhood and visitors. The latter could be frequent visitors such as people working, visiting schools and shopping in this area or infrequent visitors such as day trippers and tourists. These different people cannot necessarily undertake the same action. Since cell broadcast messages are geographically send, a message may need more than one action to serve different groups who are present in the same area.

Elements for Alarming Messages

For alarming message, a web experiment in 2006 showed that these should include the components: Risk1 (the danger), Risk2 (the location in danger) and Action [6]. Information about other media where more details can be found was less important and not necessary for a first alarming message. The experiences with receiving cell broadcast messages in 2005–2007 showed the need for additional information to be able to verify that a message indeed is an NL-Alert alarming message and to verify the relevance of the message at the moment of reading. For the latter a time stamp of the moment the message was sent by the rescue services would be helpful. These needs result in two more components: ID1 and ID2. Authorisation of the message affects the response towards a message. Authorised sources increase people's motivation to act [38, 39]. Credibility is based on believed expertise and confidence [7]. All contextual components and the two identifiers can be related to the common alerting protocol CAP [6, 25]. This protocol is for example used by American CMAS warning service.

To define the content per component literature on emergency preparedness has been studied. The results are summarised in Table 3. For defining Risk1 we referred to the 18 Dutch disaster types. In some cases the danger itself is clear, in some cases however the origin should be added. For example if a toxic cloud is released from an industrial installation. To explore required actions risk communication plans from all Dutch safety regions have been analysed. This resulted in four categories of types of actions (see Table 3). The first three categories consist of concrete actions that people can take after reading. A fourth category, appeal to act self-reliant, does not provide guidance but rather ask take actions to get safe. This fourth type of action can be used in case incident circumstances are changing to quickly to determine the suitable required action, however people should be made aware of the incident. Alarming of the population in such a case may be preferred over a directive action in the message.

Since risk communication is not related to one specific incident the component Risk2 is not covered in the preparation documents we have studied. This marks the difference between disaster and risk communication. Since the reader should be able to understand which area is in danger, the location description should include clues which are known to the general public more or less irrespective of their familiarity with the area. Gaining experiences with NL-Alert should give more insight in which details are suitable for the description of the location at danger.

Supporting Rescue Personnel to Compose Alarm Messages

A fixed and complete text cannot be defined beforehand, since the disaster type is dominant in determining the text for an alarm message. We can distinguish three approaches to compose a textual alarm message, which have little up too much freedom [14] (a) standardise approach (generic messages with empty text spaces),

Table 3 Identification and content elements [15]

Component	Elements	Importance
ID1	(NL-Alert)	Must
Risk1	Danger	Must
	Source of hazard	Depends on danger
	Source location (stationary object)	Depends on source
	Source location (transport object)	Depends on source
Risk2	Name of village (toponym)	Must
	Land marker	*Option*
Action	(a) Geographical (b) Do/don't actions after a geographical action (e.g. shelter or stay away from falling objects) (c) Do/don't actions without a geographical action (e.g. use no drinking water, use paper tissues or wash hands after contact) (d) Appeal to act self-reliant	one action element is must: Which depends on the incident (risk1) and the location (risk2)
Info	*Other media*	*Option*
	Access information (e.g., frequency)	
ID2	(Date + time information)	Must

(b) compare and adjust approach (example message which need modification for current incident) and (c) activating and learning approach (use of test criteria to compose a message from 'blank'). The first approach requires a complete library of messages for any future incident, otherwise it will not be possible to select an appropriate message. In the second approach a library is necessary as well preferably as complete as possible. Since messages can be modified, a more or less similar danger and location can be found to use as inspiration for the message. However, in this approach tunnel vision cannot be ruled out. Especially if not the generally applicable action is required but an alternative action should be communicated. The last approach can cope with the variety and special circumstances which are linked to disasters and is therefore promising. It does require to educate and to train the rescue services to gain experience in composing short alarm messages to be sent to mobile phones.

The system perspective (Fig. 4) shows an alarm text message can be considered useful for a specific threat or incident if the message is *complete*, *relevant* and *correct for the situation* [14]:

- An alarm message is complete if the receiver (the population) can determine what he or she should do to get or stay safe
- An alarm message is relevant if the receiver at the moment he or she *reads* the message can determine that the alarm is still relevant (valid) and that he or she belongs to the target group of the alarm
- An alarm message is correct for the situation if the receiver is urged to take action in accordance with the danger that is threatening him or her

For completeness the text in the alarm message should comply with the elements from Table 3. For relevance both identifiers should help as well as a clear description of the location (Risk2). The location description should be clear not only for daily present citizens but also for (infrequent) visitors. Regarding the location description rescue personnel should be aware that broadcasting a message from cells within a selected geographical area will be received by mobile phones connected to those cells. Due to the range of the antennas the mobile devices could be present within the area or outside. If the location details are exclude or too general people cannot define if the message is relevant for them. For example: “Main street” (in Dutch: Hoofdstraat) is a common used name for streets in The Netherlands. Only in combination with the name of the village one can determine the relevance. One of the fire in which NL-Alert has been sent in December 2012, the alarm message mentioned only heavy smoke and the instruction to go insight. There was no location mentioned at all. A limited number of cells broadcasted the message due to a very small area selection. Despite that, tweets expressed that people in the nearest city about 15 km away had receive messages.

Correctness relates to the message that is composed and other messages that have or will be sent regarding the same incident. The message should not be counterproductive nor reduce self-reliant behaviour. The composed message should moreover not conflict with other messages, which among other things means that a new message is required if the situation changes. Such a problem occurred with the Japanese Tsunami Warning System during the 2011 Tōhoku earthquake and tsunami in Japan. The first warning was issued quickly, 3 min after the earthquake. The predicted height of the wave changed multiple times over the course of the disaster. The updated warnings included raised predicted heights and a wider area in danger [28]. This warning system does not give instructions about the required action. The people receiving the warning should decide themselves. The first more conservative prediction had more options than the last prediction. In that case evacuation up hill is the only option, while in the first case one could also consider to stay at high floors in buildings. For each of these three test criteria a slide with rules is discussed in Jagtman et al. [14].

Alarm Messages Created by Experts

The test criteria have been used in a workshop in which groups of experts composed alarm messages. The groups included a mixture of advisors from fire services, emergency centres, (crisis) communication specialists and behavioural specialists. During the workshop each team received a short description of an emergency scenario. A brainstorm was held on what should be included (or not) in an alarm message. This discussion let to a first version of an alarm text message. That first version was subsequently tested using the criteria discussed in the previous section by the group who had composed it. The testing resulted in a revised version. The revised alarm message was shown to another expert team without the scenario description. Since all scenarios differed, the experts can be considered part of the population who received a message without knowledge of the incident and its context. The experts were asked to discuss what they would do if they received this message. Secondly, the scenario used to compose the message was revealed. Finally, the group is asked to review the alarm message text using the test criteria and if required propose a modified version of the alarm message.

The procedure of (a) writing a message, (b) testing and revising the message and (c) reviewing and revising by another group was done for six different scenarios. 14 experts participated in the workshop, who created in total 25 alarm messages. The review and revising step resulted in seven messages, where analysed in detail. These messages were found to be complete and thus contain the required elements. six of the seven messages however included more than the elements defined in Table 3. The "additional" pieces of texted statements which are common in risk communication, such as "think of others", "follow instruction of rescue services" and "limit the use of mobile phones". Analysing the relevance criteria it was found that some messages referred to one target group specifically which could confuse others. For example: "leave your car", what should you do if you are in the area but without a car? To emphasize the alarm character of the messages the experts had included words as "NOW" and "life threatening" in the text. The correctness of the messages was elaborated the most for alarm messages about heathland fires. It was amongst others discussed how to prevent to direct people towards the fire rather than away. Do people understand north and can they determine north at their current location? After the review and revise step the message had a self-reliant component "leave the area; stay out of smoke", since it does not provide guidance in what direction people should leave.

Although the messages complied with the test criteria, they included more that required content. As a result the messages were quite long, which does not meet the desire of the population to receive short messages [6]. In a recent experiment in which the population was asked to compose a message themselves, it was found that the general people write shorter messages than the experts. The respondents moreover dislike the "additional" components originating from risk communication in the messages composed by experts [16]. The discrepancy between the experts' alarm messages and the populations' preferences are used to fine tune the workshop into a training program for the employees of the Dutch safety regions who will be involved in composing alarm messages or need to advice about these messages. The training program involves three blocks: [1] composing a message, [2] review and improve a message for an unknown incident made by someone else and [3] compose a message and select and area for a complicated incident. Duos are asked to compose messages in maximum 10 min for 11 different scenarios. The alarm messages were distributed to other participants without the scenario description, thus an experience of a citizen who receives a message about an unknown incident. The participants share their thoughts on composing as well as reviewing a message.

Thirteen workshops have been carried out with this program resulting in over 220 alarm text messages. The time restriction was no problem. More problematic was the lack of knowledge to define the required action, which make participants realise they need advisors for various to fill in all elements of an alarm message. Which advisor is needed depends on the threat or hazard source. In cause of dangerous goods these are often toxic advisors, while for order disturbances advisors from the policy are more relevant. One could also think of contacting health care specialist for disease outbreaks due to for example drinking water contamination. Another important experience the participants gained is the need to include the location (Risk2) component. Many of the participants are familiar with the risk communication instructions from the campaigns to prepare for further emergencies. This component was included in about 80 % of the messages, while the danger (Risk1) and the Action were included in nearly all messages [13]. Some participants tended to address locations in terms of “leave the area” which does not explain in which municipality and at what exact area one is in danger. The reader can also not determine where to leave to, in other words how far from my current location will I be safe? By reviewing messages from others without incident context knowledge awareness was raised for the need to specify the location for the receiver to be able to determine relevance of an alarm message.

The discussion of the context of alarm messages learned the safety region employees that a cell broadcast message can never be sent only and exactly to the area in danger. A trade off need to be made between selecting a narrow area and therefore increase the change of false-negatives (thus people who should receive an alarm do not) versus a larger area and consequently increase the change of false-positive (people in neighbouring area not in danger receive an alarm). The Dutch guideline expresses preference for the latter, give that NL-Alert should only be used in case of acute action of the population is required to get or stay safe. Given that also people in neighbouring areas will receive a message the decision to send a message should also include consideration if people receiving a false alarm have enough clues to understand this from the message. This also implies in case a message is sent to an area in which a mass event is held. If people attending this event need to take another action than is being broadcasted, rescue personnel should first have confirmation that the visitors of the event are notified before they receive a message which is not meant for them. This could also apply for people travelling in by passing trains. A final lesson from the workshop is to realise NL-Alert is not a standalone alarming service. A mixture of alarming and informing means can and will be used in case of emergency. It is therefore not necessary to put every detail in a short message sent to mobile phones. Additional information is received via other media and via conversations with other people, also if you do not direct the population to an information channel. There is no need to consider that a follow up message should be sent via NL-Alert. This not possible in cases where people present in the area in danger are told to leave, since it is unknown to which other areas these people went.

Discussion: Issues to Realize an Effective New Alarming Service

As the relationships in Fig. 4 showed composing an alarm message does not stand on its own. In the round up of this chapter, author discusses four dilemmas that play a role in realizing an effective alarming system in practice. There are more dilemmas, for example relating to the characteristics of the technology, which make it impossible to monitor how many individuals spread over the area in danger are actually alarmed.

Dilemma I: Stakeholder's Responsibilities Versus Effective Alarming of the Population in Danger

The technology cell broadcast can only be effective if all the linkages from the alarm chain shown in Fig. 3 are functioning. To realise this at the moment of an incident, the emergency services should decide to alarm and compose a message while the operators' networks should be functioning. In addition citizens, who are present in the area in danger, should have their mobile phone active and their phones should be noticeable to them. Subsequently, after notifying an alarm, people should read it, understand it and respond in accordance to the guidance given in the message. Although the mobile operators cannot be held responsible for the content of the message nor for the response to the message, they should acknowledge that the effectiveness of an alarm message is not only to reach as many people as possible, but also to have the relevant people respond to a message. They should consider their role in building expectations of what their customers (whom are part of the population that may need to be warned) should do in order to be able to receive a message.

Dilemma II: Emergency Preparedness Versus Emergency Response

All the research related to cell broadcast for citizens' alarming was undertaken in non-emergency circumstances, since there is no system yet. This not only related to the trials in which cell broadcast messages have been sent, but also the investigation into the content of alarm messages. As was shown in the workshops with experts, they put items related to the main goals of risk communication in a message for disaster communication. The effect of adding these 'additional' elements is not known. It may reduce the distinguishing characteristics of alarming messages. Even though the population in various experiments have stated this to be annoying and sometimes patronising, it is not clear if that will affect a response if people are really in danger. A question about the importance of the various message components showed different answers in a questionnaire about a big industrial fire in The Netherlands that another experiment about citizens' alarming messages for fires and explosions. In that questionnaire the importance of explaining the danger (Risk1) was a lot higher, this component will help to determine relevance for the current moment [16].

Dilemma III: Alarming and Informing Via the Same Technology

In this chapter, the service to alarm the population was leading to discuss how cell broadcast can be used (see positioning of cell broadcast in Fig. 1). However, from a technological point of view cell broadcast can be used both to alarm and to inform the population about an incident. As shown in Fig. 1 many channels are available to do the latter. Citizens can however not be informed or updated about a situation before being notified. Alarming requires persuasion of reader to stop what he or she is doing and act in accordance to the message (green arrow in Fig. 3). Credibility of a sender influences compliance with the instruction in a message [2, 37, 38]. A sender is considered trustful if its communication has no conflicts of interest. Potentially alarming and information messages can have conflicts. For example, when for a first incident an information message is received for which no action is required, while for a later other incident an alarm message is received which requires immediate action. Receiving multiple informative messages could decrease the urgency for an alarming message via the same communication channel. The use of control messages, as done in the Dutch case, involves another trade off. Control message similar to information message do not require an action. However, control messages are not related to one particular incident and the moment of broadcast is planned and communicated to the public in advance. Control messages are appreciated by rescue personnel since it offers an opportunity to gain experience with the new service and to test the procedures within the rescue organisation. These messages also close the loop for citizens, because by receiving a cell broadcast control message they receive confirmation that their mobile phone is tuned correctly.

Dilemma IV: First to Alarm Versus Confirmation Unauthorized Information

Since the trial period 2005–2007 the use of social media networks increased significantly. People search at almost any place for information. In crisis communication this has shifted from the authorities will tell you what is going on to thinking in terms of a mix of means which includes both traditional media (radio, TV and newspapers) and new media (internet, social media). Most of these channels however are useful for informing but not for alarming. Since an individual will not notice something is posted on the internet if you are busy with another activity. New media have another problem. While traditional media are often criticised about being late with information, new media have shown to be inaccessible due to network overload in several disaster situations. Another problem is the trustworthiness of social media information. For emergency services social media are a new source of information, although it requires the organisation to consider to listen and validate issues posted by the public [18]. Walters [36] argues he followed the news about the a Dutch shooting via Twitter. When verifying all he had read he found that Twitter had informed him quicker but all he had learned was found to be false information about the event. A second example occurred when a national broadcast channel had posted "Beatrix Hersenbloeding" (Dutch Queen brain haemorrhage) unintentionally on Twitter instead of searching with these words [19]. The post was retweeted quickly by multiple followers and many other media subsequently paid attention to this non-news [34]. These examples show that the government will most likely not be the first to announce. This has also never been the intention. The potential of increasing amount of false information could increase the need to confirm or disprove unauthorised information.

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Optimal Policy Design for Disaster-Hit Area of Japan: Bottom-Up Systems Analysis of Special Zone for Reconstruction by the Isdm

Masaki Nishimori, Motoshi Kanke, Akiko Tsutsuki, Naohiko Kohtake, Seiko Shirasaka and Toshiyuki Yasui

Abstract This chapter proposes application of framework of system design of a special zone for reconstruction of Fukushima Prefecture which suffered serious damages from the Great East Japan Earthquake, tsunami and nuclear accident at the Fukushima Daiichi Nuclear Power Plant. The framework of system design used in this chapter is called the Interactive Social Design Model (ISDM). The ISDM is useful for aggregating stakeholders' requirements and values through the process of the interactive and bottom-up communication with stakeholders, and derivation of the optimal policy in quantitative approach. In this chapter, the optimal policy designed by the ISDM for the purpose of reconstruction of Fukushima is compared with the existing system of the special zones for reconstruction, in which local governments which suffered from the earthquake can choose support measures from the catalogue of policy measures designed by the central government of Japan.

Keywords ISDM · The Vee model · Special zone for reconstruction · The great eastern Japan earthquake

Introduction

The Eastern Japan suffered a catastrophic loss of human lives, infrastructures for daily life and industries from the great earthquake and tsunami, especially in *Fukushima* Prefecture, a serious damage and harmful rumors of radioactive contamination are obstacles to rebuild regional social and economic systems. The accident in a nuclear power plant and that sustained effect causes severe situations

M. Nishimori (✉) · M. Kanke · A. Tsutsuki · N. Kohtake · S. Shirasaka · T. Yasui
Graduate Student at Graduate School of System Design and Management, Keio University, Collaboration Complex, 4-1-1 Hiyoshi Kohoku-ku, Yokohama, Kanagawa 223-8526, Japan
e-mail: nishimori@a5.keio.jp

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that are unexpected before the earthquake. We need visualization of what are required for countermeasures against contamination and action plan for reconstruction.

The Government of Japan enacted the law for special zone for reconstruction at the end of 2011, which allows local governments of disaster areas to establish a special zone for reconstruction with approval of the central government. When local governments plan special zones, they can choose support measures from the support measures catalogue offered by the central government.

However, the policy measures in the catalogue are possibly not the requirements from the bottom of the community people's hearts that actually live in the disaster area, but the top-down policies that the central government believes them necessary for reconstruction.

The Interactive Social Design Model

This chapter empirically validates the process of policy design for reconstruction of disaster-hit area of Japan by the Interactive Social Design Model (ISDM). The ISDM is the systems approach to design a solution to the social system by participatory and collaborative works by residents [1]. The ISDM is supposed to be effective in the case if a policy maker cannot know or predict the requirements and values of stakeholders with accuracy. By the IDSM, a policy maker has opportunities of sharing information of the requirements and values by the stakeholders' participation.

The ISDM inherits its methodological structure from the Vee model [2], which is a helpful tool of description of a lifecycle of system design and development [3].

The ISDM consists of the following five phases:

Requirement Analysis
Tools: Brain-Storming, KJ Method, VOC Analysis, Scenario Graph, Value Graph, Customer Value Chain Analysis (CVCA), Quality Function Deployment (QFD), Object Process Methodology (OPM)
Architecting and Design
Tools: Morphological Design, Prototyping Rapidly, Pugh Concept Selection, Net Present Value Analysis (NPV), Cost-Benefit Analysis
Verification
Tools: Experts Judgments, Local Opinion Poll, Analytic Hierarchy Process (AHP), Scenario Analysis
Implementation
Tools: Policy Implementation
Validation
Tools: Regression Analysis, Cognitive Chronological Ethnography, Causal Loop Modeling (CLM), Multi-Agent Simulation, Structural Equation Model

However, the actual policy implementation for the special zones is delayed due to political and administrative challenges. The special zones in *Fukushima* are not yet certified as of 27 February 2012. Therefore, it is impossible at this time to compare the outcome designed by the ISDM with the central government's actual proposal for the Fukushima special zones. This chapter thus shows only the results of two phases (Requirement Analysis and Architecting and Design), and not the rest three phases (Verification, Implementation and Validation) among the above five phases.

Case Study

The Act of the Special Zone for Reconstruction

On 29 July 2011, the Government of Japan issued the "Basic Guidelines for Reconstruction in response to the Great Eastern Japan Earthquake", the policy guideline for post-disaster rehabilitation and reconstruction. Under this guideline, the Reconstruction Headquarters in response to the Great Eastern Japan Earthquake announced the government's policy in creating the "System of Special Zone for Reconstruction" as follows;

> To strongly assist the reconstruction efforts conducted by the communities subjected to the damage, a framework of Special Zone for Reconstruction is to be established. In the conduct of this scheme, proposals by affected communities are promptly put in practice in an integrated way by making use of tailor-made and innovative ideas, going beyond the conventional wisdoms and ideas. They include special measures for drastically reduced regulations and administrative procedures, as well as economic aid packages. (Reconstruction Headquarters in response to the Great Eastern Japan Earthquake [4].)

On 7 December 2011, the Act of the Special Zone for Reconstruction came into effect. This act allows local governments located in "disaster afflicted zone" to formulate and submit a plan for a special zone for reconstruction which includes the incentives of special arrangements for deregulation, the special measures regarding land use restructuring, and the grants to local governments.

ISDM

In this chapter, the policy support designed by the ISDM that is the bottom-up approach with stakeholders in *Fukushima* is compared with the existing scheme of special zone for reconstruction at the initiative of the central government mentioned in the previous subsection.

Requirement Analysis

On 11 December, 2011, a workshop was held in *Fukushima* under the aegis of "Link with Fukushima", a voluntary youth organization based in *Fukushima,* and SDM Institute of Keio University. In this workshop, seventeen participants including a local governmental official, students and staffs of the host organization discussed about the theme of reconstruction of *Fukushima* and policy making by bottom-up approach (Fig. 1).

After the workshop, we sent questionnaires to staffs of the host organization and experts of special zone planning who were in charge of special zone policy of the Cabinet Secretariat, Government of Japan. Returned answers to questionnaires were used for requirement analysis in the ISDM.

Brain Storming and KJ Method

Firstly, in this workshop, Participants had brainstorming session and proposed almost 150 ideas for reconstruction of *Fukushima* in the session. These ideas were categorized into nine groups of stakeholders' requirements and values using the KL Method; housing, radiation, medical care, agriculture, daily life, energy, regional economy, image-building, and future vision (Fig. 2).

Value Graph

The next process of the requirement analysis is to draw the value graph that can visualize relationship with the purpose of the policy designed by the ISDM, future goals, stakeholder's value and observable indices. The pivotal role of the value

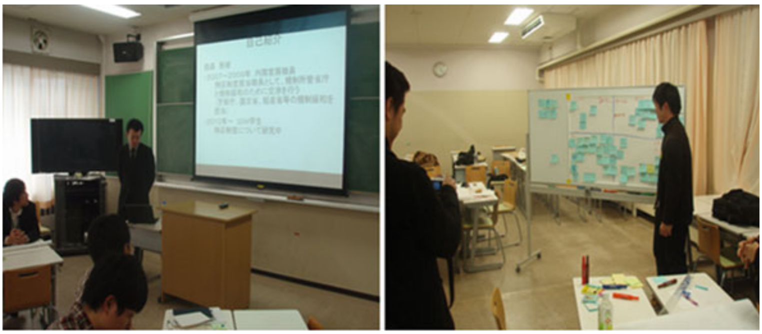

Fig. 1 The workshop for Fukushima special zone on 11 December, 2011 (adapted from link with Fukushima [5])

Fig. 2 Brainstorming and the grouping session at the session on 11 December, 2011 (adapted from link with Fukushima [5])

graph for this time is "reconstruction of *Fukushima*", that is the purpose of the policy. And the lower layers are extracted factors of "stakeholders' requirements and values" and "economic and social indices." The upper layer of the value graph shows the purpose and substantial goal of "reconstruction of *Fukushima*" (Fig. 3).

Weighted Poll

In order to weigh the importance of each factor of stakeholders' requirements and values, we conducted a survey in the form of a weighted questionnaire targeting the staffs of the workshop organizer and experts of special zones who have a career at the Cabinet Office of Japan. Twenty one respondents returned answers to the questionnaires. Table 1 shows the most important index of each factor in their answers.

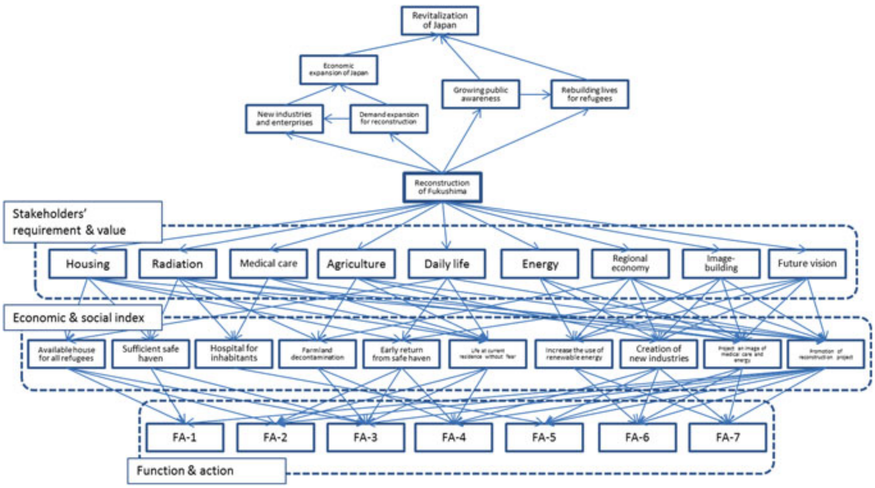

Fig. 3 The value graph for the reconstruction of Fukushima

Customer Value Chain Analysis

The Customer Value Chain Analysis (CVCA) is the method to describe the relationship with stakeholders; in the case of Fukushima, they are the central and local government, entities in *Fukushima* (enterprises and residents) and residents outside of *Fukushima*. The completed CVCA clearly shows some obstacles that have to be solved in order to make a progress for reconstruction of *Fukushima* (Fig. 4).

The central government which plans the framework of special zone can have information of needs of disaster area only from each plan of special zone by local government, not directly from the local enterprises and residents in disaster area.

Information from the central and local government and local enterprises in *Fukushima* to Japanese nationals outside of *Fukushima* is not enough to understand about the current situation in *Fukushima*, especially related matters of nuclear accident and the safety of food made in *Fukushima*, then this shortage of information causes serious harmful rumors.

Quality Function Deployment (Two Steps)

QFD-1

Quality function deployment (QFD) can analyze the structure of value graph and the connection of each factor of that graph quantitatively [6]. In this chapter, the QFD applies to the estimation of each factor of "stakeholders' requirements and values", "economic and social indices" and "function and action." The QFD has two steps for analysis of these three layers.

The first QFD (QFD-1) is QFD that analyze "stakeholders' requirements and values" and "economic and social indices." The result of the QFD-1 implies that the importance of radioactive decontamination for revitalization of agricultural industry in *Fukushima*, which has the largest weight in the QFD-1 (Table 2).

QFD-2

Based on the information of weight of each factor of "economic and social indices" from the QFD-1, the second QFD (QFD-2) that analyzes "economic and social indices" and "function and action" can be deployed. The QFD-2 shows that radioactive decontamination in farmland, residential area and school is the most important factor in "function and action" (Table 3).

Table 1 The most important index of each factor in the weighed poll

Housing	Radiation	Medical care	Agriculture	Daily life	Energy	Regional economy	Image-building	Future vision
Available house for all refugees	Sufficient safe haven	Hospital for inhabitants	Farmland decontamination	Early return from Safe haven/life at current residence without fear	Increase the use of renewable energy	Creation of new industries	Project an image of medical care and energy	Promotion of reconstruction project

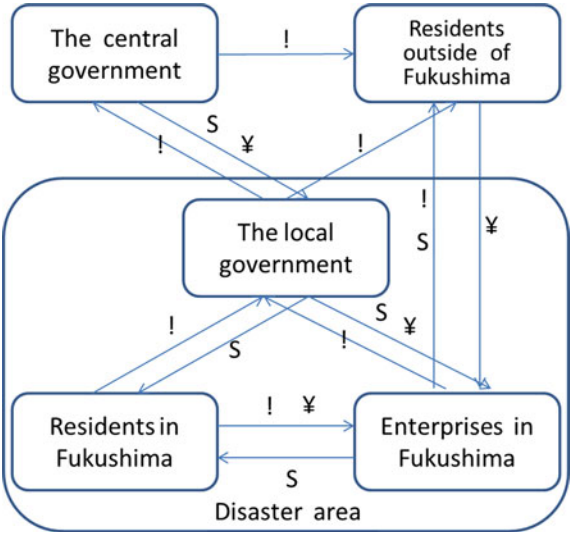

Fig. 4 The customer value chain analysis for reconstruction of *Fukushima*

Architecting and Design

Pugh Concept Selection

Pugh Concept Selection can provide a basis for comparison between solutions for each requirements [6]. Policy alternatives of reconstruction supports that are based on the ideas discussed in the workshop are as follows:

- Solution 1 "Special housing zone": Improvement of residential zone (construction of temporary housing and support of rebuilding and relocation housing) and promotion of commerce and communication in residential zone
- Solution 2 "Special zone for radiation safety": Support of development and operation of decontamination in the private sector, radiation inspection of agricultural product, and promotion of public relations campaign for radiation safety
- Solution 3 "Special medical zone": Attraction of medical center and research of radiology based on the future vision of public medical care and welfare in *Fukushima*
- Solution 4 "Special zone for energy technology and industry": Attraction of research organization of renewable energy at the nuclear power plant site and fostering and promotion of new industries and venture companies in the related fields

Solution 3 is set as a benchmark for the Pugh Concept Selection. The Pugh Concept Selection implies that Solution 2 is the most effective policy in order to achieve the given stakeholders' requirement and values (Table 4).

Table 2 The first quality function deployment (QFD-1) for "stakeholders' requirements and values" and "economic and social indices"

QFD-1		Economic and social indices										
		Weight	Available house for all refugees	Sufficient safe haven	Hospital for inhabitants	Farmland decontamination	Early return from safe haven	Life at current residence without fear	Increase the use of renewable energy	Creation of new industries	Project an image of medical care and energy	Promotion of reconstruction project
Stakeholders' requirements and values	Housing	3	9	3			3	3				1
	Radiation	9		3	3	9		3			1	3
	Medical care	3			9			3			1	
	Agriculture	9				9		3		3		1
	Daily life	1	3				3	9				1
	Energy	1							9	3	3	
	Regional economy	1				3			3	9	3	1
	Image-building	1							3	3	9	1
	Future vision	9					1		3	3	3	9
	Score		30	36	54	165	21	81	42	69	54	123
	Composition ratio (%)		4.4	5.3	8.0	24.4	3.1	12.0	6.2	10.2	8.0	18.2

Table 3 The second Quality Function Deployment (QFD-2) for "economic and social indices" and "function and action"

QFD-2		Function and action							
		Weight (%)	Building temporary housing [FA-1]	Reconstruction of residential zone/support for rebuilding homes [FA-2]	Decontamination operation (farmland, residential area and school) [FA-3]	Radiation inspection of agricultural product [FA-4]	Attraction and foundation of Medical organization [FA-5]	Increase of the use of renewable energy[FA-6]	Fostering and promotion of new industries [FA-7]
Economic and social indices	Available house for all refugees	4.4	9	3	1				
	Sufficient safe haven	5.3	9		1				
	Hospital for inhabitants	8.0					9		
	Farmland decontamination	24.4			9	3			
	Early return from Safe haven	3.1		3	3	1			
	Life at current residence without fear	12.0		3	3	1			
	Increase the use of renewable energy	6.2						9	3
	Creation of new industries	10.2				3	1	3	9
	Project an image of medical care and energy	8.0					9	9	3
	Promotion of reconstruction project	18.2	1	3	9	9	3	3	3
	score		1.06	1.13	4.39	2.83	2.09	2.13	1.89
	Ranking		7th	6th	1st	2nd	4th	3rd	5th

Table 4 The Pugh Concept Selection for alternative policies for reconstruction of Fukushima formulated by the ISDM

		Solution 1 "Special housing zone" Improvement of residential zone (construction of temporary housing and support of rebuilding and relocation housing) and promotion of commerce and communication in residential zone	Solution 2 "Special zone for radiation safety" Support of development and operation of decontamination in the private sector, radiation inspection of agricultural product, and promotion of public relations campaign for radiation safety	Solution 3 "Special medical zone" Attraction of medical center and research of radiology based on the future vision of public medical care and welfare in Fukushima	Solution 4 "Special zone for energy technology and industry" Attraction of research organization of renewable energy at the nuclear power plant site and fostering and promotion of new industries and venture companies in the related fields
Stakeholders' requirements and needs	Housing	++	S	–	S
	Radiation	–	++	–	S
	Medical care	–	S	–	S
	Agriculture	S	++	–	S
	Daily life	+	++	–	+
	Energy	S	S	–	++
	Regional economy	S	+	–	+
	Image-building	–	+	–	+
	Future vision	–	+	–	++
	Score	3+ 3S 4-	9+ 3S	–	7+ 4S
	Ranking	4th	1st	3rd	2nd

Synthesis of Design

In order to get a desirable social design, the most valuable functions chosen by the two fold QFD in the Quality Function Deployment (Two Steps) and the solution selected by the Pugh Concept Selection in section Pugh Concept Selection is better synthesized. By this synthesis, the solution which is evaluated the best by comparative design method can be equipped with the functions which are the most favored by the voice of stakeholders.

For the case of *Fukushima*, the special zone for radiation safety (Solution 2) is synthesized with the radioactive decontamination, which is the most favored by stakeholders in the weighted poll. This design implies that the supports for radioactive decontaminations are the most wanted special zone policy by the residents in *Fukushima*.

Discussion

In the ISDM, the brainstorming with stakeholders in *Fukushima* can visualize their requirements and values by bottom-up approach, and the weighted questionnaire to staffs of the host organization and experts of special zone planning and the quality function deployment can estimate the effects of potential policies for reconstruction quantitatively in two stages. That estimation allows the ISDM to suggest the optimal policy package for realization of the stakeholders' requirement and values.

This result makes clear the difference between the ISDM approach and the existing framework of special zone in which local governments in disaster area plan reconstruction strategy through the use of the central government's supportive measures as a precondition.

Conclusions

In this chapter, the effectiveness of the ISDM is verified by the optimal policy design for the reconstruction of *Fukushima* Prefecture. Especially it becomes clear that the ISDM can design a right policy by the bottom-up approach in unprecedented situation such as the greatest earthquake and serious nuclear accident on record.

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Transportation Energy Consumption and Energy Security in China

Sai-ni Yang, Dan Wu and Ming Wang

Abstract This chapter is aimed at analyzing the energy consumption of transportation industry in China and its relationship with national energy security from a macro and quantitative point of view. Based on analyses of historical transportation energy demand and relevant planning policies, regression models were established in order to estimate the demand and structure changes of transportation. Combined with the main factors affecting transportation energy consumption, an econometric model was established using the Partial Least Square Regression method to analysis and predict the transportation energy consumption scenarios as well as energy-saving rate in China in the middle and long-term. Study results confirm that China's transportation demand and its energy consumption will keep growing within a period of time, and transportation structure has changed a lot in the past two decades, with road and air transport currently the fastest developing transport modes. Future growth of transportation system's energy consumption, especially petroleum consumption will pose a serious threat to energy security in China. Technique substitution, especially in road transport mode may significantly mitigate the energy gap.

Keywords Transportation · Energy consumption · Prediction model · Energy-saving rate · China

Introduction

From the mid-1970s of the twentieth century, United State is the country with the largest oil-imports in the world. However, it is bypassed by China in December 2012. The net-oil-import reaches 6,120,000 barrels in December according to the

S. Yang (✉) · D. Wu · M. Wang
State Key Laboratory of Earth Surface Processes and Resource Ecology,
Beijing Normal University, Beijing 100875, China
e-mail: yangsaini@bnu.edu.cn

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statistics of General Administration of Customs of China. Though someone argues that the data of December is heavily affected by annual taxation and data of a single month cannot represent the trend in long run, the high oil-imports make many people anxious about energy security in China.

With the development of economy and acceleration of urbanization process, energy consumption in China grows dramatically. Among all departments, transportation industry grows even faster than that of the whole society. As pointed by many researchers "…transportation industry is the major user of petroleum. Analysis of transportation energy consumption becomes a must in China…" [1]. Transportation energy consumption has put a serious threat to the country's energy security. Meanwhile, since transportation is a major user of carbon-based fuels, it is also increasingly being highlighted as the industry, which contributes least to CO_2 emission reduction targets [2].

As the main factor that hinders sustainable development, energy consumption in transportation system has aroused extensive attention of domestic and international scholars as well as government departments. Within domestic and international study on issues related to energy consumption in Chinese transportation system, energy consumption prediction is the basic part and occupies an important position. Traditionally, predictive models are usually built using historical data to analysis and predict transportation energy consumption levels in the future, which include energy efficiency, total energy consumption [3–6]. In addition, some work has also been undertaken to further explore issues like transportation structure optimization, planning and policy strategies and transportation sustainable development from the perspective of energy consumption. Shen [7] analyzed the sustainable transportation strategies against energy insufficiency and environmental needs; Tao and Xue [8] brought forward an analytical method of tax policy research on sustainable energy for transportation system in China; Creutzig and He [9] investigated the role of demand elasticity and demonstrated that joint demand and supply-side policies provide considerable synergies. However, these researches have been restricted to the lack of a complete and objective evaluation system to determine the impact factors of transportation energy consumption on energy security. Comparability of indicators and reliable data are also needed for further study.

In this study, an energy consumption prediction model is proposed to take comprehensive consideration of factors influencing energy consumption in China in middle and long-term. Further analysis and discussion are provided on intrinsic relationship and regularity between different transport modes' energy consumption proportions, the relevant influencing factors and national energy security. This study aims at not only helping obtaining better understand on current energy consumption situation of China's transportation system, but also providing a scientific reference for the development of China's middle and long-term sustainable transportation planning as well as national energy security.

Analysis of Transportation Demand

Changes of Transport Structure

To predict the future energy consumption of transportation industry, transportation demand is an important indicator to measure the development level of transportation industry. In recent years, with the economic development and technological progress, Chinese transportation industry continues expanding, and transportation demand is surging. From 1990 to 2010, total demands of passenger volume and freight volume have increased as much as 5 times and 5.4 times, and have reached 2,789,426 million passenger km and 14,183,742 million ton km in 2010 respectively. Average annual growth of passenger volume and freight volume are 7.9 and 8.4 % during the past 21 years, which provides a strong evidence for the fast development of transportation capacity.

The proportion change of passenger and freight volume by different transport modes varies and forms different transport structure. Since people pay more and more attention to convenience and comfort besides accessibility when selecting transport modes, road transport now has replaced rail transport and become the most important transport mode in terms of passenger volume, and air transport becomes the fastest growing one. Road passenger volume proportion in China grows from 46.6 % in 1990 to 54 % in 2010. Although replaced by road transport from the first place, rail transport is still very attractive to the passengers with the improvement of comfort and speed. Especially, railway is suitable for bulk cargo transport. Therefore, it will maintain its important position in integrated transportation system in the future. Waterway shares a small part of passenger transport, while it keeps a steady growth in freight transport as well as pipeline transport because of its low cost. Freight volume proportion of water transport is 44.2 % in 1990 and it grows up to 48.2 % in 2010.

Figures 1a and b illustrated the share of passenger volume and freight volume for major modes respectively. The current rank of main passenger-transport modes is road, rail, air, waterway, and the order of freight-transport modes is waterway, road, rail, pipeline and air. Air and road transport are now the top two modes with fastest growing speed of demand.

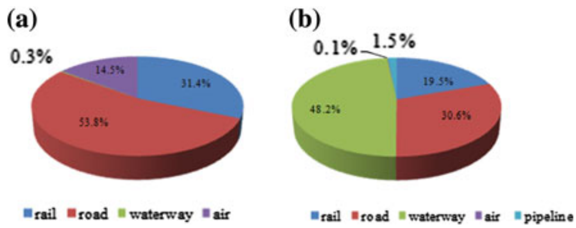

Fig. 1 **a** Passenger volume (*left*) and **b** freight volume (*right*) in year 2000 in China

Prediction of Passenger and Freight Volume

In recent two decades, integrated transportation capacity and transport volume constantly increased because of the rapid development of transportation industry. Generally speaking, transport volume is closely related to economic development. In order to predict passenger and freight volume in the future, regression equations between passenger (freight) volume and GDP are established using data from 1994 to 2010 (Eqs. (1), (2)). R^2 of the two equations are 0.9844 and 0.9966 respectively, which show that the regression equations established have a good quantitative reflection at the relationship between transport volume and national economy.

$$Freight\,volume = 1.0347GDP - 4558.5, \quad R^2 = 0.9844 \tag{1}$$

$$Passenger\,volume = 0.1812GDP + 2970.4, \quad R^2 = 0.9966 \tag{2}$$

*(Data resource: “China Statistical Yearbook”; price base year of GDP is 1990.)

According to the GDP growth prediction results provided by Chinese Academy of Social Sciences (CASS) and national development plan of the government, we make the following assumptions: by 2020, 2030 and 2050, GDP growth rate will be 7.7, 6 and 5 %, and the GDP value will be 29,292,310, 52,458,060, 139,106,800 million yuan. By Eqs. (1) and (2), predictive value of passenger and freight volume in 2020, 2030, 2050 will be obtained respectively (as shown in Table 1).

Energy Consumption Prediction of Transportation Industry in China

Current Statues of Energy Consumption of Transportation Industry

From 1994 to 2010, energy consumption of transportation industry and its proportion occupancy of the total social energy consumption show a significant upward trend (Fig. 2). In 1995, energy consumed by the transportation industry was only 4.47 % of whole society’s energy consumption. This number reached 7.05 % in 2005 and 8.02 % in 2010. Annual growth rate of energy consumption of

Table 1 Predict value of transport volume

	2020	2030	2050
Predict passenger volume (100 million passenger-km)	56,048.1	98,024.4	255,177
Predict freight volume (100 million ton-km)	298,529	538,225	1,435,608

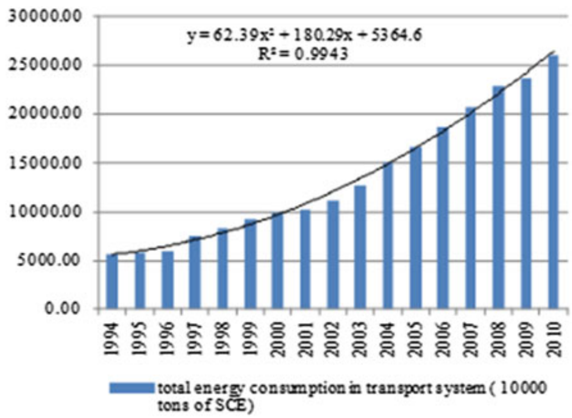

Fig. 2 Energy consumption trend of transportation industry

the whole society was 6.3 % during 1994–2010, while the annual growth rate was 10.1 % for transportation industry in the same period of time.

Compared with the developed countries, energy consumption proportion of transportation industry in China is relatively low. In 2003, energy consumption proportion of transportation industry in America is 27.1 % and the proportion is 24.4 % in Japan in 2005 [10]. While the number is only 6.93 and 7.05 % in China in the same period. There are two main factors lead to this deference: first, statistic methods are different in various countries; second, the fast booming industry sector consumes more energy than transportation industry in emerging countries like China.

As to energy structure, among the various kinds of energy consumed by transportation industry, petroleum accounts for the largest proportion, which has a closely relationship with the fast development of road and air transportation (Fig. 3). From 1993 to 2010, petroleum consumption of transportation industry in China keeps fast growth, while the domestic production of petroleum is limited

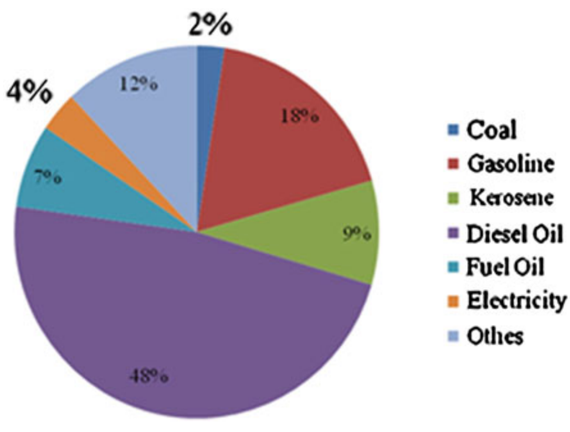

Fig. 3 Energy consumption structure of transportation industry in 2010, China

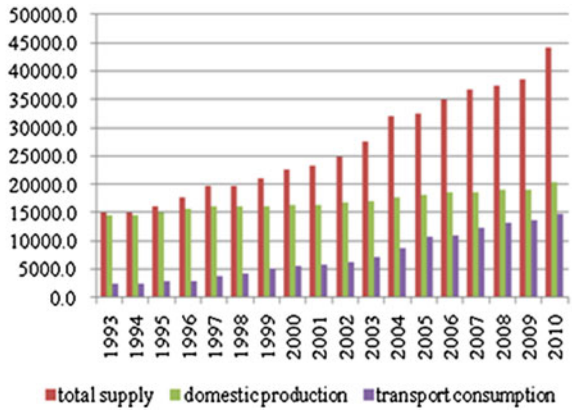

Fig. 4 Petroleum consumption (10,000 t)

since it is non-renewable energy. Large consumption of petroleum resource in transportation industry forces China's annual import volume of petroleum increase continuously (Fig. 4). In 1993, petroleum consumption of transportation industry is only 17.2 % of total domestic petroleum production. However, the proportion reached 73.2 % in 2010. Though the energy consumption proportion of transportation industry in China is much lower than that of most of the developed countries, transportation industry's heavy dependence on petroleum energy brings a great threat to China's energy security. In addition, petroleum is highlighted as the serious environment unfriendly energy since it will emit large number of green gas. The amount of petroleum energy use will directly influence the effectiveness of energy saving and emission reduction of the whole country. It is extremely important to minimize petroleum consumption proportion and adjust energy consumption structure of transportation industry in China in order to achieve sustainable development in the future.

Energy Assumption Model for Transportation Industry

Energy consumption of transportation industry is affected by various factors. The following factors are generally considered in estimation: GDP, fuel prices, population, urbanization rate, passenger (freight) volume, per capita disposable income of urban households, etc. [11]. In this study four main factors: GDP, passenger volume, urbanization rate and freight volume are selected to establish a model by PLSR method to predict energy consumption of transportation industry. 17 years' (1994–2010) national annual statistical data is used in modelling. Variables x_1, x_2, x_3, x_4 and y represent GDP, passenger volume, freight volume, urbanization rate and energy consumption respectively.

As shown in Table 2, correlation matrix shows a strong correlation exists between each selected variable.

Table 2 Correlation matrix

Variables	X_1	X_2	X_3	X_4	y
X_1	**1.000**	0.997	0.987	0.966	0.997
X_2	0.997	**1.000**	0.987	0.966	0.996
X_3	0.987	0.987	**1.000**	0.924	0.987
X_4	0.966	0.966	0.924	**1.000**	0.968
y	0.997	0.996	0.987	0.968	**1.000**

We use data from 1994 to 2009 to establish the prediction model by PLSR method, and data in 2010 to validate this model. With software SXLTAT, we get the regression Eq. (3), and R^2 is 0.996.

$$y = -7198.524 + 0.055x_1 + 0.305x_2 + 0.055x_3 + 224.4x_4 \tag{3}$$

Table 3 shows that the model prediction results and actual energy consumption values of transportation system in China from 1994 to 2009, which are quite similar. The maximum relative error is 7.6 %, the average relative error is 3.05 %, and the relative error in the test year 2010 is 4.66 %. The study results indicate that the prediction model established by the PLSR method is applicable to predict the transportation energy consumption if without structural change.

Table 3 Prediction results of PLSR model for transportation industry

Year	Actual energy consumption value (10,000 tons of SCE)	Calculate results of PLSR model (10,000 tons of SCE)	Relative error (%)
1994	5,625.58	5,298.1865	−5.82
1995	5,862.90	5,857.5001	−0.09
1996	5,994.45	6,449.8131	7.60
1997	7,543.10	7,327.1145	−2.86
1998	8,245.02	7,982.5477	−3.18
1999	9,242.62	8,821.7007	−4.55
2000	9,916.12	9,858.4443	−0.58
2001	10,257.08	10,869.096	5.97
2002	11,086.49	11,920.339	7.52
2003	12,740.10	12,647.83	−0.72
2004	15,104.00	14,903.872	−1.32
2005	16,629.00	16,573.04	−0.34
2006	18,582.72	18,431.389	−0.81
2007	20,643.37	20,901.074	1.25
2008	22,917.25	22,668.849	−1.08
2009	23,691.84	24,691.845	4.22

Prediction of Energy Consumption of Transportation Industry in Mid-Long Term

To estimate the energy consumption of transportation industry in mil-long term, urbanization rate in the future needs to be first determined. According to the forecast of CASS and the World Bank, urbanization rate of China will be 57.67 % in 2020 and 67.81 % in 2030. While 68 % may be the top of the next 20 years, after 2050 the urbanization rate will remain at that level in a long time. By bringing the above predictive value of GDP, passenger volume and freight volume into the PLSR model, prediction results of energy consumption of transportation industry in 2020, 2030 and 2050 are obtained, as shown in Table 4.

The petroleum consumption in whole society and transportation industry is illustrated as in Fig. 4. The petroleum consumption of transportation industry is nearly the total domestic production in 2010. If we further look at the consumption and market share of major energy resources in transportation industry (Figs. 5 and 6), oil is the dominant energy resource, while the consumption and market share of coal are both declining. In the past 15 years, there is no significant market share increment of electricity but the total consumption has a similar trend as that of petroleum.

The annual petroleum production is about 3,820 million tons globally and about 200 million tons domestically in 2010 [12]. Based on these estimated energy consumptions, if the energy consumption structure maintains the same as that in 2010, the annual consumption of petroleum by transportation industry in China will reach 659 million ton in 2020, 1,173 million ton in 2030 and 3,050 million ton in 2050. That is, the oil dependency will soar to 456 million tons by 2020,

Table 4 Prediction results of transportation energy consumption in the future

	2020	2030	2050
Predict energy consumption (10,000 tons of SCE)	115,987.37	206,419.94	536,957.34

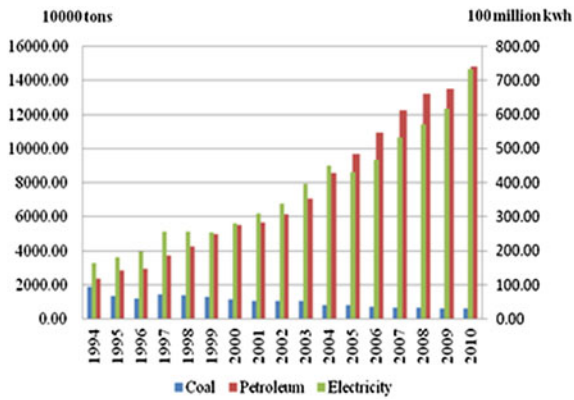

Fig. 5 Consumption of three major energy transportation industry

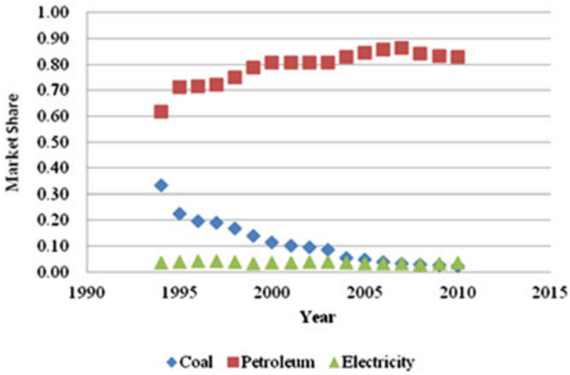

Fig. 6 Market share of three major energy resources in transportation industry

970 million tons by 2030, and about 2,850 million tons by 2050, if there no significant change in domestic oil-production. 2,850 million tons is more than 70 % of the current global annual production. It is impossible to satisfy such a huge demand of the transportation industry in one country. The current development path is unsustainable in the energy perspective. What can we do to achieve energy security?

Analysis of the Energy-Saving Potential of Transportation System

Integrated Energy Intensity Analysis

Energy intensity is one of the main factors that affect transportation energy consumption, and it can be represented by energy use per passenger km or ton km [13]. Although the transport volume proportion of high energy consumptive transport modes, such as road and air, keeps growing, integrated energy intensity of transportation industry in China has shown a fluctuated downward trend since 2003 (Fig. 7). This is because of the efficiency improvement of fuel utilization due to science and technology development. Figure 8 shows the change of energy intensity of each transport mode in recent 15 years. We found that the energy intensity of each transportation mode in a logarithmic scale shows a clear descending linear trend except road transport. As a result of the elimination of a large number of steam locomotive and increment in the proportion of diesel locomotive and electronic locomotives, energy intensity of rail transport dropped significantly. However, with the elimination of steam locomotive completes, trains speed up, and equipments become more comfortable, it may be rather difficult to further reduce energy intensity of rail transport in the future. Both water and air transports show a clear downward trend in energy intensity, due to new design,

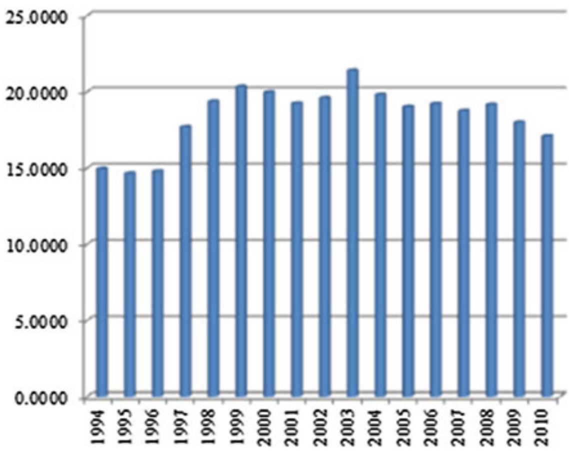

Fig. 7 Integrated energy intensity (tce/million-t-km)

new technology and operations optimization. As to pipeline transport, its energy intensity is greater than that of the waterways and railways in recent years, and the main influencing factors are the long update cycle of equipments and unsaturation of transport volume. However, toad transport, as the mode that contributes most to energy consumption in transportation industry, its energy intensity keeps growing [11]. These send an important message that the energy technique innovation of road transport is the key to energy security of China.

Prediction of Energy-Saving Rate in Transportation Industry

Transportation energy-saving rate is an important indicator to reflect transportation development level and energy saving effect, which refer to the ratio of energy saving in a specific period and the energy consumption in the base period. It can be expressed by Eqs. (4) and (5) [14].

$$E = \alpha \cdot Q \tag{4}$$

$$\varepsilon_t = (E_0 - E_t)/E_0 \cdot 100\ \% \tag{5}$$

where, E is the energy consumption amount; α: energy intensity; Q is the transportation volume; ε_t is energy-saving rate in predicted year; E_t is the energy consumption in predicted year and E_0 is the energy consumption in the base year.

With the calculated transport volumes of various transport modes in the forecast years and based on the assumption that transportation structure in the predicted year is the same as that in 2010, transport volume in each mode is converted to standard transport volume using the following conversion factors: rail transportation is 1:1, road is 10:1, waterway is 2:1 and air is 13.7:1. Thus, combined with the prediction results of passenger and freight volume in 2020, 2030 and 2050 in

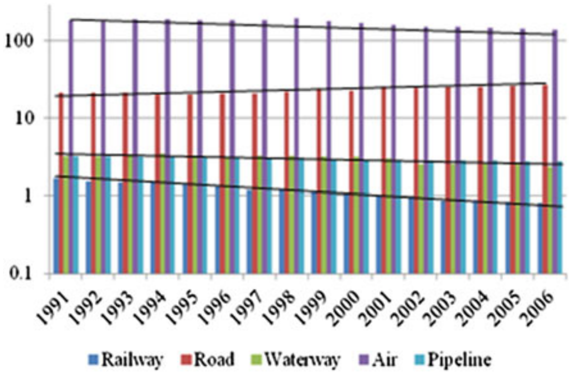

Fig. 8 Energy intensity of each transport mode in a logarithmic scale (PJ/100 million ton)

section Prediction of Passenger and Freight Volume, we can get the converted volume for different transport modes (Table 5). According to the "Middle and long-term Railway Network Plan" of the National Development and Reform Commission and the "Highway and Waterway Mid-long-term Energy Conservation Plan" of Transport Management Department of China, as well as reference of related research [15], reduction of integrated unit energy consumption of various transport modes 2020, 2030 and 2050 are determined as follows with 2005 as the base year (Table 6). If these goals are achievable, by solving Eqs. (4) and (5), energy-saving rates of 2020, 2030 and 2050 can be obtained respectively.

Table 7 shows that energy saving rate of five major transport modes in China in the future. Among these transport modes, energy-saving rates of road, pipeline and air will be the top three. Rapid growth of energy consumption of road transportation is mainly enhanced by the increment of traffic volume and energy intensity. Energy consumption of air transportation will keep growing though its energy intensity declines with the updates of machine and ascension of occupancy rate, mainly due to the rapid increase in transport volume attracted by its fast, comfortable and efficient features. Energy consumption of pipeline also shows an

Table 5 Total transport volume after conversion (100 million ton-km)

	Rail	Road	Waterway	Air	Pipeline
2020	75,789.24	94,341.54	144,064.80	968.91	4,624.49
2030	135,691.67	169,927.64	259,735.49	1,714.89	8,337.60
2050	359,956.71	452,909.78	692,787.80	4,507.71	22,238.90

Table 6 Proposed reduction of unit energy consumption for various transport modes [15]

	Rail (%)	Road (%)	Waterway (%)	Air (%)	Pipeline (%)
2020	20	15	20	20	15
2030	30	35	30	30	20
2050	35	45	40	40	25

Table 7 Predicted of energy-saving rates in the future

	2020	2030	2050
Rail	−1.26	−2.55	−7.73
Road	−7.33	−10.48	−24.89
Waterway	−1.32	−2.66	−7.36
Air	−2.40	−4.26	−10.85
Pipeline	−2.61	−5.13	−14.33

Negative value indicates the growth of energy consumption

obvious upward trend because its construction speed in recent years continues to accelerate and its transportation capacity keeps expanding. As traditional transport modes, rail and waterway transportation have a relatively slow growth rate of energy consumption because of two main reasons. On one hand, there is less margin in demand for these two modes; on the other hand, energy intensity has decreased due to operation optimization and technology improvement. Take the energy assumption in 2020 for example, road transportation's energy intensity reduced more by 1 % will contributes 1.3 % to its energy consumption reduction, but 1 % more reduction of energy intensity will contributes 1.8 % to energy consumption reduction for air transportation. Again, all these depend on the fulfilment of the targeted unit energy consumption reduction.

Under target energy saving scenario, the future energy consumption in 2020, 2030 and 2050 are computed as in Table 8, with the assumption that the transportation structure maintains the same as in 2010. Compared with the prediction results in section Prediction of Energy Consumption of Transportation Industry in Mid-long Term, the total energy consumption reduced 20.4, 36.5 and 44.5 % respectively. Correspondingly, the petroleum consumption in 2020, 2030 and 2050 will be 524, 744 and 1,692 million tons respectively. These amounts are still too much given the petroleum current production level. The proposed reduction of unit energy consumption alone cannot solve the national energy security issue. Significant changes have to be made in energy structure and transportation structure to ensure sustainable development.

Table 8 Predicted energy consumption for transport modes and transportation industry (10,000 tons of SCE)

Year	2020	2030	2050
Rail	5,371.94	8,415.60	20,729.90
Road	72,286.88	99,566.90	224,549.44
Waterway	9,692.68	15,290.63	34,958.07
Air	4,346.55	6,729.85	15,161.36
Pipe	598.90	1,016.25	2,541.24
Total energy consumption in transportation industry	92,296.95	131,019.23	297,940.03

Conclusions

Through data analyses and established prediction models, we get the following implications: With the strong confidence in economic develop in China; transport volume in China will maintain a rapid growth in the future. Passenger volume will reaches 25,517,700 million passenger km and freight volume will reaches 143,560,800 million ton km in 2050, which indicate energy consumption of transportation industry has become a serious threat to China's energy security, especially to petroleum security.

Petroleum energy consumption by transportation industry shared only 12 % of total domestic petroleum production in 1990, while the proportion reached 73.2 % in 2010. If the current consumption structure is not changed, the petroleum consumption in 2050 will reach 3,050 million tons, and this amount is about 1,500 % of the current domestic petroleum production and about 75 % of the global petroleum production. Adjustment of energy consumption structure and reduce the integrated energy intensity in transportation industry become the key to ensure energy security and sustainable development in China and in the world.

Transportation structure has changed significantly in the past decades since modern transportation pays more attention to transportation efficiency, comfort and convenience. In terms of passenger transportation volume, both road and air transport have significantly improved due to their speed and convenience. Road transport has replaced rail and becomes the major transport mode. Waterway and railway are still dominant in terms of freight transport. Road, pipeline and air become the top three transport modes with the fastest energy consumption growing speed. By 2020 their predict energy consumption values will be 8.3, 3.6, 3.4 times higher than that in 2005 respectively due to their high-energy intensity. This will exaggerate the total energy consumption in transportation industry. Therefore, the adaptation of technologies, such as new energy resource, electric cars and operation optimization may have a significant impact on petroleum consumption and energy security in the middle and long-term, and the adjustment of transport pattern with scientific guidance is the backbone of energy saving in transportation industry.

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Part IV
Equity, Ethics, and Infrastructures

Equity and the Ethics of Water Governance

Neelke Doorn

Abstract Water is recognized to pose some very urgent questions in the near future. A significant number of people are deprived of clean drinking water and sanitation services, with an accordingly high percentage of people dying from water borne diseases. At the same time, an increasing percentage of the global population lives in areas that are at risk of flooding, partly exacerbated by climate change. In this chapter, it is argued that ethics should be an integrated part of water governance in order to address these pressing issues. This chapter consists of two parts. In the first part, some conceptual groundwork is done to clarify a number of persistent ambiguities and misunderstandings in the debate on water governance. In the second part, three distributive questions are outlined, concerning (1) the distribution of scarce resources, (2) the distribution of risks, and (3) the distribution of responsibilities. The chapter concludes with an outline for an ethics of water governance.

Keywords Water · Access · Allocation · Equity · Ethics · Distributive justice · Human rights · Values · Property regimes

Introduction

Water is essential for human life. However, due to its scarcity, the management of water is a topic of great concern. Inadequate management may lead to famines, food insecurity, ecological destruction, and resource-based conflicts, and

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N. Doorn (✉)
Delft University of Technology, Department of Technology, Policy and Management, P.O. Box 5015 2600 GA Delft, The Netherlands
e-mail: N.Doorn@tudelft.nl

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eventually to human suffering and the loss of millions of human lives. Whereas some official organizations speak of a water crisis [27, 28], others argue that there is sufficient water but that the water sector needs to be reformed to avoid a water crisis in the future [8]. Whether or not one uses the term "water crisis," the numbers are not encouraging. In 2010, more than one out of nine people (0.8 billion people) lacked access to safe drinking water, and more than one out of three (2.5 billion people) lacked adequate sanitation. Almost 2 million people die every year from water borne diseases, most notably diarrhea [26]. There are no official numbers on resource-based conflicts, but fact is that there are over 260 river basins shared by two or more countries, which may provide a source of (regional) instability or conflicts when strong institutions and agreements are missing. In the light of climate change, the impact of the global water crisis is expected to increase in the coming decades.

Traditionally, water management has been seen as primarily a technical issue, belonging to the field of engineers and hydrologists. However, it is increasingly recognized that an adequate management of water requires that the institutional constraints and juridical context be taken into account. Both in academia and policy circles, the attention has therefore shifted from water management towards water governance, requiring the combined and coordinated effort of both technical (engineers, hydrologists) and non-technical experts (lawyers, economists, political and social scientists). Although different definitions of water governance exist, most of them refer to something like "the range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society" [23], mostly also including a reference to conflicting or diverse interests and cooperative action (cf. [3]). With the shift from water management to water governance, the principle of equitable utilization has emerged in the literature as an important principle for allocation (cf. Convention on the Protection and Use of Transboundary Watercourses and International Lakes 1992 ("*Helsinki Watercourses Convention*") [art. 2]; United Nations Convention on the Law of the Non-Navigational Uses of International Watercourses ("*UN Watercourses Convention 1997*") [art. 5]; ILA Berlin Rules on Water Resources 2004 [art. 12]).

Notwithstanding recurrent pleas to include issues of "equity" and "social justice" in the governance of water, ethicists or social philosophers have so far not or only barely been involved in the discussion. In this chapter, the author shows that water governance prompts some urgent distributive issues. I argue that moral philosophers should become more involved in the discussions on water governance in order to develop an integrated account of water governance. The outline of this chapter is as follows. After clarifying some issues concerning the nature of water and people's legal endowments in section Classification of Resources and People's Legal Endowments, section Distributive Questions in Water Governance is dedicated to three urgent distributive issues that need to be addressed. In the concluding section, I provide a preliminary outline for an ethics of water governance.

Classification of Resources and People's Legal Endowments

A recurrent theme in the discussion on water governance is the common-versus-commodity controversy. This controversy is often confused with the discussion whether or not people have a basic right to water. These are two separate questions, though, and they should be kept apart. Whereas water as a human right refers to *people*'s legal endowments, the common-versus-commodity controversy is an issue of property regime, which is applicable to *resources* [4]. This section contains some conceptual background to clarify the debate.

Typology of Goods and Property Regimes

The debate concerning the typology of goods mainly takes places in economics and public administration, where an ongoing discussion takes place on the role of government in allocating resources. In these fields, goods are usually classified along two dimensions, viz. the subtraction criterion and the exclusion criterion. The subtraction criterion distinguishes private consumption goods from public consumption goods. In case of private consumption goods, each individual's consumption of the good leads to subtraction of the amount of that good available for others. Common or collective goods, to the contrary can be enjoyed "in common in the sense that each individual's consumption of such a good leads to no subtraction from any other individual's consumption of that good" [24]. The exclusion criterion indicates whether or not someone can be excluded form benefiting once the good is produced [19]. Combining the two criteria yields a two-by-two matrix with four types of goods, as shown in Table 1 [21].

Although classification along the subtraction criterion seems more or less given, property regimes and both technical and physical boundaries can affect the capacity to exclude potential beneficiaries [6]. Hence, it is possible—to some extent at least—to shift between the rows in Table 1. Unlike public goods, common-pool resources face problems of overuse, because they are both subtractable and without exclusion mechanisms to limit individual people's use, which may ultimately lead to a tragedy of the commons [12]. In order to avoid or solve this

Table 1 Typology of goods

	One person's consumption subtracts from total available to others	One person's consumption does not subtract from total available to others
Exclusion is feasible	Private goods	Toll goods
Exclusion is not feasible	Common-pool resources	Public goods

Source [21]

problem, it has been proposed to implement exclusion mechanisms such that the common-pool resources turn into private goods. This “common-versus-commodity” controversy is now also topic of debate in water governance. Given the scarcity of water, water should be assigned a price in order to avoid overuse, some people argue (cf. the fourth of the Dublin principles stating that “Water is a public good and has a social and economic value in all its competing uses”).

Empirical data suggest that some exclusion mechanism is indeed required for the sustainable management of scarce resources (cf. [2]). However, exclusion has its price, be it not (only) in monetary terms. Treating water primarily as an economic good in an attempt to accommodate its value may result in affordability problems and paradoxically deprive people of access to water, even though the exclusion mechanism was implemented to reduce water scarcity. Alternative exclusion mechanisms are therefore required to allocate the scarce water resources and this is where the property rights come into play. Based on her work with Schlager ([22, 25]) and the work of Aggarwal and Dupont [1], Ostrom shows how differentiation between various forms of property rights affect the incentives that people face to manage scarce resources, where property is defined as “an enforceable authority to undertake particular actions in a specific domain” [20]. By introducing so-called bundles of rights, Ostrom argues against the conventional (and simplistic) notions of full and exclusive property and ownership. She distinguishes between five types of rights, that constitute different bundles of rights associated with particular holder positions (Table 2).

Although space does not allow to go into detail about the particularities of the different property rights, the key message here is that, by varying between different bundles of rights, people may be encouraged to manage scarce resources effectively and still allow access to people who would otherwise be deprived of water.

In other words, although the *type of good* is conceptually distinct from the *property rights* that people can exercise on these goods, they are related in the sense that the different property regimes affect the possibilities of effective management and the question to what extent the good is prone to collective action problems.

Table 2 Bundles of rights associated with positions

	Full owner	Proprietor	Authorized claimant	Authorized user	Authorized entrant
Access	X	X	X	X	X
Withdrawal	X	X	X	X	
Management	X	X	X		
Exclusion	X	X			
Alienation	X				

Source [22]

The Human Right to Water

Over the past decade, and partly as a response to the economic approach to water governance, the discussion on access to water is increasingly framed in terms of human rights. Although often presented as an antidote to a pure economic approach to water governance, the human right approach to water does not exclude an economic or commodity approach to water. In order to understand this, it is good to take a closer look at the history of how this right became recognized by the respective UN bodies.

Although the idea of water as a human right was mentioned in several international treaties before, the political recognition came in 2002, when an expert body of the UN Economic and Social Council (ECOSOC) assessed the implementation of the International Covenant on Economic, Social and Cultural Rights (ICESCR). The committee asserted that "[t]he human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses" (ECOSOC Committee on Economic, Social and Cultural Rights, General Comment No. 15 [GC 15], 2002). The GC 15 prompted discussion on the nature of this right; the formulation was not clear on whether it was to be interpreted as a subordinate right necessary to achieve a primary human right (e.g., the right to food, health, or life) or as an independent human right [5]. The committee was explicit, though, in the obligations it imposed on States. A more political recognition of the human right to water came when, based on the Millennium Development goals, the concept of water as a human right was adopted by the UN's General Assembly (General Assembly Resolution 64/292 of July 28, 2010). This decision was later confirmed by the Human Rights Council, which recognized that "the human right to water and sanitation are a part of the right to an adequate standard of living and inextricably related to the right to the highest attainable standard of physical and mental health, as well as the right to life and human dignity" (Human Rights Council Resolution 15/9 of September 30, 2010).

Irrespective of the (in)dependency of the human right to water to other human rights, the ECOSOC Committee identified four key elements to provide normative content to this particular right to water (GC 15, paragraph 12). First, water should be available in sufficient quantity for personal and domestic use. Second, water required for each personal or domestic use should be safe. Third, water and water facilities and services have to be accessible to everyone without discrimination. This element is further specified in terms of (a) physical accessibility (distance from each household, educational institution and workplace); (b) economic accessibility (affordability); and (c) non-discrimination (accessibility to all). Fourth, information concerning water issues should be accessible. It is debatable whether these criteria are not equally applicable to, for example, the human right to food or whether the normative content cannot be derived from the human right to food. However, it should be clear that the way this human right is formulated does not exclude privatization of the water sector. It should suffice that people have access to water, by whomever this is provided.

One important point of criticism against the idea of water as a human right is that it lacks enforcement mechanisms and arrangements concerning water use [9]. Equity and sustainability, for example, would seem to require specific mid-level principles concerning "minimum water rights" and "maximum water use" [13]. There are examples where the introduction of a water right has increased water use by already well provided people at the expense of downstream users, simply because people want to exercise their right [18]. Hence, implementing water rights is not trivial and does not automatically lead to an improved situation for the people who are deprived of water.

Distributive Questions in Water Governance

In this section I discuss some distributive issues or questions that should be included in an integrated account of water governance. Space does not allow to describe all aspects that are relevant for an ethics of water governance in full detail, so I will limit myself to three important points.

Distribution of a Scarce Resource

Water is both a source of risks and a scarce resource. Most of the literature on water governance focuses on the scarcity of water, operationalized in the notion of access to water. One of the complicating issues of water governance is that access to water includes the need for an adequate infrastructure for delivery and sanitation services. Discussing access to water solely in terms of available quantities misses (a) the fact that people have to travel unequal distances to collect their water, (b) the importance of water *quality*, and (c) the issue of infrastructure maintenance. Concerning the first point, in most developing countries, an extensive range of people is deprived of adequate access, most notably women, people with disabilities, children, refugees, prisoners, and nomadic communities [14].

Concerning water quality, current discussions on water governance seem too one-sidedly focused on water supply, overlooking sanitation and wastewater management. The latter are equally important for human health and they should therefore be taken into account when talking about water governance. This holds even more in situations where the use of water leads to pollution of traditional water sources, for example due to agricultural run-off or industrial waste. As for the issue of maintenance of water infrastructure, insufficient funding may aggravate water shortage problems. It also prompts distributive questions concerning responsibilities, which I will discuss in section Distribution of responsibilities.

Distribution of Risks

Most discussions in water governance focus on water scarcity. However, the risk of flooding is, in some areas at least, equally or even more urgent. Especially in places where the local hydrological circumstances are affected by large infrastructural projects (such as hydro-power plants), both the risk of flooding and potential water scarcity may be present and solutions to the one problem may exacerbate the other problem. Where water scarcity prompts distributive questions concerning resources, flood risks prompt distributive questions concerning "safety": where to implement flood risk measures, what level of safety is required, is it acceptable that people living in one area have a higher level of safety compared to people living in another area?

In the philosophy of risks, several criteria have been developed for assessing the acceptability of risks [11]. These considerations should also be taken into account in the context of flood risk mitigation. For flood risks, three criteria are especially important. The first concerns the distribution of risks and benefits. When implementing measures to reduce existing risks, it is important to take into account the degree to which risks and benefits are distributed. It is, for example, not fair if the same people always have to carry the risks whereas others gain benefits. The second concerns the question to what extent people have consented to the risk. If people have freely chosen to live in particular flood-prone areas, they can be considered to have consented to a lower level of safety. The word "freely" is crucial, though. If people have no other place to live, the choice for this flood-prone area cannot be considered to be made with full consent. This brings us to the third point, viz. the question whether or not people exposed to a particular risk have alternatives at their disposal.

To illustrate this, consider the following two hypothetical situations. In the first situation, a group of farmers live in a polder that is vulnerable to flooding but which is also very fertile, especially for the type of crops these farmers are growing. There is no land nearby with similar favourable characteristics. Now compare this situation with a typical commuter town in a similar polder. Most residents work in the city 50 km away. They do not like to live in the city and prefer to live in the countryside. However, they are indifferent as to which particular area. There is an area nearby with a significantly lower risk of flooding. In the first situation (farmers), the inhabitants do not really have an alternative place to live. In the second situation (commuters), the inhabitants have alternative places to live. Even if they do not want to live in the city, there is an alternative location nearby where they could live with a lower risk of flooding. If people still prefer to live in the polder with the high risk, it seems that they have voluntarily chosen to be vulnerable to this risk level. From the perspective of social justice, if may be defensible that the government provides different standards of safety against flooding in these two situations.

This simple example shows that the choice for particular safety measures and safety levels cannot be made on sheer numbers. Other considerations play a role when deciding on the acceptability of particular safety levels and, accordingly, on the distribution of risks.

Distribution of Responsibilities

The last distributive question I would like to discuss is the distribution of responsibilities. In terms of responsibilities, water governance is very complex. In this chapter, I briefly touch on three points that may often obscure the distribution of responsibilities in water governance. The order in which I discuss these points does not reflect any priority or importance.

First, water governance is often closely related to a particular infrastructure, which needs to be constructed, operated, and maintained. These tasks do not necessarily have to be done by one and the same actor. This prompts questions concerning the definition of different actors' responsibilities: Where does one person's responsibility stop and begins the other person's responsibility? The responsibility for maintenance, for example, may be unclear when large water infrastructures are built with a double purpose, such as hydro-power plants which are also intended as flood risk measures [15].

Second, the distribution of responsibilities may become unclear when certain tasks are delegated, for example, the implementation of water rights. With water services increasingly being privatized, it is important that the different actors' responsibilities are identified and that some regulatory system is put in place to guarantee compliance ([16, 17]).

Third, water governance is a global issue. Only rarely is water flow confined within state boundaries. In most situations, rivers flow through several countries. Upstream activities in one country may affect water availability in downstream countries, which may pose a source of potential conflict. In international law, the principles of equitable and reasonable utilization and of diligent prevention of significant transboundary harm have been introduced to facilitate peaceful cooperation with respect to scarce water resources [7]. These global arrangements seem indispensable for coordinating water withdrawals with transboundary impact. However, at the institutional level, the subsidiarity principle requires addressing water issues at the lowest community level possible. As a result, the water sector has seen a significant change, with water users and other stakeholders gradually playing a much more active and constructive role; a trend which is widely supported by academics and field workers alike. There is a potential tension between the need for global arrangements and a meaningful mandate at the lower community levels. The question how to strike the balance between local and global arrangements and how to distribute the responsibilities (between states and between the different management levels) is one of the pressing challenges for water governance at this time [13].

Concluding Remarks

In the previous section, I derived three important distributive questions: distribution of scarce resources, distribution of risks, and distribution of responsibilities. I hope to have shown that these questions cannot be answered on the basis of efficiency criteria alone. Ethics should be an integral part of water governance. Although the terms "equity" and "reasonable utilization" are often mentioned, they are only weakly substantiated in the legal literature, whereas it is recognized that they play a vital role in building cooperative relations in water networks [17]. Moreover, questions concerning risks and questions concerning different actors' responsibilities are often left aside or based on misleading dichotomies between privatization and commodification on the one hand, and water rights on the other. Herewith, I do not want to claim that we should adopt an economic approach to water, but I want to avoid muddled debates based on fuzzy conceptions.

The claim in this research is that applied philosophers should become more actively involved in the water debate, in particular for clarifying and trying to answer the distributive questions that are characteristic for water governance.

How are we to proceed? For sure, philosophers do not have the answer to all questions, especially not if they lack practical knowledge of the issues at stake. Addressing real-world problems also requires empirical insight in these processes. I therefore argue for a multidisciplinary approach and to let philosophers join forces with disciplines like law, hydrology, policy science, and new institutional economics (see [10] for a similar plea). If the ethical aspects of water governance are to be adequately addressed, the philosophical skills should be complemented with profound knowledge of water, including partly technical (hydrological) knowledge, knowledge of the prevailing legal constraints, combined with insights from policy sciences and institutional economics. Debate should be conducted at various levels of generality and specificity, and so must a proper account of water ethics include an assessment at various levels of abstraction. At the most abstract level, basic moral concepts, such as equity, justice, and democracy, need to be developed assessed, which requires the involvement of both legal and political theorists, and philosophers. At the mid-level, principles of equity and efficacy need to be translated to actual water governance practice. This cannot be done without also paying attention to local socio-cultural *and* hydrological circumstances. Additionally, the legal context (international treaties, national water law, etc.) determines the room for maneuver and should therefore be taken into account as well. At the most concrete level, specific institutions and strategies need to be designed. At this level, the involvement of policy theorists and scholars from institutional economics may play a crucial role. By including these different perspectives, we may contribute to the articulation of detailed and useful moral principles of water governance.

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Alternative Urban Technology for Future Low-Carbon Cities: A Demonstration Project Review and Discussion

Kien To and John E. Fernández

Abstract This is the century of the city. Climate change, fossil fuel depletion, rapid urbanization and the continued escalation of energy consumption are accelerating the critical and global need for resource efficiency toward a future of low-carbon cities. To that end, new waves of development in novel urban technologies may play an important role in sustaining the growth of existing cities as well as empowering the sustainable planning and design of new townships. First, this chapter highlights renewable energy–based alternative urban technologies (AUTs) that may aid in the significant reduction of urban carbon emissions, and then proposes a general classification system of technological systems and discusses AUT future trends. The review part of this chapter seeks to establish state of the art of AUTs that target three primary urban systems: the built environment, transportation and energy.

Keywords Alternative urban technology · Renewable energy · Demonstration projects · Resource efficient · Low-carbon

Introduction

In 2008, for the first time in history, the world reached an invisible but momentous milestone: more than half of its human population lives in urban areas [1]. With this new urban reality, coupled with challenges of climate change, escalation of demand

K. To (✉)
SUTD-MIT International Design Centre, Singapore University of Technology and Design (SUTD), 20 Dover Drive, Dover 138682, Singapore
e-mail: tokien@sutd.edu.sg

J. E. Fernández
Department of Architecture, Massachusetts Institute of Technology (MIT), Cambridge, MA 02139, USA

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for and actual consumption of fossil fuels and energy, depletion of critical resources, and the rapid urbanization occurring in different parts of the world particularly in Asia, the global demand for urban resource efficiency has become greater than ever. China, the world's second largest economy as well as top energy consumer [2], is a good example. The Chinese government considers urbanization to be the main engine of growth for domestic economic activity in the years ahead, giving the government scope to boost domestic demand and infrastructure investment [3]. As cities grow to create expanded metropolitan regions, they compete with each other for economic growth and infrastructure improvements that require reliable and perpetual access to critical resources. Some cities will be far better positioned than others partly due to their capability to properly assess novel technologies available to assist in the development of their built environment, transportation and energy systems, thereby increasing their overall resilience and competitiveness. The potential for adopting innovative strategies will partly rely on the development of alternative urban technologies (AUTs) which are substantially based on renewable energy (RE). The most important developments will be those that can replace the least efficient components of the least efficient urban infrastructure while continuing to allow for robust and sustained economic growth. Besides development, sustaining and improving the quality of life should be aware and valued, and AUTs are expected to offer novel solutions to achieve this goal.

With regard to terminology, *urban technology* refers to the technology primarily applied in cities or towns, which are in contrast with other geographical contexts such as sub-urban and rural areas, deserts, mountains, oceans, etc. *Alternative technology* refers to any source of innovative and environmental friendly technology (also often known as clean-tech) intended to replace polluting and high carbon footprint (CF) technology.

To illustrate and document the sustained wave of AUT development in practice, this chapter reviews state of the art of AUT demonstration projects from around the world, with a focus on three primary urban domains: the built environment, transportation, and energy (Fig. 1). AUTs focused on energy, and in particular RE, will serve to illustrate developments in both the built environment and transportation in a holistic viewpoint. In order to ensure that the latest and ongoing developments as well as up to date introduction of novel technologies are highlighted, this chapter cites diverse sources of information, particularly numerous web-based resources. The authors are aware of the risks that accompany such an approach but wish to provide a review that is both relevant to current practice and illustrative of future trends.

Background

Recently, there have been a number of reviews of technological development directed toward urban contexts. For instance, Moreno reviews technologies applied to urban sustainable development [4], while Hounsell et al. review urban

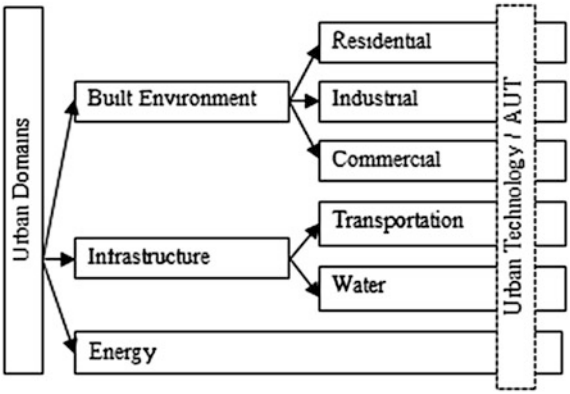


Fig. 1 Urban domains and the broad impact of urban technology/AUT on all of the domains

traffic management and the impacts of new vehicle technologies [5]. Liserre et al. [6] and Kateeb et al. [7] assess future renewable energy sources and the advent of the green smart grid, while Sheikh and Kocaoglu take a more focused approach to comprehensively assess solar photovoltaic technologies [8]. Sithan and Lai analyze the application of green technologies in developing countries [9], and Pacheco et al. review the energy efficient design of buildings [10]. For sustainable buildings, Shi and Chew review the state of the art in designing RE systems, specifically solar-based energy system to gain optimal performance [11], while Hepbasli reviews low exergy heating and cooling systems [12]. Leung and Yang review wind energy development and its environmental impact [13], while Taibi et al. review and analyze the potential for RE in industrial applications [14], etc.

However, much of the literature of urban technologies focus on one or two urban domains, have a geographical focus, and/or aim to describe and elaborate the technologies themselves rather than highlighting test bed introductions and demonstration projects. Moreover, due to the increasing awareness and demand for novel resource efficient solutions in this "flat and crowded world", the pace of development and introduction to the marketplace of AUTs is proceeding at an accelerating pace and therefore demands a periodic review to understand the breadth of these activities.

AUT Demonstration Projects

In most AUT demonstrations, harvesting, storage and distribution of RE is an essential pathway toward resource efficiency while promising a fundamental impact on both the built environment and transportation sectors. Another form of non-RE AUTs that we review relates mostly to energy efficiency technologies.

RE often refers to natural replenish-able energy source such as solar energy (photovoltaic-PV and thermal), wind, rain, tides, biomass and geothermal heat. According to the "Renewables 2011 global status report", "changes in renewable energy markets, investments, industries, and policies have been so rapid in recent years that perceptions of the status of RE can lag years behind the reality" [15]. The report also shows that the renewable energy sector continues to perform well despite continuing economic recession, incentive cuts, and low natural-gas prices. In 2010, RE supplied approximately 16 % of global final energy consumption and delivered nearly 20 % of global electricity. Renewable capacity now accounts for about a quarter of total global power-generating capacity. "During the period from the end of 2005 through 2010, total global capacity of many renewable energy technologies—including solar PV, wind power, concentrating solar thermal power (CSP), solar water heating systems, and biofuels—grew at average rates ranging from around 15 % to nearly 50 % annually. Biomass and geothermal for power and heat also grew strongly. Wind power added the most new capacity, followed by hydropower and solar PV" [15]. The "World Energy Outlook 2012" by International Energy Agency stated that "the rapid increase in renewable energy is underpinned by falling technology costs, rising fossil-fuel prices and carbon pricing, but mainly by continued subsidies: from $88 billion globally in 2011, they rise to nearly $240 billion in 2035" [16].

In this chapter, the authors classify AUT projects by their energy features. RE projects include solar (PV and thermal) energy (S), wind energy (W), hydro-energy (H), geothermal heat (G), biomass (B) and the hybrid RE systems among some of them (E.g. S+W, S+B+G, etc.). Non-RE projects primarily relate to energy efficient technological solutions. The demonstration projects' profiles are introduced in the following formats:

- For projects: Project name (location/expected year of completion/developer or designer).
- For products: Product name (place of origin/year of unveil or launch/developer or designer).

Built Environment Projects

The built environment sector has been widely affected by RE technology and energy efficient solutions (such as passive building design). Therefore, this review classifies projects by their RE types. The reviewed projects vary in size (such as city-scale down to building-scale) and sector (such as commercial, industrial and residential).

Solar Energy Projects

At the small town/district scale, the *Fujisawa Sustainable Smart Town* (Fujisawa, Japan/2014/Panasonic company) is expected to be one of the most advanced eco towns in the world (Fig. 2). About 1,000 homes, stores, healthcare centers, public parks and green spaces will be built on the site of an old Panasonic manufacturing plant. Each house will be equipped with a solar panel system that can produce more energy than the household's needs (energy positive), making the town completely energy independent. The community aims to reduce 70 % of CO_2 emissions and 30 % of household water usage [17]. This is not only a model for new urban low-carbon lifestyle but also may hold the potential as a profitable business model by developing a brownfield site resulting from structural shifts in the industrial sector of the corporate owner. Major challenges that exist with these kinds of projects are typical of much real estate development; correlating market needs for housing with the particular conditions of the site and the amenities that coexist with the green technologies deployed on site.

For industrial and big complex projects, the *Kansai Green Energy Park* (Kansai, Japan/2011/Sanyo Company) is another notable example. The park has a 1 MW solar panel system and a 1.5 MWh Lithium-ion mega battery system, which can produce and sustain enough electricity for about 330 standard households. The park has also advanced sensors and energy usage visualizations with real-time data. The administration building of the park has double-facade panels on its roof and facades that can absorb solar radiation from both the back and the front sides. PV panels can be found on many other buildings in the compound. The company encourages their staff to use electric bikes to commute and to move around the park, and provides a solar roof parking lot that charges the e-bikes parked there [18].

The two projects have become more important as examples of pathways forward particularly after the Great East Japan Earthquake followed by the catastrophic nuclear crisis in 2011 that highlighted the advantages of the clean energy

Fig. 2 Fujisawa sustainable smart town (*Source* [17])

movement in the country as well as in many parts of the world. Specifically within the country, there has been growing interest in RE infrastructure that is safe and secure with storage battery systems installed on a community basis.

At the building-scale, the *Federation of Korean Industries Tower* (Seoul, Korea/2014/Adrian Smith + Gordon Gill Architecture) will incorporate a photovoltaic wall system that reduces energy usage while generating power. The 800 foot-tall tower will feature large solar electric facades on all sides that generate almost enough energy needed for the building. The accordion-style exterior wall will contain building-integrated PV panels facing upward, while glazing is inclined toward the ground. This setup exploits the potential of the panels by giving them a preferred orientation, and the glass will be able to reflect a larger percentage of summer sun, thus reducing cooling loads [19]. Nevertheless, the simplicity of the design may also suffer from being "too simple" or monotonous when deployed on large areas. In addition, the investment in placing PV panels on the facades that receive much less sun light than others is questionable.

Another new project of note is *Brackfriars Railway Station* (London, UK/2012/Solar Century Company) (Fig. 3). This project features 4,400 solar panels developed by Solar Century that can generate about 900 MWh per year, and help provide half of the station's electricity need. The solar panels do not simply generate electricity but also provide shading on the bridge. In this way, it offers thermal comfort to the people who travel under shade and may enable drivers to reduce their air conditioning when waiting in slow traffic; a possible improvement on the energy intensity of idling traffic. Another benefit of this deployment of RE in coordination with large scale infrastructure is the diversification of the sites for RE energy production. This may lead to the lessening of development pressures on peripheral urban and rural land as the sites for large scale RE PV farms. This would also address the growing concern that RE sites, both PV and wind, are considered by some communities as industrial in nature and unsightly. Infrastructure, as essentially the machinery of the city, is an ideal armature for the inclusion of RE technologies at very large scales. Brackfriars Railway Station also sun pipes to provide natural lighting, so less electric lighting is required [20]. This project, when completed, will be one of the largest solar bridges in the world, and will hopefully prompt a new wave of solar bridge development, and infrastructure generally as the site for large-scale RE installations.

The *Mehrfamilienhaus in Liebefeld* (Bern, Switzerland/2008/Peter Schurch) is one of a growing number of examples of affordable eco-house (Fig. 4). Having won the 2010 Passivhaus Architecture Award, the house is a highly energy efficient three-apartment building that achieves a strict 13 kWr/m^2 of energy consumption per year. The building features comprehensive passive house design by applying natural and local materials, harvesting plenty of daylight (by using glass over 50 % of the façade), and having r-52 walls and a solar-electric green roof. The apartment building was also awarded the Minergie (minimal energie) certification, a low-energy standard in Switzerland [21]. Of particular note is the contention that residences like this apartment building can be built at lower cost than many other comparable homes. This assertion gives positive reinforcement, if

Fig. 3 Brackfriars railway station (*Source* [20])

Fig. 4 Mehrfamilienhaus in Liebefeld (*Source* [21])

proven at the scale of the mass market, that passive energy design and innovations can substantially contribute to the reduction of carbon emissions and energy consumption.

Wind Energy Projects

The *Strata* (London, UK/2010/Multiplex Living), also known as "the Razor" by its look, is one of the world's first buildings with integrated wind turbines built into facades (Fig. 5). The building can generate about 8 % of its energy needs. It also achieves 6 % above the energy efficiency requirement under building regulations by different approaches, e.g. via a natural ventilation system or a natural light system through massive glass facades that also increase insulation and reduce noise [22]. However, the aesthetics of the design have been criticized and the building was voted "Britain's ugliest new building" by readers of the Building Design magazine. Another concern is whether it is windy enough to activate the turbines frequently.

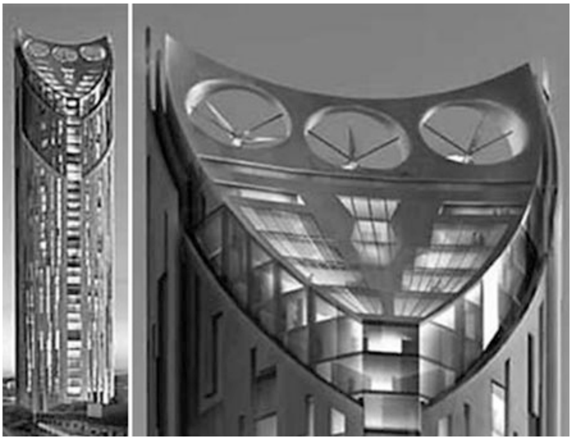


Fig. 5 The Strata building in London (*Source* [22])

The Strata is not alone among efforts to build wind-powered skyscrapers. The *Bahrain World Trade Centre* (Manama, Bahrain/2008/Atkins) has wind turbines hung between its two towers [23]. And the *Phare Tower* (Paris/2015/Morphosis) will be Paris's tallest new building with a rooftop wind farm by its completion in 2015 [24]. Although the amount of wind energy harvested in these projects is not significant, the eye-catching turbines in the first two projects may help raise public awareness on RE technologies and their proliferation. The obvious drawback of the wind turbines, however, is that the spinning blades generate a range of noises and vibrations that affect adjacent occupied floors.

Hydro Energy Projects

The renovation project of the *New Deutsche Bank towers* (Frankfurt, Germany/2011/Deutsche Bank) received the Best Green Intelligent Buildings Award in 2011. The towers were built during 1979–1984, and refurbished between 2008 and 2010 (Europe's largest building renovation at that time). The project highlights the importance of recycling, local sourcing, energy savings and stakeholder engagement in a retrofitting project. In particular, the building features a number of green features; for example, the building is highly hydro powered, CO_2 is cut by almost 90 %, electrical use is cut by half, water use is cut by almost 75 %, heating energy is cut by 2/3, thermal concrete mass of the old building is used to collect and store heat, etc. [25, 26]. This project is important as it pushes forward the retrofitting movement and shows how beneficial retrofitting can be, particularly in the European context with many protected classical buildings and complexes. Nevertheless, it is also important to consider the variety of negative impacts of hydro power (as discussed in "AUT Future Trends").

Biomass Energy Projects

The *7 More London* (London, UK/2011 (renovation)/PricewaterhouseCoopers) combines RE with other energy innovations. The building is biodiesel-fueled, and its good energy performance provides a 70 % improvement on building regulations with an Energy Performance Certificate (EPC) "A" rating and 25 % of its energy need will be produced on-site. There are other environmental innovations such as the recycling of 80 % concrete used, recycling of waste heat to cool and warm the building [27]. The fact that this is the first major office in the UK to receive the BREEAM "outstanding" rating has proved the project's success in practicing and promoting green innovations at the highest level.

Hybrid RE System Projects

Hybrid RE system projects are some of the most important projects in the built environment, and the featured demonstrations vary dramatically in scale and typology.

At the city-scale, ecocity projects are highlighted here. Richard Register first coined the term "ecocity" in 1987 and defined "ecocity as an ecologically healthy city" [28]. An ongoing ecocity project is the *Sino-Singapore Tianjin Eco-city* (Tianjin, China/2020–2025/Surbana Urban Planning Group/RE: S+W+G). Once an uninhabited wasteland of abandoned salt pans, this environment was badly polluted by chemicals from the nearby factories. The Sino-Singapore Tianjin Eco-city (Fig. 6) is taking shape with an aspiration to be environment-friendly with green spaces distributed all over the city and the existing wetlands and biodiversity to be preserved. Harvested RE will include solar, wind and geothermal energy. 3R-based integrated waste management will be implemented. A light-rail transit system supplemented by a secondary network of trams and buses will be the main low-carbon transportation system in the city [29]. The Sino-Singapore Tianjin

Fig. 6 Sino-Singapore Tianjin eco-city (*Source* [29])

Eco-city is another example of brownfield regeneration in this case driven by strong political support from two national governments. However, there is cause for some concern regarding the top-down approach, consequent suburbanization of the core city Tianjin, limited impacts on neighboring cities as well as others in the country, etc.

Another ecocity project under construction is the *Masdar Eco City* (Abu Dhabi, UAE/2020–2025/Abu Dhabi Future Energy Company/RE: S+W+G+H). In 2007, the government of Abu Dhabi announced that it would build “the world’s first zero-carbon city” called Masdar, which would rely entirely on RE (mostly solar) and would produce zero waste. All transportation was to be via PRT vehicles (see “Personal Rapid Transit”) -and use half the energy of a settlement of the same size, etc. However, reality has proved “truly zero-carbon city” to be too challenging, given the current limitations of RE—so now the target is for low carbon. Transport within the city will include electric buses and other mass transit to the PRTs. Some completed parts of the city are good examples of proven urban green features; the streets are narrow and friendly to pedestrians, sheltered by walls that block the desert sunlight, while openings in the walls channel a refreshing wind that—according to Masdar officials—makes the city feel as much as 21 °C cooler than its surroundings. The buildings take advantage of green materials (e.g. durable Douglas fir, super strong tetrafluoroethylene plastics that redirect sunlight and insulate the interior, etc.). Windows have shades angled to avoid direct sunlight, providing light without unwanted heat. There’s a 43 m wind tower—a contemporary and high-tech version of traditional Arabic design—that can funnel wind to the street [30]. Although many of the stated goals or claims by the government have been questioned and directly challenged, the project still serves as an important large scale test bed for new urban form and technologies.

At the district-scale, the *Hammarby Sjöstad New Eco-district* (Hammarby, Stockholm, Sweden/2011/the city of Stockholm/RE: S+B), situated to the south of Stockholm’s city center, was one of the first eco-districts to implement a holistic environmental system incorporating waste, energy and water aspects as part of an integrated sustainable system. Regarding RE, solar energy is harvested to primarily heat water, accumulated waste is used to produce electricity and heating, waste heat is extracted from the wastewater of a nearby wastewater treatment plant. Figure 7 shows a district cooling network in Sweden [31, 32].

The eco-district features a new eco-model often known as “Hammarby Model,” which promotes the integration of a wide range of technical supply systems, and the waste of one system can be a resource for another to make an eco-cycle [33]. Figure 8 shows a theorized version of the Hammarby Model, that signals potential scalability for future eco-district design.

For large complexes, the *Denver International Airport Parking* facility (Denver, USA/2010/DesignworksUSA/RE: S+W+G+B) is a LEED Gold certified project that aims to reduce energy consumption and emissions by applying a variety of solar, geothermal and wind power systems. The shuttles are also powered by compressed natural gas, biodiesel and hybrid fuel. The lot is also equipped with ten free Juice Bar chargers for those who drive electric cars [34]. Although

Fig. 7 Hammarby eco-city (*Source* www.sweden.se)

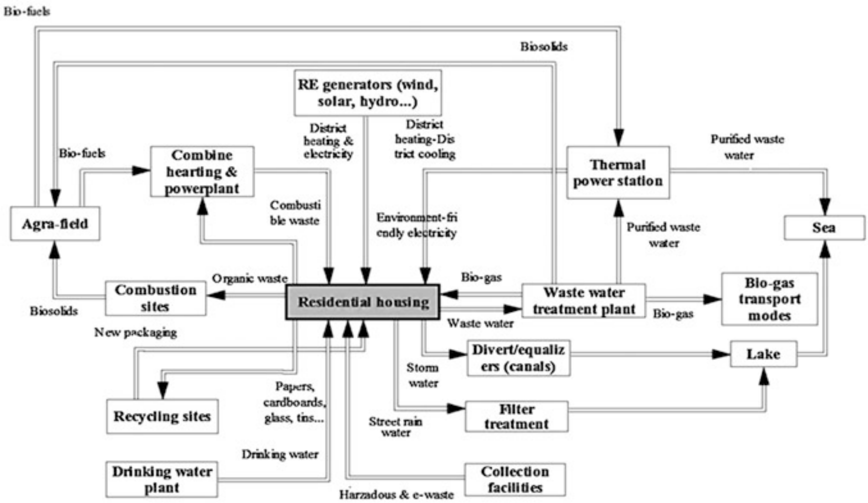


Fig. 8 A theorized holistic eco-cycle based on Hammarby model (Adapted from [33])

car parking is actually not "green" as private cars are not among greenest modes, the effort that Denver International Airport took in this project is encouraging, as it helps shift American driving habits toward resource efficiency by promoting RE systems, electric vehicles (EV) as well as the necessary infrastructure that support EVs.

Berghotel Muottas Muragl (Alps, Switzerland/2010/not available/RE: S+W+G+B) is a 104-year-old hotel that has recently completed a renovation that incorporates RE and resource sustainability (Fig. 9). The hotel generates RE through different sources. For instance, the 750 m long solar panel system along the side of the tramway leading to the hotel produces enough electricity for the entire hotel. Additionally, sixteen thermal loops at the lower levels of the building generate geothermal energy and store the unused energy gain. The loops can also recover waste heat from other cooling units and exhaust air from the machine room, making the system a closed energy cycle [35]. The hotel won the 2011 Swiss Solar Award and 2011 PlusEnergieBau Solar Award. This is an important project because of its utilization of RE strategies in a remote and environmentally challenging location.

Non-RE Energy Efficient Systems

A Passive House is a building, for which thermal comfort can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to fulfill sufficient indoor air quality conditions—without a need for recirculated air [36]. It is a very well-insulated, virtually air-tight building that is primarily heated by passive solar gain and by internal gains from people, electrical equipment, etc. Energy losses are minimized. Any remaining heat demand is provided by an extremely small source. Avoidance of unwanted heat gain through shading and window orientation also helps to limit any cooling load, which is similarly minimized [37]. One of the very few disadvantages of the Passive House is that super insulation requires significantly thicker exterior walls resulting in smaller interior spaces unless the increase in dimension can be accommodated by an overall increase in the building footprint. Passive House is well-known for its innovative energy efficiency and reduction of ecological footprint. Passive energy systems can work together with RE systems to achieve a zero or low carbon target for the building.

H27D (*Constance, Germany/2012/Kraus Schoenberg*) is a passive house example awarded the Royal Institute of British Architects (RIBA) 2012 EU Award. This private apartment building of four units with a ground floor retail shop was constructed entirely with lightweight fair-faced concrete that serves as both structural support and thermal insulation. The walls (50 cm thick) reflect medieval-style solid walls which perform as a weather membrane and thermal mass storage, yet are built with modern methods and advanced materials. These lightweight concrete walls can be demolished easily and the material is fully recyclable, so no waste is ultimately produced. Moreover, the building utilizes solar thermal energy system for domestic hot water, a high efficiency gas boiler for heating with under-floor heating, and waste water collection for flushing toilets and irrigating gardens. The thermal mass of the exterior reduces energy use and the covered south-facing arcade in the courtyard and the balconies work to minimize solar heat gain in summer [38].

Aside from the passive house example, there are many low energy and green buildings that could be highlighted here; for example, the *Volkswagen's Plant in Chattanooga* (TN, USA/2011/Volkswagen). The building was the first automotive manufacturing plant in the world to receive LEED Platinum. It is located in a former brownfield, which has been revitalized. LED lights are extensively used, and dedicated special parking spaces for green vehicles, carpoolers and cyclists are

Fig. 9 Berghotel Muottas Muragl (*Source* [33])

arranged. There are large tanks located around the plant that store rain water for use in gardens, toilets and cooling towers. The plant is also well insulated, boasting six-inch insulated walls in some areas (twice as thick as what is standard). Almost half of the materials used to build the plant were recycled from previous products, and the used materials can be reused and recycled should the plant ever shut down [39]. The new plant features brownfield rehabilitation, passive design solutions and sustainable systems toward high energy efficiency in the industrial sector.

In a number of instances, *Urban Farming* is beginning to provide examples of solutions toward resource efficient and low-carbon food production for contemporary societies. This type of agriculture is the practice of cultivating, processing and distributing food in, or around, a village, town or city [40]. Urban farming purports to deliver numerous socio-economic and environmental benefits. It reduces the CF in the city, provides more "green lungs" as well as ecological landscape, with the added value of improving freshness, nutrition, the taste of the food and the elimination of the need for preservatives. In terms of energy efficiency, urban farming is beneficial as it provides food locally and thus can save the energy used to transport food from distance. In contrast, urban farming may result in issues such as the risk of spreading of diseases and harmful insects from vegetation to urban communities, the competition and conflicts against urbanization for the access and use of limited land and against rural agricultural production that may cause more rural unemployment and poverty, land ownership, etc.

Urban farming comes in two forms: the traditional horizontal farms (typically on rooftop) and vertical farms (built structures for high-density and intensive urban farming). The first form can be found in many locations (For example, just within New York City, there are at least five successful horizontal farms: *Brooklyn Grange*-the largest rooftop farm in the country (Fig. 10), *Added Value*, *Tenth Acre Farms*, *Urban Farm at the Battery* and *Gotham Greens*) [41].

This chapter aims to address the second and relatively newer form, in which more new technologies are applied to increase the intensity and productivity. Covered in plant material the *London Tower Farm* (London, UK/not available/ Xome Arquitectos) is a combination of vertical farm and residential building that creates a mini eco system (Fig. 11). Roof-top RE systems generate power for the

Fig. 10 Brooklyn Grange urban farm (*Source* [41])

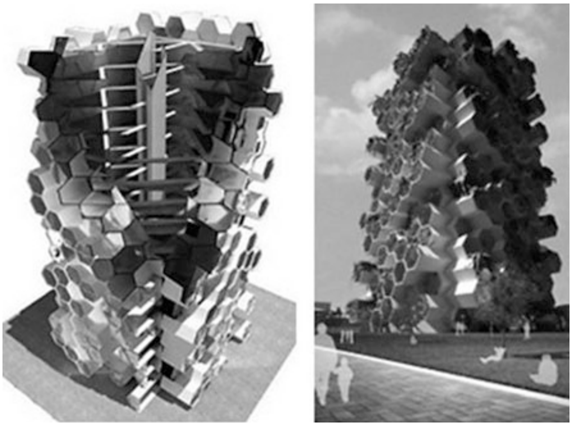


Fig. 11 London tower farm (*Source* [41])

building and rainwater is collected and used for tank farming, showers and toilets. Food is grown in the center of the tower, so residents can easily access that area from all directions. The harvested fruits and vegetables are produced for the residents as well as for sale to the public [42]. Some concerns are, for instance, how the lower growing areas receive light, or how to prevent dead and decomposing leaves and plants from spreading diseases in this dense setup, etc. In the US, a proposal of similar concept is the *Whittier Organic Food Center* (Los Angeles, USA/not available/Daniel Toole) [43].

A supporting technology for urban food production is the product: the *VertiCrop*^{TM} (Vancouver, Canada/2009/VertiCrops Company). This patented technology may represent a paradigm shift in farming and food production, and was selected in 2009 by TIME magazine as one of the World's Greatest Inventions. The technology was developed to grow food naturally in bustling urban environments and in any climate, with a small environmental footprint. The system can be positioned vertically or horizontally on rooftops and other tight spaces. It can provide up to 20 times the yield of normal field crops while using only 8 % of the water typically required for soil farming. LED lights are on standby to supplement waning natural light when necessary [44].

In fact, green vertical systems may provide another pathway that is closely related to passive buildings. Green vertical systems of buildings are comprised of four fundamental functional attributes similar to those used by passive buildings. These functional attributes are the interception of solar radiation by vegetation, the thermal insulation provided by vegetation and substrate, the evaporative cooling that occurs by evapotranspiration from the plants and the substrate, and finally, the variation of the effect of the wind on the building [45]. While this loose association between passive house strategies and urban farming, and more generally plant material itself, is possibly inspirational much work needs to occur to arrive at a point in which urban farming and low energy building are directly collaborating in the improvement of urban resource efficiency.

Transportation Projects/Products

Like the built environment, the transportation sector is beginning to be influenced by RE and energy efficient solutions. Our review covers technology scenarios from large-scale transportation systems down to a variety of innovative traffic modes, and projects/products, also classified by their RE types.

Solar-Powered Vehicles

Tindo (Adelaide, Australia/2010/Designline International) is the world's first solar-powered electric bus that uses 100 % solar energy. The bus is air-conditioned, can carry up to 40 passengers, and provides free wifi internet and particularly free service to the people of Adelaide. Tindo is able to travel about 200 km between recharges under typical urban conditions. The bus has no combustion engine so it operates quietly and produces zero emission. Another positive feature of the bus is the regenerative braking system that saves up to 30 % energy consumption. In its first year of operation, the bus saved an amount of over 70,000 kg of CO_2-e [46]. Although it is necessary to consider the latent CF of the components within the entire system (see discussion in Technological Systems: A Proposed General Classification System) as well as the land required for solar arrays to power this bus, the development of a solar bus like Tindo is still encouraging, and may help boost the potential lucrative market of the green bus, thereby reducing CF.

Electric Vehicles

The *Honda Fit EV* (USA/2013/Honda) has been given the EPA's highest fuel-efficiency rating ever: 118 MPGe (EPA: US Environmental Protection Agency; MPGe: miles per gallon gasoline equivalent). The EV's 20-kWh lithium-ion battery can give it a range of 82 miles, which surpasses range ratings of the Ford Focus Electric and the Nissan Leaf [47]. This product is one of the successful examples of achieving both zero-emission and high-energy efficiency.

Mercedes-Benz-owned Smart has unveiled an ultra-compact plug-in electric pickup truck called the *For-us pick-up truck* (Germany/2012/Mercedes Benz). The vehicle will use the same platform as a Smart manufactured car, but only seats two and provides a rear docking station for two e-bikes, so the driver can charge the e-bikes while traveling to or from an e-bike ride [48]. This pick-up may suit young couples with an active lifestyle, and is a smart solution for combining short and longer travel distances to be covered by two green modes. However, since it is just a small car with a short range (86-miles on a full-charge), it may not be adopted in low density markets like the United States and Australia. And although it is a "green" car that can carry "green" bikes, the battery itself is still a "un-green" component.

Hydrogen-Powered Vehicles

Hydrogen-powered vehicles have gained more attention particularly since the 2011 Tokyo motorshow, when Toyota unveiled their new *fuel cell concept car FCV-R* (Japan/2011/Toyota Company). The car seats four and has a travelling range of about 434 miles on a full tank. The company aims to launch the product in 2015 [49]. In UK, an initiative called *UKH2Mobility* (UK/2012/UK government and industry) has been launched by the government and 13 companies. According to UK Business Minister Mark Prisk, "hydrogen fuel cell electric vehicles are increasingly being recognized as one of the viable options as we move to a lower carbon motoring future […] The UK wants to play a major part in their manufacture for global markets, and fuel cell vehicles could hit the road in 2015" [50]. These two initiatives show a good addition of eco-car choices for future customers and signals future competition in this new market share that may help lower car prices.

Other Smart and Eco-Transport Systems

New Electric Vehicle Infrastructure

New infrastructure for electric vehicles (Israel, Denmark and others/2012 (pilot)/ Better Place Company) is an example of this type of hybrid system. A startup called Better Place has been installing about 500,000 charging outlets at parking spaces in Israel and subsequently in Denmark, which provide sufficient changing outlets for EVs during the day. The company has partnered with the automaker Renault to manufacture EVs for sale, which have over a hundred miles of range (good for most daily driving) and their batteries can easily be swapped out. For longer trips, the depleted battery can easily be exchanged to a new fully charged one at a station by a simple robotic system within a few minutes. Better Place will build 125 such stations in Israel and slightly more in Denmark. EVs are typically recharged at night, so the system may match well with wind power, since at night the wind is strong and demand for electricity is usually low. To make this system work, the company will sell cars in an unusual way: Drivers will sign a contract for a set number of miles and buy a car for a subsidized cost. The subscription will cover the cost of battery renting, changing, and the electricity for charging it up. The number of miles driven will be tracked using a wireless network and the cost of the car will depend on the contract length. It is expected that the car will cost no more than a comparable gasoline model [51].

Personal Rapid Transit

Personal Rapid Transit (PRT), also called podcar, is a new public transportation mode of small automated vehicles running on built guide ways. Each vehicle typically carries around 3–6 passengers. The guide ways are built in a network, with frequent merge/diverge points. This design allows nonstop, point-to-point trips that bypass all intermediate stations. The point-to-point service can be compared to a taxi. A 1.2 km PRT system (one way) was developed by 2getthere [52] and went into operation in Masdar City, UAE in November 2010. The *PRT system at Heathrow Airport, Terminal 5* (London, UK/2011/ULTra PRT) also came into service in 2011 (Fig. 12) [53].

Several cities have recently expressed interest in PRT, and two small city-based systems are currently under development: *Personal Rapid Transit Unit* (Suncheon,

Fig. 12 PRT system at Heathrow Airport, Terminal 5, London (*Source* [53])

Korea/2013/Posco) [54] and *Automated Personal Transportation System* (Amritsar, India/2012/ULTra Global PRT) [55].

Fuel-Efficient Vehicle

The *Hypermiling concept car* (Cambridge, UK/2011/Cambridge Design Partnership) is an example of high fuel efficient vehicles that can travel 1,325 miles on a single gallon of diesel.

The car was designed for the educational purpose of engineering, technology and ecological sustainability. Cambridge Design Partnership used some new technologies for the car such as lightweight oxygen concentrator and a special "Go" real-time tracking service for system optimization. The car also features low-friction tires that can increase mileage [56]. As gas prices rise rapidly and the trend will likely continue, fuel-efficient vehicles like Hypermiling have been becoming more crucial than ever. The perpetual search for higher fuel efficiency is foreseen as a common trend for most automobile companies in the future.

Vehicle Automation

An autonomous or driverless car is a car that can sense its environment and navigate by its own. A destination may need to be chosen, but no human operator on the vehicle is required. Autonomous vehicles are illegal to operate on public roads anywhere in the world except in the state of Nevada, USA (from June 2011) [57]. The *Google driverless car* (San Francisco, USA/2010/Google Company) is one of the pioneering products, alongside programs such as the DARPA Grand Challenge, a prize competition for American driverless vehicles, funded by the Defense Advanced Research Projects Agency. There are a number of advantages of driverless car. We may potentially:

- Reduce the number of cars, thereby reduce fuels consumption and carbon emissions.
- Reduce the number of accidents, thereby eliminate all adding up costs such as medical costs, property damage, productivity loss, legal costs, etc.
- Reduce the number of wasted commute time and energy.
- Reduce the required parking space thanks to reduced necessary gaps between cars or the car can self-drive to a distant parking place to park.
- Reduce costs for road construction, traffic control.
- Increase roadway capacity.
- Increase traffic management quality.
- Create lucrative business opportunities to serve new customer needs etc. [58].

On the other hand, there are certainly disadvantages involved in vehicle automation, such as legal issues, high cost or the complexity of technical maintenance, etc. For instance, in the event of an accident, who would be liable, the person sitting by the steering wheel (but not actually driving) or the maker of the software? However, with vehicle automation, there is a major potential to significantly improve the traffic system, automobile industry, energy systems as well as the environment. If driverless cars will be legalized to operate more broadly, they may substantially change our mobility as well as way of life.

Bicycle Sharing System

Bicycle sharing systems are a service that provides free or affordable access to available bicycles for temporary shared use to the public who do not own them. It has evolved greatly since the first program was launched in the Netherlands in the mid-1960s. As of May 2011, there were estimates for 136 bike sharing programs in 165 cities around the world, with 237,000 bikes on the streets [59]. The latest systems to be launched include *Bixi* (Montréal, Canana/2009/Public Bike System Company), *Capital Bikeshare* (Washington D.C., USA/2010/Alta Bicycle Share), Shanghai Bike sharing Program *Forever* (Shanghai, China/2010/Xuhui District's Tourism Bureau), *New Balance Hubway* (Boston, USA/2011/Alta Bicycle Share), *Decobike* (Miami, USA/2011/DecoBike LLC), etc. The *Hangzhou bike sharing system* (Hangzhou China/2008/Hangzhou's Public Transport Corporation) was recently developed to become one of the largest bike sharing systems with 60,600 bikes [60]. Bicycle sharing system is typically used to cover short-distance trips in an urban context and solve the "last mile" problem, which refers to the provision of travel service from the nearest public transportation node to a home or office [61]. It is as an alternative and green mode to motorized transport, thereby reducing traffic congestion, noise and air pollution. The blossoming of bicycle sharing system around the world is an important achievement of the global green movements, particularly those originating in cities and local communities.

Smart Bicycles

Weighing 10.8 kg, travelling at 23 km/h and being able to fold/unfold in just 15 s, the *Yikebike* (Christchurch, NZ/2010/Grant Ryan) is among the smallest folding electric bikes in the world. Having anti-skid regenerative brakes, the bike allows the rider to stop with confidence on different kinds of surfaces while charging the battery for maximum efficiency, and the charging cost at any power outlet can be very low (Fig. 13) [62]. The bike can be carried into trains, buses and even airplanes, so theoretically you can go almost everywhere with it. However, it may be challenging for many people to carry the bike along. The first author has tried riding a Yikebike, and it was fun but the bike was heavy. Adding ones belongings, it is challenging to carry them.

Smart and responsive, the *Copenhagen Wheel* (USA/2009/MIT SENSEable City Lab) is also another novel design for urban mobility. It transforms ordinary

Fig. 13 Yikebike, the world's smallest folding electric bike (*Source* [62])

bikes into hybrid e-bikes that also serve as mobile sensing units. Controlled through the rider's smart phone, the wheel can capture the energy produced during cycling and braking and save it for future need. It can also map pollution levels, traffic congestion, and road conditions in real-time [63]. Nevertheless, there may be some drawbacks for some people in certain contexts, such as the great difficulty to read the screens in the sun or when used by the elderly, the added weight of the wheel, the cost, potential vandalism issues, etc.

Special Smart Grid Linking Homes and Vehicles

Toyota has developed a new *vehicle-to-home* (V2H) *power system* (Japan/2012/Toyota) for the mutual power sharing between EVs and homes, that can greatly contribute to low-carbon and efficient electricity usage. The electric power supply system can work two-way: from home to vehicle and vice versa. Toyota plans to test the system with their Toyota Prius plug-in hybrid vehicle (PHV). An AC100 V inverter of the Prius PHV converts stored power into AC for home use. The power flow is controlled according to communication between the EV, the charging stand and the home. With this new technology, the vehicle's drive battery can store low-carbon electricity generated from regional or home solar generators and then supply power back to the home during peak consumption times. Particularly during a power outage, the EV's batteries can substantially provide power for the home. The company estimates that with a fully charged battery and full tank of gasoline, a Prius PHV can supply enough electricity for an average Japanese household to use for four days [64]. This system is useful since the recent nuclear crisis in Japan that caused electricity shortages and scheduled power cuts. Moreover, since Japan is a country with frequent disasters, Toyota also developed

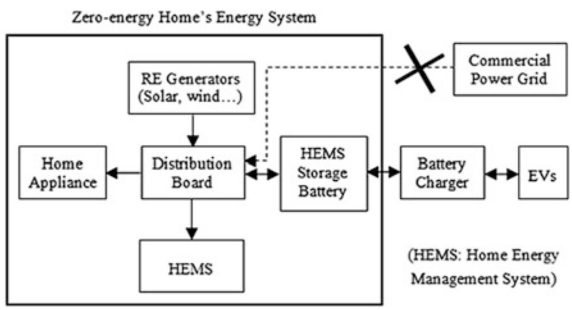


Fig. 14 A "near-zero carbon home + mobility" model drawn based on the V2H energy system

devices that can supply electricity directly from PHVs to devices at emergency shelters.

Based on the concept of this system, a "near-zero carbon home + mobility" model is proposed (Fig. 14). In this model, assuming that powerful integrated RE sources (such as rooftop solar panels and wind turbines, etc.) can be installed for a home that will provide enough energy for the home uses plus charging the electric vehicles used by the household. In this case, traditional commercial grid power (that latently carries CF, dotted line) will not be required. The whole system can provide a "near-zero carbon" life for the home's residents (at least their home living and moving around). The term "near-zero carbon" has been used after taking consideration of possible latent CF as discussed in Technological Systems: A Proposed General Classification System.

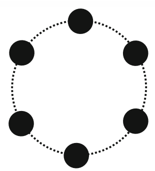
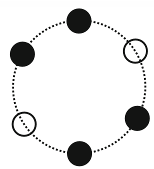
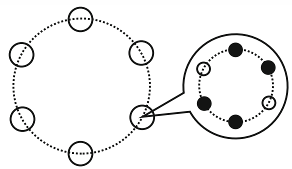
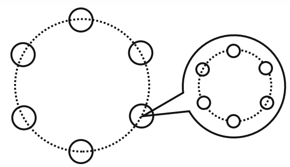
Discussion and Future Trends

Technological Systems: A Proposed General Classification System

As we can see through various AUT demonstration projects reviewed above, incorporating RE sources can apparently make the system cleaner and "greener". But in fact, it does not mean the system can become completely clean and "green", that is, extremely low or zero carbon emission. That is because many people including various stake-holders of the RE industry are either not aware of or ignore the "big picture" of the system's CF, and consequently overvalue their projects and/or products.

For instance, an electric car can be seen as a greener mode, but in fact, it can only be called a green mode if it is charged by RE sources, not by conventional commercial power, which latently carries CF from unclean factories that generated the electricity. Let's take this viewpoint further by looking at an electric car that is traveling from city X to city Y. The car, if charged by commercial grid in city X may bear a CF ratio that is different from the CF ratio when charged in city Y, if

Table 1 Classification of technological systems based on Carbon footprint level

Type	Traditional	Alternative		
Class	**1.Traditional System**	**2.Improved System**	**3.Novel System**	**4.Advanced System**
Description	Comprises of high CF elements	Comprises of conventional high CF elements and new green elements	Comprises of all new green elements	Comprises all new green elements
	Conventional	Innovative	Novel	Breakthrough, advanced, ideal
	Resource inefficient	More resource efficient	Very resource efficient	Extremely resource efficient
	High CF	Middle CF	Low CF	Ultra low or zero CF
	Un-green, unclean	Greener, cleaner	Green and clean But its elements, if "zoomed" in, are made of various components including high CF ones	Its elements, if "zoomed" in, are made of "near- zero CF" components
Example	A conventional household commercial power grid	A household power grid combined of conventional commercial power source with renewable sources (PV panels, wind turbines, geothermal…)	A household power grid supplied entirely by RE sources. In this case, the house is often called zero-emission house, and can be a zero-energy or energy-plus home. But some components of the RE devices may have been manufactured in un-green factories and transported by un-green vehicles, and thus bear latent CF, so the entire system is ultimately not clean. Some components are made from non-recyclable materials	A similar grid as in class 3, but the components of RE sources were made in "green" factories and transported by green vehicles, and thus originally had ultra-low CF. The components are made from recyclable materials. This is the ideal system but may not be achieved in the near future, because an "almost zero CF" system means the entire production chain from factory, logistics to end-user should be completely clean
Schematic diagram				

Black dots = un-green/unclean; white dots = green/clean; CF = Carbon footprint, RE = Renewable energy the grids in the cities are supplied by different factories that produce different carbon emissions.

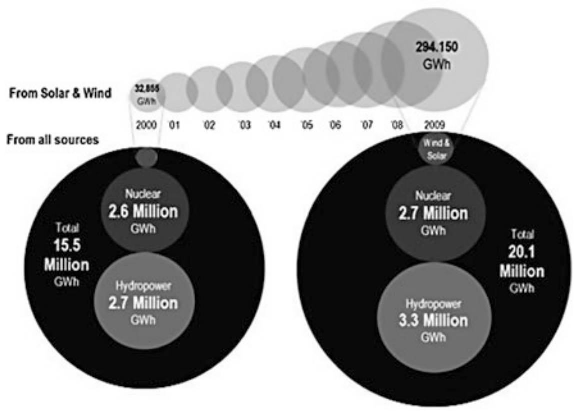
Table 1 introduces a new classification of technological systems in terms of CF level based on this viewpoint about "the big picture" of CF. It ranks the traditional technological system as class 1 (most unclean, un-green) and then describes alternative technological systems, which are ranked as class 2, 3 and 4. Most of the AUT demonstration projects in Section AUT Demonstration Projects fall into class 2. Some are moving forward toward class 3 (e.g. "near-zero carbon home + mobility" model). Class 4 is ideal and can unlikely be achieved in the near future.

AUT Future Trends

AUTs are an important element of the continued development of the built environment, the transportation and RE potential of current and future urbanization. The trends for the development of diverse AUTs demonstrate strong growth and investment across all of these sectors. North and central European countries such as Germany, Denmark, Sweden, Finland, etc. are still leading the world in terms of green technologies development while United States and China are accelerating their direct investment and application of AUTs.

However, there is a great challenge ahead for RE sector and for the majority of AUTs. "Wind and solar power are ramping up quickly, but the world's demand for electricity is growing much faster. The use of wind and solar power rose almost ninefold from 2000 to 2009, the most recent year for which the International Energy Agency has made data available, but that has not significantly shifted the overall mix of the world's electricity supply. Worldwide demand for power is growing on a different scale. Figure 15 shows that from 2000 to 2009, as the annual generation from wind and solar rose by about 260,000 GWh, total

Fig. 15 Total world electricity generation (Adopted from [65])



generation increased by nearly 4.7 million GWh. As a result, CO_2 emission from electricity production, which represents roughly 40 % of the world's energy-related emissions, keeps rising. Asia, the continent of the world's fastest urban growth, is also the region that consumes energy the most […] In short, RE still has a long way to go" [65].

Other challenges may include some of the negative impacts of RE development that may hinder them from thriving further. For example, currently both solar farms and wind farms require huge areas of land, so the loss of land as well as its potential economic benefits that could be gained if no solar farm or wind farm was to develop will significantly add in the costs of the RE investments. This is one of the reasons why many solar farms and wind farms are being developed in rural or ocean areas. Another example of the negative impacts of RE development—the case Hydropower—are the issues of high construction cost, flooding in rainy season and droughts in dry seasons, land use and landscape changes (not to mention the catastrophic risk of dam breaking), the water scarcity of the downstream regions (e.g. the current Xayaburi dam project on the Lower Mekong River in Laos and its threats to food security in Cambodia and Vietnam), etc.

In the future, it is forecast that the next generation of energy systems would be based heavily on RE systems and energy efficient systems (passive) and hybrid or full hybrid systems will be dominant. Hybrid RE systems are the integrated systems of two or more RE types (e.g. S+W, W+G+B….) while full hybrid energy systems are formed by both RE systems and energy efficient systems (Fig. 16). In theory, this type of full hybrid energy systems is the most advanced and "greenest" as it empowers the building to naturally respond to the dynamics of the local environment on one hand (passive way) while ensuring the possibility to use a selection of RE on the other. It can potentially make the building become an energy-plus one (a building that produces more energy than it consumes).

With regards to energy efficient systems, it may be necessary to mention the "rebound effect", which measures the behaviorally induced offset in the reduction of energy consumption following efficiency improvements. The fundamental spirit of the "rebound effect" lies on a hypothesis that greater efficiency leads to even greater energy use because it causes people to consume more goods and services [66].

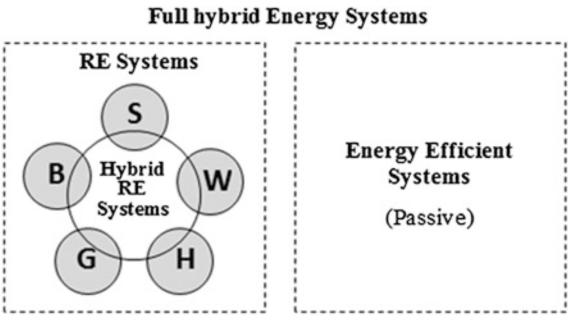


Fig. 16 Next generation of energy systems *Notes*: *S* solar, *W* wind, *H* hydro, *G* geothermal, *B* biogas, Hybrid RE systems: combining two or more RE types

There have been a number of debates about this and how big rebound effect is. For instance, Frondel and Vance warn not to belittle the rebound effect in energy efficiency [67], while Gillingham et al. prove that in energy policy, the rebound effect is overplayed [68]. Sharing the same opinion that the rebound effect is small, Steve Nadel, executive director of American Council for an Energy-Efficient Economy (ACEEE) writes in an ACEEE white paper that: "Overall, even if total rebound is about 20 percent then 80 percent of the savings from energy efficiency programs and policies register in terms of reduced energy use. And the 20 percent rebound contributes to increased consumer amenities and a larger economy. These savings are not "lost" but are put to other generally beneficial uses" [69]. This chapter agrees with the notion that the counterproductive aspect of the rebound effect should be taken into account, yet many of the reviewed demonstration projects show that improving energy efficiency apparently makes direct positive impacts on the environment.

The current global economic recession may slow down the investments in RE and AUTs in the short run (e.g. the year 2012) but not in the long run. In fact, it may provide good opportunities for their development, as many enterprises, institutions as well as households are looking for innovative solutions to harvest "free" energy resources and/or save energy to cut costs. In the next coming years, it is forecasted that RE, AUTs, green development/renovation as well as many other green initiatives will continue to grow strongly, particularly thanks to:

- The competition among cities/regions and the competition in the global technological market, which substantially decreases the upfront investment costs and boosts up the race of AUT development.
- The increasing global consensus and movement on going-green and the blossom of green initiatives.
- New governmental spending, regulation and policies on RE. For examples, after the launch of the "American Recovery and Reinvestment Act" in 2009 that includes more than $70 billion in direct spending and tax credits for clean energy and associated transportation programs [70], Cleantech Group has reported that in 2011, U.S.-based venture capital investments in clean technologies increased from $5.1 bill. in 2010 to $6.6 bill. in 2011 (30 % up) [71].

The latest report of Clean Edge's Annual Trends Report (Mar 2013) outlines five key trends that will impact clean-energy markets in 2013 and beyond:

- Smart devices and big data empower customers, open new chapter in energy efficiency.
- Distributed solar financing comes of age.
- Under the electric vehicle radar, microhybrid technology saves big on fuel consumption.
- In the U.S. and overseas, geothermal picks up steam.
- Perfectly natural: Biomimicry makes its mark on clean tech.

The report also provides a global clean energy projection as seen in Fig. 17 [72].

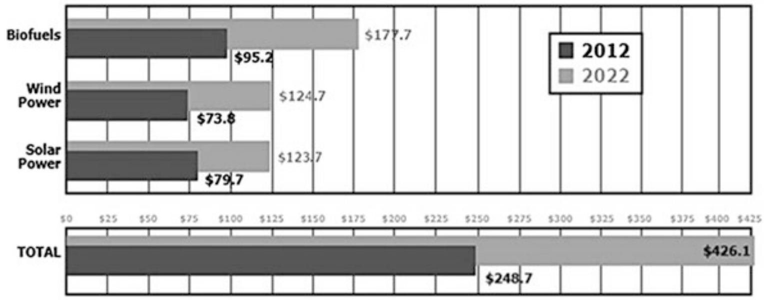


Fig. 17 Global clean energy projected growth 2012–2022 ($US Billions) (*Source* Clean Edge, Inc [72])

Conclusion

This chapter is a review of state-of-the-art AUT demonstration projects around the world, with a focus on three primary urban systems: the built environment, transportation and energy. Through this study, we can see the important role of RE as well as its broad and diverse application in changing our traditional urban technologies substantially in order to transform our cities innovatively toward a low-carbon future. The classification of technological systems shows that there are different levels of alternative solutions in correspondence with different levels of environmental impacts. However, all of the three latter classes (2, 3 and 4) are seen as "alternative" technological systems to replace the traditional anti-ecological ones (class 1), and thus, should be explored, praised and learnt from.

From this review, we can also see that RE-based projects have not only developed strongly within a respective RE sector (such as solar, wind, geothermal…) but also thrived dramatically in forms of hybrid RE systems, as showcased in Hybrid RE System Projects. Those hybrid RE systems can potentially provide the greatest harvest of RE, have the least CF and thus, become the cleanest systems. More significantly, several novel showcase projects show that some RE types can be intelligently combined and greatly complementary to each other (e.g. PV panels harvest the sun energy during the day for the system where energy storage is not available, and wind turbines work at night when it is most windy). For example, Toyota's vehicle-to-home system is an example of a smart integration system and from there we could move forward toward a more advanced "near-zero carbon home + mobility" model as seen in Fig. 14. In addition, the Brackfriars Railway Station project (Solar Energy Projects) proves a novel and innovative solution for developing solar infrastructure as shelter for an urban bridge, while reducing the opportunity cost and lessening the pressure on land use for large scale RE farms. Finally, *new infrastructure for electric vehicles* (New Electric Vehicle Infrastructure) demonstrates an innovative method for promoting the sales of electric cars, overcoming one of the biggest challenges that have kept AUTs from being widely adopted: the high upfront cost.

By proposing a general classification system (Technological Systems: A Proposed General Classification System), this chapter emphasizes the importance of taking into account the “big picture” as well as “latent impacts” of the entire system, as discussed with the examples of CF, hydropower, land loss due to solar/wind farm development, etc. Also, by exploring some of the most innovative demonstration projects, it addresses the important potential prospects of AUTs (as articulated in AUT Future Trends.), and provides the basis for informed speculation about moving toward a low-carbon and sustainable future for our cities.

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Complex Socio-Technical Problems for Engineers: Pedagogical Motivation and Experience at the Undergraduate Level

Afreen Siddiqi, Regina R. Clewlow and Joseph M. Sussman

Abstract Engineering courses, focused on complex, sociotechnical systems, at the undergraduate level, have been rare. Traditionally, most students develop technical understanding in a specific engineering discipline, but get little opportunity to analyze engineered complex systems, where both technical and social issues need to be well understood for devising long lasting solutions. In this chapter, authors describe the motivation, design, and learning outcomes of an introductory course on Engineering Systems that has been developed and offered at the Massachusetts Institute of Technology. The course is based on the theme of critical contemporary issues (CCIs) including energy, mobility, sustainability etc. The aim of the course is to expose undergraduates to quantitative tools for methodically analyzing complex contemporary engineering challenges. The course consists of lectures on system dynamics, networks and uncertainty, along with semester-long team-based projects. For the first pilot offering of the class (Spring semester 2011), the students gave an average rating of 5.9/7.0 regarding how likely they were to recommend this class to others (7 being absolutely certain). There was also evidence (however, based on limited and anecdotal data) of continued student interest (outside of class) in engaging with the complex socio-technical problems they worked on during the term.

A. Siddiqi (✉)
Research Scientist, Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
e-mail: siddiqi@mit.edu

R. R. Clewlow
Lecturer and Postdoctoral Fellow, Stanford University, MC 3-68, 450 Serra Mall, Stanford, CA 94305, USA
e-mail: rclewlow@stanford.edu

J. M. Sussman
JR East Professor of Engineering Systems and Civil and Environmental Engineering, Massachusetts Institute of Technology Cambridge, Cambridge, MA 02139, USA
e-mail: sussman@mit.edu

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Introduction

Many of our most interesting, complex engineering challenges do not fit into the neat silos of academic disciplines—they are interdisciplinary and require *systems thinking*. The level of complexity and interactions in modern systems requires a new level of expertise and trans-disciplinary perspectives that perhaps were not needed before. Systems thinking, and the skills to tackle complexity, need to be inculcated in engineering students sooner rather than later. It is becoming more important for young engineers (not just senior practitioners) to obtain such skills. To date, the development of analytical skills for studying such problems has been largely reserved for graduate-level engineering education. However, engineering students are increasingly interested in working on contemporary challenges earlier in their careers. Students entering engineering programs today are more aware and better equipped for conducting sophisticated analysis due to their access to information, knowledge and tools that previously were not available to prior generations. It is therefore, important—both for retaining students in engineering and for harnessing their curiosity towards potentially finding new solutions—to offer *undergraduate* courses that allow them to engage with complex, contemporary problems.

This chapter describes the development and implementation of a novel course, ESD.00- *Introduction to Engineering Systems,* offered by the Engineering Systems Division (ESD) at the Massachusetts Institute of Technology [1]. Primarily intended for first and second year engineering students (but open to all undergraduates), it has been designed to engage and challenge a new generation of students who are passionate and more involved than ever before in understanding and impacting contemporary problems.

The new course centers around the theme of Critical Contemporary Issues (CCI)—important and difficult problems pertinent to our present times on topics including sustainability, mobility, energy and the environment, healthcare, communication, the internet etc. In this course, we integrate introductory instruction in system dynamics, networks and uncertainty with team-based semester-long projects. Through this approach, we enable students to engage in and understand the issues related to a problem of their interest, appreciate the scope of the socio-technical complexities in CCIs, and gain an introduction to analytical tools that can help in addressing some of these issues. This chapter discusses the overall philosophy and motivation for establishing the course, the design of the curriculum, the execution and integration of team-based projects, the teaching and learning experiences over two terms, and plans regarding its future evolution.

Motivation

Historically, engineers have largely acquired expertise and understanding of complex systems through practice in their profession. Little attention was paid to creating structured curricula, classes or degree programs focused on studying complex engineering *systems*. However, we are presently part of an era in which the inventions of the past two centuries for energy, transportation, and communication have coupled together to form highly interdependent, large-scale systems [2]. Thomas Edison's light bulb, James Watt's steam engine, and Alexander Graham Bell's telephone have not only transformed into more sophisticated devices today—but they also now form only a part of larger systems within which they function and without which they will not deliver value. The light bulb requires a functioning electric grid, the locomotive engines require transportation networks, and the modern phones are of use within the larger signal and communication networks. While we have, to a great degree, advanced our knowledge in the art and science of designing new products, we have yet to explore the domain of design, operation, and management of complex engineered systems with considerable nonlinearity and feedback.

Furthermore, engineering education has traditionally focused on systems where the boundaries encompassed materials, machines and constructed facilities. It is has now become important to expand those boundaries to include humans and institutions. Such an expansion essentially extends the focus from simply technical to *sociotechnical* systems, where technical as well as societal, economic, political, and regulatory factors weigh in prominently.

As historically disparate technical systems become inter-twined and humans and societal factors become non-negligible variables in design decisions, engineers of tomorrow will need to deal with requirements that are not just physical, but also increasingly social, political, economic in nature. At some level, this has always been the case. However, such considerations were not needed to be as integrated in the design, management and operation of engineering systems as they are increasingly required now. This new, increased level of integration requires a rethinking and redesigning of how we go about training our future engineers who will, for instance, have to deal with global manufacturing and supply chains, create and maintain new interdependent infrastructures, design systems for accessible and affordable healthcare and so on.

This course is an initial step, at the undergraduate level, towards inculcating broad, holistic thinking in our next generation of engineers. While learning the technologies central to these systems is essential, our students need to learn how social sciences and management ideas are integrated into our study of CCIs, creating that holistic individual. It is necessary to teach methods related to analysis of natural phenomenon and material or component behavior (such as Finite Element Analysis, Computational Fluid Dynamics etc.) to engineering students. It is now also important to offer the students an exposure to sophisticated methods for understanding system interdependencies (using tools of networks and graph theory), understanding uncertainty (based on probability theory) and tools for decision-making (such as decision analysis, multi-attribute utility theory) etc.

The Engineering Systems Division at MIT is driven by this vision of research and education in large-scale engineering systems and is focused on complex, socio-technical problems. The division was established in 1998, and since its inception there has been strong and increasing student interest in terms of enrollment and class registrations (see Fig. 1).

However, to date the educational efforts of the division have been primarily targeted towards graduate students. Figure 2 shows the total graduate-level course offerings (across all semesters) by departments in School of Engineering at MIT. This data counts joint-listed courses (i.e. same classes listed with different numbers in multiple departments) only once. Joint-listed classes were associated with a department that is designated as 'Master' department for the class in the registrar's office. Furthermore, course numbers for thesis work and directed/individual student research classes were not counted. It can be seen, in Fig. 2, that while the number of graduate courses offered by ESD are significant, the undergraduate courses are the smallest in number within the school.

A more in-depth analysis of the course offerings was done to determine how many classes were focused on 'systems' (in any domain or context). As a crude proxy of this measure, class titles that had the keyword 'system' were tallied for each department. The results are shown in Fig. 3. The reader should note that from the viewpoint of full-time equivalent (FTE) faculty, ESD is the smallest unit in the School of Engineering with 13 FTEs.

A review of the undergraduate classes currently offered by ESD shows, that apart from ESD.00, there are 6 listings. These include courses related to engineering leadership offered through the Gordon-MIT Engineering Leadership program [3], statistics and data analysis, technology and public policy etc. There had been no undergraduate class, offered by ESD, which focused on concepts and methodologies for analysis of complex large-scale, engineering systems from a

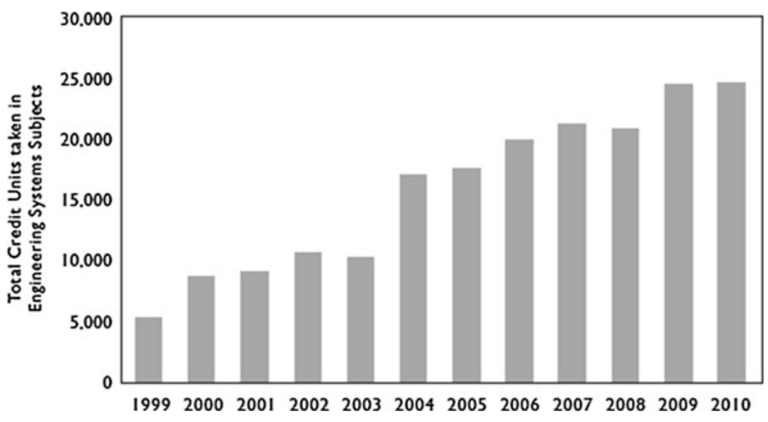

Fig. 1 Student enrolment in ESD classes at MIT [2]

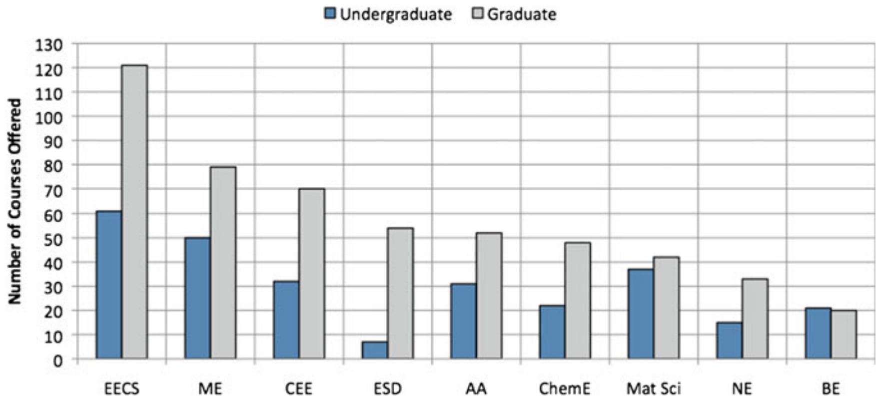

Fig. 2 Number of classes currently offered (across all semesters) in School of Engineering. *Abbreviations*: *EECS* Electrical Engineering and Computer Science, *ME* Mechanical Engineering, *CEE* Civil and Environmental Engineering, *ESD* Engineering Systems Division, *AA* Aeronautics and Astronautics, *Chem E* Chemical Engineering, *Mat Sci* Materials Science and Engineering, *NE* Nuclear Engineering, *BE* Biological Engineering

domain neutral perspective. The new course, ESD.00, was thus developed to close this gap and create new learning opportunities for undergraduates. The one undergraduate 'systems' class shown in Fig. 3 for ESD is due to the recent inclusion of ESD.00 in the listing.

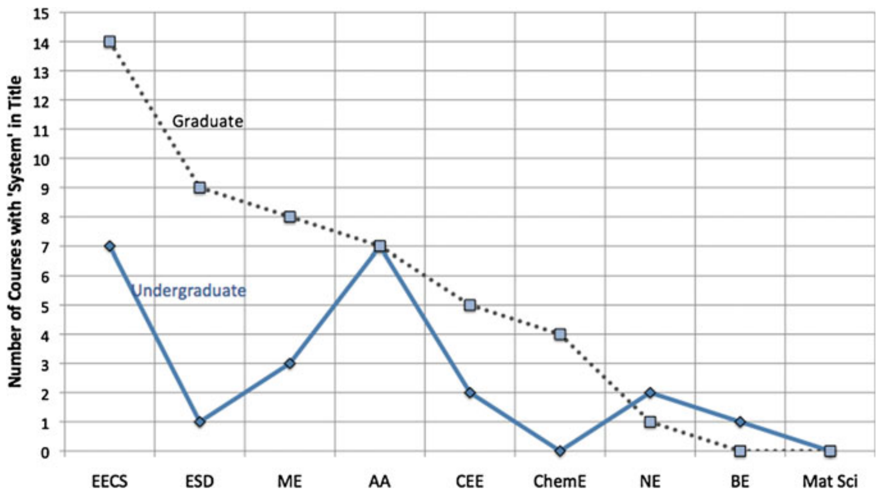

Fig. 3 Number of courses with keyword 'system' in course title

Introducing Socio-technical Problems to Engineers

Objectives

The basic objective of the course was to expose undergraduate students to concepts and methods that can be used for tackling critical, contemporary issues associated with socio-technical systems such as that of energy, mobility, communication, healthcare etc. A key feature was emphasis on project-based learning [4], and the goal was to have student teams work on specific projects as part of this class. There were seven goals that were outlined for the course:

1. To introduce concepts and methods of engineering systems at a level that can be understood and applied by undergraduate students in real-world projects.
2. To enable students to gain conceptual understanding of the complex interplay among technical, social political, and cultural aspects of socio-technical systems.
3. To motivate and energize students via project work with student teams and faculty mentors on complex global issues.
4. To develop students' problem solving and critical thinking abilities in deciding how to model and analyze a complex socio-technical system as part of their project work.
5. To enable students to draw directly on their math, science, and social studies background in conceptual understanding and practical application of engineering systems concepts and methods.
6. To introduce and provide practice in use of mathematical methods and computer simulation tools used in modeling, analysis and design of engineering systems.
7. To develop students' abilities in teamwork, oral communication and written communication as part of completion of team projects.

These objectives were largely driven by motivation to expand course offering for undergraduate students on topics of engineering systems (as discussed above in Sect. 2) as well as to use projects to enrich their learning experience. In retrospective analysis, we evaluated the goals using program-level outcomes defined by the Accreditation Board of Engineering and Technology as a basis of assessment [5]. The outcomes (commonly referred to as Outcomes 3a–3k and described in Table 1) are used to evaluate engineering programs.

The expectation is that the core set of classes in a program will collectively produce the outcomes at the required levels [6]. While the outcomes are for program-level evaluations, they provide a basis for assessing specific courses as well. In general, a single course cannot fully cover the full spectrum (from 3a to 3k). A comparison of how the goals (from 1 to 7) for the course connected with the outcomes 3a–3k is shown in Fig. 4. A dark blue box in the matrix indicates that the goal in its corresponding row is linked with the outcome in its corresponding

Table 1 Program-level outcomes 3a–3k as defined by ABET [6]

3a	An ability to apply knowledge of mathematics, science, and engineering
3b	An ability to design and conduct experiments, as well as analyze and interpret data
3c	An ability to design a system, component, or process to meet desired needs
3d	An ability to function on multidisciplinary teams
3e	An ability to identify, formulate and solve engineering problems
3f	An understanding of professional and ethical responsibility
3g	An ability to communicate effectively
3h	The broad education necessary to understand the impact of engineering solutions in a global and societal context
3i	A recognition of the need for and an ability to engage in lifelong learning
3j	A knowledge of contemporary issues
3k	An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

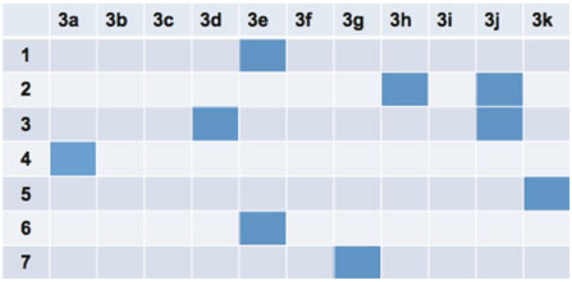

Fig. 4 Comparison matrix of class objectives with ABET's program-level outcomes

column. Note that in this figure only links are marked, but the level of connection (i.e. *how strongly* a goal links to an outcome) is not assessed at this stage.

Structure and Content

In terms of class structure, we designed it to be principally a project-based class, grounded with weekly lectures and a few supplemental tutorials. The lecture component provided the means for introducing the concepts and methods relevant for the class as well as a forum for in-class discussions. The projects were supervised by a graduate student or faculty member, and were conducted in small teams over the course of the entire semester. The projects served to engage the students' interest and provided real-world examples for applying the concepts and methods introduced in the lectures. Figure 5 provides a schematic representation of how the class was structured.

The lecture topics were selected carefully to reflect the introductory level of the course, but also to enable the students to acquire understanding of important concepts related to complex engineering systems. We selected three key topics:

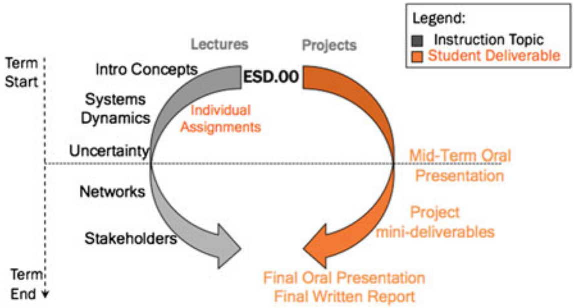

Fig. 5 Two-pronged approach for ESD.00—theoretical instruction and practical application

systems dynamics, uncertainty and networks. These topics collectively provide means for studying non-linearity, feedback, interconnections, and ambiguity that characterize most real-world problems and are often not adequately covered in classical engineering courses at the undergraduate level. Given the rich body of literature and a fair level of maturity that exists for these topics, a substantive and well-grounded material, suitable for undergraduate instruction, could be presented. Additionally, the *application* of these methods towards studying sociotechincal systems is well developed and recognized not just in a theoretical sense, but also in actual practice and real-world applications [7–9]. The application of these methods and approaches towards modeling and analyzing systems with both technical *and* social aspects was emphasized and demonstrated. Usually, these topics are covered in various engineering courses (especially uncertainty and to some extent systems dynamics through differential equations); however, the examples and applications are typically focused on technical and physical modeling only. The key difference in this class was how these topics were introduced and explained, and the kinds of examples used so that the students could understand how these methods apply to analysis of sociotechnical systems.

In addition to the key topics that were treated in depth (with multiple lectures devoted to each), we included lectures on basic systems concepts and definitions, stakeholders and evaluative complexity, and other lectures on related topics.

We took special care to integrate the two segments, the lecture and the projects, of the course. The integration was done through assigning mini-project deliverables to each team, in which the methods and concepts discussed in lectures were applied to the projects. For instance, each team was asked to create causal loop diagrams (as taught in systems dynamics approach), identify key uncertainties, and create network models for their respective systems. This integration of lecture material with projects was expressly designed to ensure cohesion between the two threads of the course as well as to allow students to apply the concepts to actual applications.

A detailed description of the course and the syllabus can be accessed at [10]. The class materials (as offered in Spring 2011) are also available through MIT's open courseware website [11].

Term Projects

As discussed earlier, this class was fundamentally designed around term projects. The idea was to have students grapple with open ended problems with no canned methods to apply or 'right' answers to compute. The students were equipped with instruction on multiple methodologies, and were given freedom to choose appropriate methods and tools that would be applicable in their judgment to the questions under investigation.

In the first offering of the course (in the spring semester of 2011), the students worked on three projects on healthcare, transportation, and communication that were broadly designed and supervised by ESD faculty and engineering systems Ph D students. In the second offering (currently on-going at the time of submission of this article), the student teams have projects on using electricity from renewable energy sources, decision modeling for flu vaccination, and site selection for nuclear waste disposal in the US. It is noted that the projects touch upon different critical contemporary issues, and are in fact well aligned with a number of grand challenges of engineering that have been outlined by the National Academy of Engineering [12]. Figure 6 shows how the fourteen grand challenges, as described in [12], connect to more general categories into which the ESD.00 projects (that have been offered to date) can be classified.

The project numbers in Fig. 6 (in the small inner most circles) correspond to projects 1–6 discussed as follows:

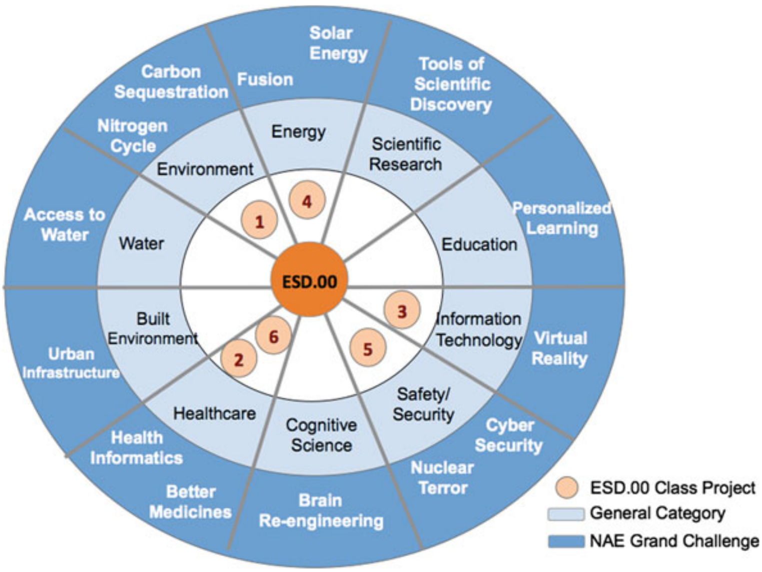

Fig. 6 Mapping grand challenges in engineering to projects offered in ESD.00

Life-Cycle Assessment of High-Speed Rail and Aviation

This project focused on a life-cycle assessment of high-speed rail and air transportation in the U.S. Northeast Corridor. The primary objective was to compare energy use and CO_2 emissions of the Acela Express as compared with short-haul flights in the Northeast Corridor.

The team examined future projections of demand for both modes of transportation between three corridors: Boston to New York, New York to Washington, D.C., and Boston to Washington, D.C. The life-cycle energy consumption and CO_2 emissions associated with these corridors were assessed utilizing a combination of the Economic Input–Output Life Cycle Assessment (EIO-LCA) method for transportation infrastructure and "well-to-wheel" approach for vehicle emissions.

Stroke Care Chain

The objective of the project was to analyze and then suggest improvements to the process of how patients are provided medical care after they suffer a stroke. The students were provided with an elementary systems dynamics model executable in VensimTM (originally prepared by a team of MIT and Harvard graduate students that had conducted exploratory work on the topic).

The students focused their analysis on the state of North Carolina, a state that has a 10 % higher death rate from strokes as compared to the US national average. The students used the model to first determine key variables that impact the stroke care process and can lead to tangible improvements, and then explored various policy options based on costs and benefits. The policy options included deployment of in-field ultrasound technology, increasing staffing of stroke care personnel at medical facilities, and increasing awareness through public out-reach and education.

The Digital Divide

Broadband has increased from 8 million in 2000 to 200 million in 2009 in the US, but there are still 100 million Americans that do not have broadband. The focus of this project was to understand the barriers to broadband adoption in the US, and to identify solutions that may help in increasing broadband accessibility. The team analyzed recently released (February 2011) data from a large Federal Communications Commissions (FCC) survey. The students used R, a statistical package, to compile and visualize the data in order to formulate a broadband adoption model. The key task was to explore the social, economic and technical factors that contribute to broadband and internet access trends in the US.

Electricity Power: Combining Renewables, Capacity Expansion, and Demand Response

This project explores the challenges in using electricity generated from renewable sources. Production of electricity with renewable will reduce carbon emissions but will increase the cost of electricity and require the electric power system to adapt in order to absorb the characteristic intermittency of wind and solar generation. Motivated by the need for low emissions, low cost and security of supply, a number of questions regarding optimal technology choices to balance competing objectives, and role of demand response were investigated.

Finding a Nuclear Waste Repository Site in the US

A multi-attribute approach to evaluating nuclear waste sites was designed in the late 1980's. Using expert elicitation to determine rank orderings and estimates for repository impacts, the methodology was applied to five potential waste repository sites, including Yucca Mountain. This project aimed to update that methodology for the new political and public resistance in 2011 in which the Yucca Mountain site has been ruled out. The team project consists of establishing a value tree (considering a wide range of metrics that should be used in selecting a site for a waste repository in the U.S); a network analysis on five candidate waste sites to determine which are optimal from a transportation-minimization perspective; a multi-attribute analysis of two possible project sites, and then inclusion of uncertainties using a decision-analytic approach.

Multi-Criteria Decision Models and Influenza Vaccination

This project is based on modeling decision making for vaccination and evaluating effectiveness of vaccination policies. Every year, a new influenza vaccine is available for the general public during the influenza season (October–March) and there is a brief period to monitor the outcomes of this vaccine—both its safety (adverse events) and its effectiveness (avoidance of influenza-related illnesses). Of course, the effectiveness of the vaccination policy depends on the public's perception of the benefits and risks of influenza versus getting vaccinated against influenza. These are dynamic measures that only become fully known after an influenza season is over. Federal regulators have a difficult job communicating these changing/developing benefits and risks for a myriad of reasons and continually cope with significant scientific misinformation surrounding vaccination and vaccines. The project uses Systems Dynamics modeling to investigate the problem.

Assessment

The course was reviewed by both students (through end-of-term evaluations) and by the faculty to gauge learning outcomes (largely based on final project presentations). At the time of submission of this article, data regarding assessment and evaluation of the first offering (of Spring 2011) was available. The second offering (of Spring 2012) is on-going, therefore its evaluation data was not available.

Student Assessment of Learning

Student feedback for the course was elicited through a focus group at the end of the semester and through an online course evaluation form. The course evaluation was specially customized for the class and was not simply the generic evaluation used for all classes at the Institute. The response rate was 100 %, and the overall feedback was very positive. Many students gave the highest 'strongly agree' rating to the question of whether they would recommend this class to others. Across all responses, the average rating for this question was 5.9 on a 7-point scale.

Table 2 summarizes students' expectations of their learning outcomes, and the extent to which the course met their expectations. These results are based on responses the students provided in the customized, end-of-term course evaluation. The responses were on a 7-point scale defined as follows: 1 = Not at all, 4 = Somewhat, 7 = To a Very Great Extent.

In general, the effectiveness of the course in meeting their expectations was ranked highly, with the highest mean score (6.7) associated with the project-related expectation. The students also agreed that they had "gained knowledge" about tools used to analyze engineering systems, as well as learned to "apply" those tools analyze engineering systems. The students' strong self-assessment of their ability to "apply" tools for engineering systems analysis is a useful initial evaluation that could be strengthened with further outcomes-based assessment of the course.

Faculty Assessment of Learning

In terms of faculty assessment, the evaluations for student learning were made through a combination of individual homework assignments (given in first half of the class), quality of class discussions, mid-term oral presentations and final project oral presentations and a written report. As a sample of the evaluation that was conducted, Table 2 shows the rubric used for evaluating the oral presentations of the final projects. A total of 10 evaluators (faculty and research staff with four who were not affiliated with the ESD.00) attended the presentations and orally quizzed the students on their work. A scale of 1–7 was used which was defined as follows: 1 = poor, 4 = satisfactory, 7 = superior. The results are summarized in Table 3 and also shown in a radar plot in Fig. 7.

Table 2 Summary of student evaluations

		Mean score	**Responses**	**Standard deviation**
Student expectations	*What were your expectations of the class?*			
	Expected to learn about engineering systems and how they connect with some critical contemporary issues	6.0	7	1.0
	Expected to work on a complex, engineering systems project	6.6	7	0.79
	Expected to gain knowledge about tools used to analyze engineering systems	5.7	7	0.95
	Expected to learn to apply tools used to analyze engineering systems	5.6	7	1.27
Effectiveness meeting expectations	*How effectively did the class meet expectations?*			
	Learned about engineering systems and how they connect with some critical contemporary issues	6.4	7	1.13
	Learned to work on a complex, engineering systems project	6.7	7	0.49
	Gained knowledge about tools used to analyze engineering systems	6.0	7	0.82
	Learned to apply tools used to analyze engineering systems	6.1	7	0.9

Table 3 Final project assessment

Category	Project 1		Project 2		Project 3		Project 4		Project 5		Project 6	
	Mean score	Standard deviation	Mean score	Standard deviation	Mean score	Standard deviation	Mean score	Standard deviation	Mean score	Standard deviation	Mean score	Standard deviation
1. Understanding of engineering systems concepts	5.6	1.2	5.7	1.1	5.8	1.1	6.6	0.7	5.9	0.7	6.3	1.0
2. Conceptual understanding of interplay of social, technical, political factors	5.3	1.5	4.9	1.4	6.1	0.9	5.7	0.4	5.8	0.8	6.6	0.8
3. Understanding of different stakeholder perspectives	5.2	0.9	5.1	1.3	6.3	0.6	5.6	0.4	5.6	0.8	6.3	0.5
4. Application of quantitative modeling methods	5.9	0.8	6.0	1.1	5.4	1.2	6.7	0.7	6.5	0.7	5.8	1.0
5. Analysis of results and understanding implications, limitations	5.3	1.1	5.4	1.6	5.4	0.7	5.6	0.9	5.4	1.1	6.4	0.8
6. Teamwork	5.4	1.2	5.9	1.1	6.0	1.0	6.0	2.9	7.0	3.8	6.7	3.4
7. Oral communication	5.8	0.9	5.5	0.8	5.6	0.6	6.1	1.0	5.9	0.2	5.8	1.0

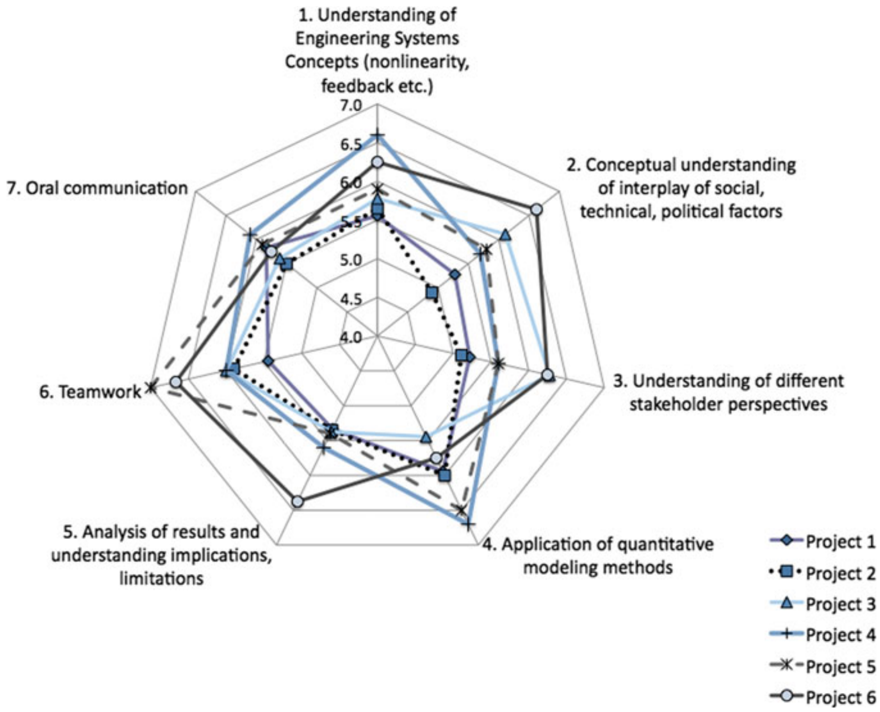

Fig. 7 Project evaluations

Summary

The Engineering Systems Division at MIT, in building up from its advances in graduate-level teaching and research, is now making efforts towards unique additions to the undergraduate engineering curricula. ESD.00 represents an initial attempt into defining and establishing a new set of topics that have largely been absent at the undergraduate level.

Lessons Learnt

Based on student reviews of the first completed class (of 2011) and the instructors' experiences, this effort has taken off on a strong footing. The overall experience has been encouraging. Perhaps a key indicator of success was the fact that some students were drawn into the problems they worked on in class to the extent that a few expressed desire in continuing work on their project after the conclusion of the course. They were interested in subsequent undergraduate research experience and wanted to pursue actual implementation. Since a main motivation in creating this course was to enable undergraduates to engage with real, complex socio-technical problems, this outcome of continued student interest was greatly encouraging. A related factor regarding the student enthusiasm was the reality and relevance of the problems. Ranging from nuclear waste disposal (where the project leader is engaged with actual policy makers and shapers on the issue), to the stroke care chain project (where the researchers are working with practitioners on the issue and so on, the projects connect the students to actual, on-going problems. The students show great motivation and excitement to work on such projects (rather than on hypothetical scenarios and issues).

At a structural and organizational level, a mix of different class-years in the student teams (e.g. a mix of freshmen and sophomores) worked well. It allowed and enriched a collaborative learning experience for the students. Furthermore, the varied background of the students (with majors spanning mechanical engineering, biological engineering, civil and environmental engineering, chemical engineering, mathematics and biology) provided a unique opportunity to students to participate in a multi-disciplinary forum—something that is not typically available to undergraduates within engineering classes.

A key issue, pertinent to replicating this class model, is its scalability. A large degree of success at MIT has been dependent on active participation of engineering systems PhD students and multiple faculty members who are engaged in research on contemporary problems. At institutions where a large research base may not exist, this model will be difficult to replicate. Even within ESD at MIT, there can be challenges towards sustaining this model for large class sizes. Another issue—which we hope to resolve over time—is to expand the supplementary reading material that touches upon topics and concepts of engineering systems, systems architecture, performance, evaluation, modeling methodologies etc. While a rich body of literature (books and teaching notes) exist—the majority cater to graduate-level studies. A long-term goal is to create suitable instruction and reading material for engineering students at the undergraduate level.

Future Directions

In the future, our vision is to offer a suite of courses that collectively offer undergraduates the opportunity to learn—and to a modest degree specialize—in the methodologies that allow for analyzing and designing complex, large-scale, engineering systems. For a new generation of engineers, that needs to address the *grand challenges* [12] of its times, augmenting the skill-set knowledge with tools for modeling complexity, interdependency, emergent behavior, and trading off technical as well as environmental, social and regulatory constraints will be greatly beneficial. Our hope is that this course, and others motivated by this broader vision, will serve to provide this opportunity to our future engineers.

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Part V
Modeling and Simulation

Infranomics Simulation: Supporting System of Systems Understanding by Gaming

Andreas Tolk

Abstract This contribution evaluates serious gaming as a mean to better educate decision makers that have to manage system of systems. Systems of systems are understood to be operationally and managerially independent, geographically distributed, are developed evolutionary, and show emergence. Each infrastructure is constrained by the principles of infranomics, embracing the totality of the technical components, stakeholders, mindframes, legal constraints, etc. In simulation, the agent-based paradigm has been identified to support systems that can best support such an environment for a game.

Keywords Agent based paradigm · Decision support systems · Infranomics · Serious gaming · Simulation · System of systems

Introduction

Learning to make better decisions in complicated, complex, or agile environments is difficult. In many domains, learning on the job is not possible, as bad decisions are connected with severe consequences. The idea to use games to train decision makers is a logical consequence [5]. Driven by the defense industry, Serous Games are used in many domains to enable better decision-making. Nevertheless, the use of such approaches in systems engineering and engineering management is not very well established.

Moreover, there are exceptions. Professor Frederic Vester (1935–2003) was an environmental entrepreneur long time before environmental concerns became ubiquitous. He introduced the idea of interconnected thinking to European

A. Tolk (✉)
Department of Engineering Management and Systems Engineering, Old Dominion University, Kaufman Hall, Room K241E, Norfolk, VA 23529, USA
e-mail: atolk@odu.edu

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decision makers: the idea, that in a system all components are interrelated, and that this relations are often not linear. To make people aware of what this means for decision makers, he developed the game "Ökolopoly" around 1978. The game first was designed as a board game, published by the Otto Maier Verlag, Ravensburg, Germany, followed by various computer game adaptions, often used in schools. Today, the current version is distributed under the name "Ecopolicy" and is still used for education purposes in Europe.

The idea behind the game is to control a country by using your action points to influence domains. You can add action points to the domains of production, quality of life, cleanups, und education. These domains are interconnected with the additional domains environmental effects, population, reproduction rate, and policy. All the domains are interconnected finite automata. Once the action points are distributed, the new states of all domains are calculated and new action points are computed as well.

All rules and connections are pretty obvious and more or less self-explaining, such as that cleanups reduce negative environmental effects or that negative environmental effects decrease the quality of life. However, even with such a limited number of finite automata interrelated by non-linear control cycles players easily lose oversight and therefore control and cannot avoid that their economy collapses, as they underestimated the negative effects of their actions or overestimated the regularly power of positive effects. After several rounds, players usually understood the dynamics of this game enough to avoid crashes and make better decisions. Vester [10] is a collection of related ideas in English, although most of Vester's work is published in German.

Serious Gaming for System of Systems and Infranomics

The observation described in the introduction motivates the idea to use gaming for system of system thinking and understanding in general and infranomics in particular.

Although the term *system of systems* has no widely accepted definition, Maier [3] notes that the notion itself is widespread and generally recognized. The following distinguishing characteristics have been proposed [3, 6]:

- *Operational Independence*: A system of systems is composed of systems that are independent and useful in their own right. If a system of systems is disassembled into the component systems, these component systems are capable of independently performing useful operations independently of one another.
- *Managerial Independence*: The component systems not only can operate independently, they generally do operate independently to achieve an intended purpose. The component systems are generally individually acquired and integrated and they maintain a continuing operational existence that is independent of the system of systems.

- *Geographic Distribution*: Geographic dispersion of component systems is often large. Often, these systems can readily exchange only information and knowledge with one another, and not substantial quantities of physical mass or energy.
- *Emergent Behavior*: The system of systems performs functions and carries out purposes that do not reside in any component system. These behaviors are emergent properties of the entire system of systems and not the behavior of any component system. The principal purposes supporting engineering of these systems are fulfilled by these emergent behaviors.
- *Evolutionary Development*: A system of systems is never fully formed or complete. Development of these systems is evolutionary over time and with structure, function and purpose added, removed, and modified as experience with the system grows and evolves over time.

When a decision maker works in an environment characterized by these attributes, many of the usual means are not applicable or may fail. It is pivotal to understand that operational and managerial independence require to work with establishing common objective and constraints instead of directly influencing the system specific decision processes, e.g., by giving orders or rules. The geographic distribution may result in longer times before effects can be observed. Emergent behavior is another factor that is not part of the usual and expected feedback for decision makers, as emergence results in behavior outside of the expected and designed system results. Finally, the fact that systems evolve adds another level of complexity for the decision maker.

For a decision maker, a system of systems is worse than a black box: it is a collection of interrelated black boxes, each of those following their own rules and regulations, governed by decision makers with their own agendas and objectives. What makes it even more complicated is the fact that these systems of systems are embedded in a multitude of tangible and intangible value systems that do not even have to be correlated. You can make the same request to two systems, and based on their managerial independence they will react differently. Actions and reactions will be time delayed; emergence will contribute to blur effects and effect of effects into observable system states. While the tool set the decision maker learned from academia works well in systems, this hostile environment breaks such tools easily. New methods are needed, or at least a better understanding of this environment.

To make things worse, the mostly technology driven world-view is no longer sufficient to address the new challenges the decision maker is faced with. In order to address these new challenges better, Gheorghe and Masera [2] identified infranomics as a crucial discipline for this century.

- *Infranomics*: the body of disciplines supporting the analysis and decision-making regarding the metasystem. The metasystem is defined by the totality of the technical components, stakeholders, mindframes, legal constraints, etc., composing the set of infrastructures. It is the set of theories, assumptions, models, methods, and associated scientific and technical tools required for studying the conception, design, development, implementation, operation, administration, maintenance, service supply, and resilience of the metasystem.

As such, Infranomics will be the discipline-of-disciplines grouping all needed knowledge.

While interconnected systems address one system, the system of systems idea extends these ideas into an infrastructure that connects several of those systems to provide for a new common objective without touching their operational and managerial independence. Infranomics provides the framework of ideas to cope with challenges if several of these infrastructures need to be addressed in a common objective as well. Examples are the national critical infrastructures that provide the backbone of each nation's economy, security and health. Each component is already by itself a system of system, such as the transportation infrastructure, or the electric power infrastructure. In addition, they are interrelated, as the electric power infrastructure needs a working transportation infrastructure to provide the necessary fuels, etc. Vice versa, the transportation infrastructure needs electricity for their traffic lights and more complex control means. The information infrastructure emerged as the common component of many infrastructures, as all of them require some form of information processing support, be it for health records, financial transaction, or operationally relevant information needed to support decisions.

Nevertheless, how can games help to support gaining a better understanding? Games are usually associated with entertainment. However, as Smith [7] points out, most games are built on competition. The players are trying to achieve their objective within the context of the game. In earlier games, several players were needed, but with the rise of computers and artificial intelligence, which includes the sub-domain of heuristic optimization and implementation of decision making algorithms, in particular in computer or video games the player can play without any partners involved. Zyda [12] introduced a series of definitions leading to the term serious game as follows:

- *Game*: a physical or mental contest, played according to specific rules, with the goal of amusing or rewarding the participant.
- *Video game*: a mental contest, played with a computer according to certain rules for amusement, recreation, or winning a stake.
- *Serious game*: a mental contest, played with a computer in accordance with specific rules that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives.

Serious games have been developed on game consoles, gaming PCs, portable handhelds, and cellular phones. Recently, hybrid devices that combine games with other devices are gaining popularity as well. According the Smith [7], the reason why serious games became quite successful in particular for training is that they support active, realistic and engaged learning environments. Training conducted with a serious game is not only engaging and accurate; it also provides variability, measurability, and repeatability. In particular, digital natives are very comfortable with the idea to train in virtual worlds for real world challenges.

Besides training, decision-making support is another application domain of serious games. As stated by van Dam [9]: "*If a picture is worth a 1000 words, a moving picture is worth a 1000 static ones, and a truly interactive, user-controlled dynamic picture is worth 1000 ones that you watch passively*." This observation makes simulation in general and serious games in particular very interesting for managers and decision makers. Tolk [8] introduced the definition of decision support simulation systems that can easily be adapted to serious gaming applications:

- *Decision Support Simulation Systems*: simulation systems supporting operational (business and organizational) decision-making activities of a human decision maker by means of modeling and simulation. They use decision support system means to obtain, display and evaluate operationally relevant data in agile contexts by executing models using operational data exploiting the full potential of M&S and producing numerical insight into the behavior of complex systems.

The highly agile, complex, and non-linear context of infranomics and system of systems is therefore an ideal realm for the use of serious gaming for training and decision support simulation systems.

Using Agents to Provide Training and Decision Support for System of Systems and Infranomics

Among the different simulation paradigms used to develop serious games, the agent paradigm showed a significant growth and richness of applicability [11]. Agents have been defined to be situated, it perceives its environment, and it acts in its environment. It communicates with other agents for collaboration or completion, e.g., it shows social ability. Agents are autonomous; they act free without the need for interaction following their internally coded value system. Agents mediate between reactive behavior, being able to react to changes in its environment, and deliberativeness to pursue its goals. Agents also learn from their experience and often are mobile.

These characteristics make agents particularly interesting for infranomics and system of systems. Márquez et al. [4] show the need to support a variety of value systems in the agent population in order to support the analysis of complex social systems. This variety is not implemented by agents representing different value system, but each agent follows a multi-dimensional value system that reflects that the same agent can be driven be different motivations, that may be correlated, independent, or even contradicting. An agent can, e.g., represent a Christian scientist who believes in a Creator but also tries to understand and contribute to the scientific explanations of his area of expertise.

This kind of multi-dimensionality is needed for system of systems and infranomics as well: the operational independency is supported by individual agents representing the building systems. Other systems or agents can request services, but it is in the decision space of the representing agent if and how to react to such a request. The internal rules that are followed in this process represent the managerial independence. Each agent maximizes his objectives. As agents are social, they can be mutual supportive or competitive in their best effort to reach their goals. The distribution of agents also supports the geographic distribution of systems of systems. Their ability to adapt their rules and learn supports the evolutionary development. Finally, emergent behavior is understood as one of the must distinguishing characteristics of agent simulation approaches since Axelrod's work on the complexity of cooperation [1].

These agents, representing the system of systems, are situated within the set of infrastructures defined by infranomics: the totality of the technical components, stakeholders, mindframe, legal constraints, etc. Each infrastructure establishes at least one-value systems, so that the set of infrastructures results in the multi-dimensional approach envisioned by Márquez et al. [4]. These value systems are furthermore defined by a set of theories, assumptions, models, methods, and associated scientific and technical tools. They can furthermore be modified based on the phase of study: conception, design, development, implementation, operation, administration, maintenance, service supply, and resilience evaluations.

Like the decision maker in Vester's ecopolicy games, the manager who needs to be trained to better understand the constraints and potentials of system of systems and infranomics can now slip into the role of the controller in charge. However, his decisions are going to trigger a far more complex chain of reactions in the agent-based implementation of system of systems.

In this agent-based serious game, however, the manager is not only confronted with a set of interconnected nonlinear effects, but each system will make its own decisions regarding the requests, based on operational and managerial independence. There are also spatio-temporal considerations to be taken into account, as the systems are geographically distributed and evolve over time. Furthermore, emerging effects can influence the reaction that is furthermore defined by the current phase and infrastructure, defined in the realm of infranomics.

Conclusion

The use of serious games to train managers and provide them with decision support has already a long history in domains such as defense and healthcare. Agent-based technology can help to provide a realistic, yet measureable and repeatable virtual environment for system of systems and infranomics. Such an environment can be used effectively to provide high-level decision makers with tools to better understand the constraints and potentials of this new reality of agile, complex, and non-linear decision spaces as defined in current situations.

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Speeding Up Energy Transitions: Gaming Towards Sustainability in the Dutch Built Environment

Iman Mohammed and Erik Pruyt

Abstract The built environment accounts for a significant proportion of energy consumption in the Netherlands and elsewhere. It is estimated to be responsible for 33 % of national greenhouse gas emissions. This substantial proportion makes it an essential sector to address in the sustainable transitions agenda. In the Netherlands, it is apparent that the energy transition of the built environment with the current policies is much slower than required given the urgency of the foreseeable problems and the substantive system delays. Hence, there seems to be a need for experimentation with innovative policy instruments, governance mechanisms, and systemic conditions to fill the gaps in understanding. In this context, this chapter explores the use of games for understanding why there is so much inertia in the transition process. To arrive at some conclusions the authors develop a System Dynamics Model-Based experimental game, for hypothesis-testing purposes. Results of the game are provided and the chapter concludes with exploring possible future research.

Keywords Simulation game · Energy transition · Built environment · Inertia · Learning effect · Model-based gaming · Hypothesis-testing

Introduction

Transition and Inertia

The Dutch energy system needs to become sustainable over the next 10–50 years in order to dramatically reduce its climate change impact and to be able to deal with foreseeable energy supply problems. However, energy systems and societies

I. Mohammed (✉) · E. Pruyt
Policy and Management, Delft University of Technology, 5015 2600 GA, Delft, The Netherlands
e-mail: I.S.Mohammed@tudelft.nl

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are examples of large-scale socio-technical systems (STS) that generally change slowly and gradually—typically with time horizons of 50–100 years—and not necessarily in the desired direction, even if many actors see the urgency of system changes. This phenomenon is also reflected in the current state of the Dutch energy transition. The ranges of possible sources of clean energy are plenty and concepts for a successful transition are available or are currently under development. In the residential sector alone, many technologies already exist that are proven, available and affordable. Yet, the adoption of these concepts are much slower than required given the urgency of the foreseeable problems and the substantive system delays. Hence the system is characterized by high inertia.

The literature on the causes of inertia is fragmented and dispersed. There seems to be gaps in knowledge and understanding that cannot be closed with traditional approaches. Although plausible causes of inertia have been recognized, it is still not fully understood what inherently holds back real energy system actors, how their individual actions cause inertia and slows down energy transitions towards sustainability, and what may actually speed up energy transitions. In view of this, we have developed an integrative conceptual framework, which combines the explanations giving in transition and urban sustainability literature [1–5, Rogers 2003], on the possible key barriers to the diffusion of innovations in the built environment as illustrated in Fig. 1. Distinguishing between different barriers to the diffusion of innovations is important for designing appropriate policies for coping with the inertia. In this research, we classified the barriers to the realization of significant energy and emission saving potential into four main categories based on the major categories observed by the European Alliance of Companies for Energy Efficiency in Buildings (EuroACE): Market and information barriers, political and institutional barriers, technological barriers and behavioural barriers.

Barriers to the Diffusion of Innovations in the Built Environment

Economic and Information Barriers

The Economic barriers refer to all those barriers that are financial (i.e., stem from the market environment such as the costs of energy, low access to capital by home owners and high initial costs of the energy efficient innovations) as shown in Fig. 1. The information barriers refer to those barriers that are inherent due to a lack of, or exchange of, information such as that associated with asymmetric information and knowledge on sustainable buildings.

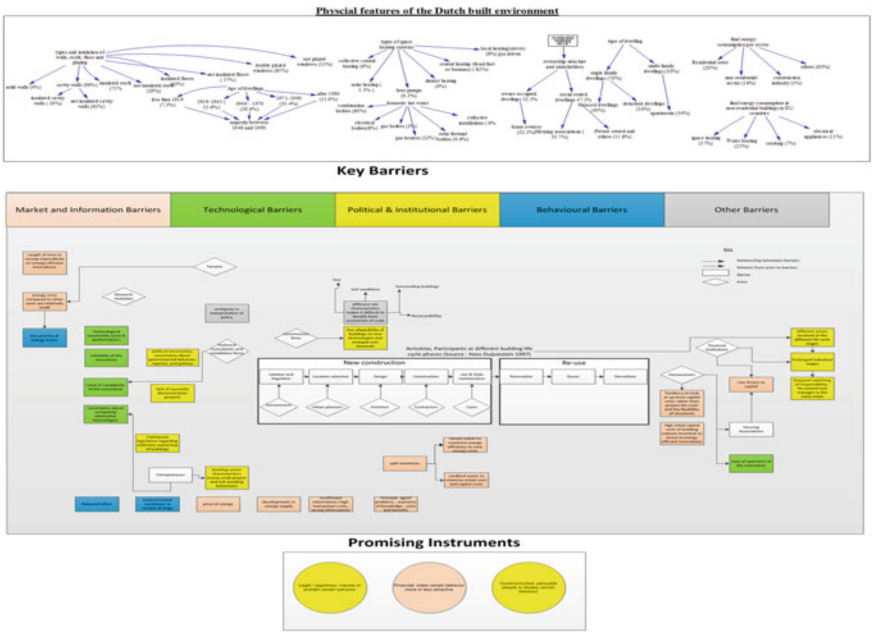

Fig. 1 Conceptual framework, outlining the physical environment, key barriers and policy instruments in the diffusion of innovations in the built environment

Technological Barriers

These forms of barriers refer to those that are specific to the energy efficient technology itself, for example, technological uncertainty in terms of costs and performance. In addition, the ease of process integration of the new technology and the lack of proven innovation effectiveness all serve as impediments to the adoption of those particular technologies.

Political and Institutional Barriers

Political barriers refer to those barriers relating to government and its conduct. Institutional barriers on the other hand, consist of formal, planned institutions such as (state) organizations and regulations, and, more informal evolved institutions characterized by ground rules: institutions act as interaction patterns that structure, but do not determine behavior, and they define the space within which actors act, select problems and solutions, and set priorities [6]. Some examples of political barriers related to the diffusion of innovations include political uncertainty (uncertainty about governmental behaviour, regimes, and policies) and ambiguity in interpretation of current policy (see Fig. 1). With regards to institutional barriers a typical example is related to the overall characteristics of the building sector—which generally comprises many small players and risk avoiding behaviour [4], resulting in a sector resistant to change, innovation and to government interventions (including voluntary policy instruments for the promotion of change).

Behavioral Barriers

Behavioural barriers are sometimes referred to as 'social barriers' because they are comprised of society's attitudes and beliefs which then act as barriers to action (Reed and Wilkinson [23]). For example, one particular group of barriers revolves around a lack of knowledge or understanding of issues. An example is the rebound effect; this effect in this context refers to the situation where a measure aimed at reducing environmental impact induces a behavioural response (or any other systematic response) that actually offsets the intended effect of the measure in question [4]. It happens that sometimes, interventions aimed to support sustainability have undesirable effects. Well-known examples of how technological innovation aimed to save energy backfired include the standby feature of home appliances. Instead of turning off the appliances, people leave the appliances running on stand-by mode [4], thus using more instead of less energy, our perspective is that user-convenience, in itself, may be problematic in this context.

Model Based Gaming

Figure 1 also illustrates the conceptual model of key components of the physical and social characteristics of the Dutch built environment. Essentially, the model depicts the complexities (multiple dimensions and multiple actors involved at different life cycle phases of buildings) as well as the uncertainties (technological, market & political uncertainty) which act as barriers to the diffusion of innovations in this environment. One of these barriers is the focus of this chapter. Namely the market and information barriers with regards to the lack of understanding (information) of key actors and the tendency for potential adopters to look at up-front initial capital costs rather than project life costs. This chapter makes use of a system dynamics model- based simulation game to test one of many hypotheses of this highly complex setting.

It is challenging to make appropriate policies/decisions for issues that are particularly characterised by complexity, uncertainty and multiple stakeholders without using some form of simulation model that allows for an illustration of the dynamics of the system of interest and allows for the assessment of the long term effects of specific interventions. However, traditional quantitative models generally assume that decision makers are rational agents or make optimal decision routines, based on traditional economic assumptions. Model-based simulation games provide a means to challenge these assertions as it provides an environment where the decisions of actors are directly imputed into the model.

Furthermore, decision makers and individuals in general tend to be mostly reluctant when it comes to making policies/decisions when facing deeply uncertain dynamic issues, such as climate change, adoption of unfamiliar energy innovations etc., despite the professional advice of experts or scientists. There seems to be a need to go beyond knowing, but also feeling that a particular policy/decision is the appropriate one. As noted by [7]. Our opinion is that the complicated and anomalous explanations for inertia in energy transitions suggest that it would be futile to attempt to explain it solely through economic rational actor models and implementing economically rational policies.

The added value of simulation games in this context is in multiple ways: (1) it may allow for real experimentation with policy instruments, governance mechanisms, and systemic conditions (e.g. competition between innovative technologies, interaction between different actors, deep uncertainties and lack of information etc.) before real-world policy implementation, hence, assisting policy makers in responsible decision making (2) improvement and validation of decision making agents and decision routines in quantitative transition models, and (3) accelerated experiential learning by real system actors. In light of these possibilities, we aim to develop and use several model-based system games, ranging from simple flight simulators to multi-actor systems games for multiple purposes, in order to understand what the causes of inertia and what policies could be used to speed up the transitions in the built environment.

In this chapter, we explore how we can use simulation games in an experimental fashion to test for some hypothesis, as derived from our conceptual model with a focus on the market barriers to the diffusion of innovations in the built environment. Our case study focuses on energy used to supply domestic hot water and evaluates the extent to which market and information barriers, such as a lack of understanding of basic dynamic systems, as represented by learning curves of domestic energy technologies (Micro—CHP and high efficiency boilers) in the residential sector as well as the extent to which the initial costs of these technologies have an impact on decision-making.

Section Methodology introduces the system dynamics (SD) model—supported interactive game and illustrates the use of the model-based game (MBG) for testing hypothesis related to inertia in transitions in the built environment. In section Results and Discussion we present the results of the game and discuss possible reasons for the performance of the participants. As our results did not find many significant performance differences, the conclusions section (Concluding Remarks and Future Steps) focuses on future research.

Methodology

Introduction

Simulation games server several purposes. Through a review of simulation game literature [8–13], we derive some of the common uses/types of simulation games:

1. Experimental games
2. Learning Games
3. Training Games
4. Validation Games
5. Evaluation Games
6. Fun Games
7. Experiential Games.

This types of games listed above are by no means exhaustive, however, they point to some interesting uses of games that may be useful for facilitating decision-making. In this study, we make use of model based experimental game to test for hypothesis related to the lack of understanding of learning effects. Experimental games may be a useful approach as its benefits are twofold, first, by providing a much needed safe setting for participants to experiment and second, the possibility for analysts to make use of the results of the game for testing relevant hypotheses.

Illustration/Case: Learning Curves in Dynamic Systems

The challenges faced with decision making under complexity in dynamic systems have been researched by a number of authors [14–21]. Learning curves, one of these complex dynamics, have been identified in a range of industries their strategic implications have also been extensively explored. Learning curve research indicates that as cumulative production increases, unit costs decreases due to cumulative firm experience (Dutton and Thomas 1984). In simple terms, it expresses the relationship between production experience over time and unit costs of a good or service. These resulting learning effects have an effect in dynamic systems, where their impact is associated with delays, nonlinearities and feedbacks. Such systems are usually quite complex, and research has shown poor decision making in these settings. A number of articles [1–4, Itard and Meijer 2009] have emphasized the negative impact of high costs on the market diffusion of novel and efficient energy technologies, however few have explored the possibility of a lack of understanding of these dynamics as a key barrier to the market diffusion/adoption of energy innovations.

Here we address this knowledge gap by making use of the system dynamics (SD) model—supported interactive game, called the ‘Learning Effect Sim’. We randomly selected two domestic heating boilers in the residential sector (Micro-CHP and High Efficiency boilers), which provide substantial energy savings and are at different phases of the market diffusion and technological life cycle phases of development; thereby making it easier to distinguish between the learning curves of both technologies.

Hypotheses

The main purpose of this experimental game was three fold: (1) To test whether there will be a difference in responses between learners who received both textual and graphical information about learning effects on the interface as compared to those who received only textual information (2) test whether highly educated people faced with graphical dyamic effects, can successfully interpret these graphs and (3) test whether people show better performance after having made a model about the learning curve (specific modelling experience).

Method and Materials

The experiment made use of an online, web based system dynamics simulation (constructed on http://www.forio.com). 131 participants from the Bachelor of Science courses of the Faculty of Technology Policy and Management of Delft University of Technology took part in the experiment. The students were divided into two groups, the treatment group and the control group.

Experimental Design

The whole experiment was conducted in three versions. In the first version of the interface, the research participants were assigned randomly to one of two experimental conditions (one with graphical and textual inputs) and the other without the graphical input. After reading this information players proceeded to the actual simulation page where they could actually adjust sliders for the main input variable of the model (desired fraction of gas boilers), based on the required amount of boilers to be installed and see the effects in the form of graphs on the sales price/ unit cost of both boilers (gas (high efficiency) boilers and solar (micro-CHP) boilers.

Figures 2, 3, and 4 shows that performance in the first version of the game was poor. Performance was improved using information provided in our interface as well as the underlying model itself which led to the creation of version 2 of the game.

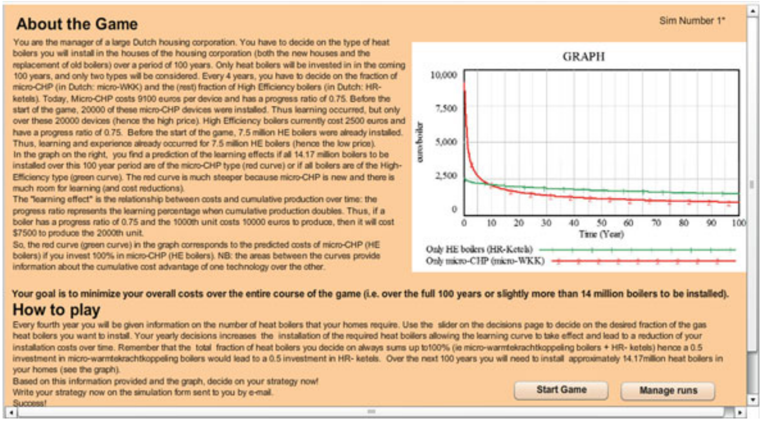

Fig. 2 Interface of the learning effect simulation (version 2, instructions page) decisions page

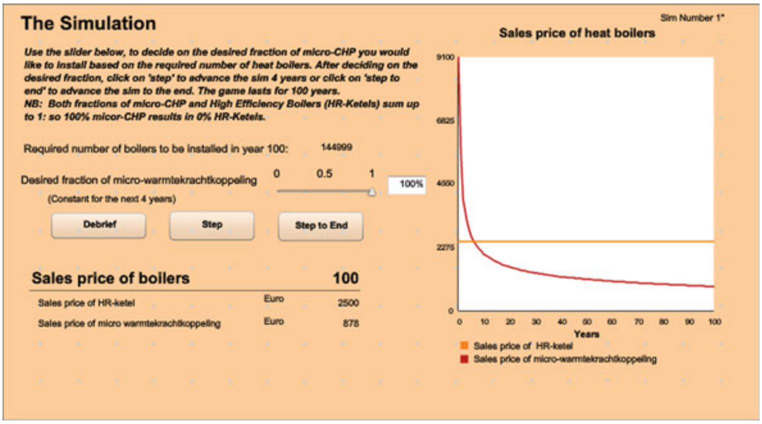

Fig. 3 Interface of the learning effect simulation (version 2, treatment)

Version 2

In the second version of the learning effect simulation, there were a number of changes made to the previous version mainly with respect to information provided on the interface: (1) We used different domestic boilers, Micro-CHP and High efficiency boilers (2) Version 2 provided information that learning and experience had already occurred on the previous boilers installed (3) In version 2 there was an explanation of the steepness of the learning curves. Micro-CHP boilers was said to have a steeper curve because it was newer and hence there was much more room for learning and hence cost reducing (this gave some suggestion into which investment would have higher net gains) (4). In this version it was explicitly

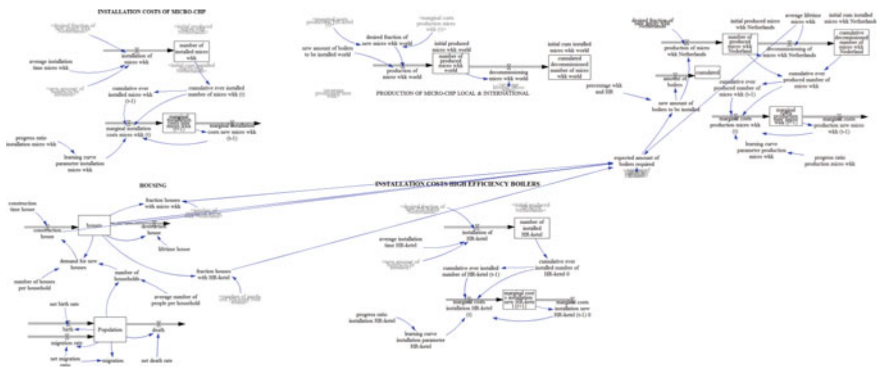

Fig. 4 Full stock and flow diagram underlying the learning effect simulation interface

explained that the area between the curves provided information about the cumulative cost advantage of Micro- CHP boilers over high efficiency boilers, a quick look at the graph would have shown that there was more cost advantage in the Micro-CHP boiler over the high efficiency boiler. Though results here were still disappointing they were slightly better than version 1.

Multiple Choice Examination Question

In order to test for learning outcomes and ensure that participants were obliged to make the best decisions as they possibly could, we made use of an objective multiple-choice examination question at the end of the course as Table 1 shows. Those multiple choice questions tested understanding of the model (e.g. the main cause-effect relationships), provided perfect information on learning effects, provided full control over learning effects (no global effects) and specified that there was no discounting required. This ensured that players could make the best decision possible without worrying other factors coming into play.

The Benchmark

An optimal solution is intuitively simple given that we have provided players with the definition and effects of learning over time on the unit costs of the two technologies; additionally, we provided them with graphical evidence of the learning effects of both innovations over time. The graph shows that though one technology (in version 1 solar boilers, in version 2 Micro-CHP boilers) has a higher initial value than the other (in version 1, gas heat boilers, in version 2 high efficiency boilers) an increase in its cumulative installation over time reduces its unit costs to

Table 1 Multiple choice question

As manager of a large Dutch housing corporation, you must decide on the types of boilers that will be installed by the housing corporation in the next 100 years. Suppose you can only choose from two types of boilers: HE-boilers or micro-CHP installations. Micro-CHP installations are still very expensive to buy, e9100 per unit (one unit corresponds to one boiler), but recent cost reductions have been spectacular. Experience with micro-CHP so far, 20,000 micro-CHP units in total, shows that the 'progress ratio' equals 0.75. HE-boilers nowadays only cost e2500 because of years of experience (equivalent to 7.5 million installed HE-boilers), and are characterized by a 'progress ratio' of 0.75 too.

The graph below shows a perfect prediction of the cost reduction of both types of boilers if all 14 million boilers to be installed in the next 100 years by your housing corporation are either of the micro-CHP type (red curve) or of the HE-boiler type (green curve). The red curve is much steeper because micro-CHP is new and there is still much room for descending the learning (hence the marginal cost) curve.

The 'learning curve effect' is the relationship between production costs and the cumulative production over time: the *progress ratio* provides insight into the cost reduction for each doubling of cumulative production. So, if a boiler has a progress ratio of 75 % and it costs e10000 to produce the 1,000th unit, then it will cost 7500 Euros to produce the 2,000th unit.

The red curve (or green curve) in the graph is thus the perfectly predicted production cost per micro-CHP device (or boiler) if you install 100 % in micro-CHP (or HE-boilers) the next 100 years. Note: the surfaces between the curves provide insight into the cumulative cost advantages of one technology over another.

Suppose that you are the only one installing boilers (hence, the destiny of your housing corporation is fully under control), and the future is perfectly predictable (no surprises, perfect foresight), and discounting is not required (e1 now is worth as much as e1 in 100 years and at any time in between), which of the following strategies minimizes the total investment costs over the full 100 years (or 14 million boilers)?

(a) 100 % in HE-boilers: HE-boilers are cheaper and will always be cheaper.

(b) 100 % in micro-CHP: the surface area to the right of the intersection point is much larger than the surface area to the left.

(c) 100 % HE-boilers for the first 10 years and 100 % micro-CHP afterwards in order to take advantage of the lowest cost over the full 100 years.

(d) not 100 % in HE-boilers nor 100 % in micro-CHP, but somewhere in between (which could be calculated), in order to fully profit from the evolution of both technologies.

values below that of gas heat boilers. More importantly the area between the two graph curves reveal that there is more cost advantage in investing in solars (Micro-CHP) boilers than gas (high efficiency) boilers.

Procedures

The participants themselves were introduced to the interface during the lecture and encouraged to participate in the simulation. Participants could log in for the study and, based on their user names, were randomly directed to one of two web URLs, one of which pointed to test game (with graphical information) and the other to the control game (without information) of the program. Participants were only allowed to play the game once. Data was automatically stored to a secure web server. After 2 weeks, a debriefing of the results occurred via email.

Results and Discussion

Hypothesis 1

Our first hypothesis was the following: (1) to test whether there will be a difference in responses between learners who received both textual and graphical information about learning effects on the interface as compared to those who received only textual information. The statistical test revealed that there was no significant difference between the participants given the graphical information on the interface and those only giving textual information. Somewhat disappointedly, the overall performance on the game with graphical information in both versions of the game was only marginally better than the game without information (version 1) 12 % better and version 2: 6 % better) as Table 2 shows. Because the tests were not significant, we cannot make any firm conclusions that participants performed better or worse across the game types. However it is interesting to consider the possible reasons for the poor performance.

In this case, motivation may play a significant role, participants were not rewarded for their efforts played in the game and hence may have lacked the necessary motivation or time to carefully read and understand the information before proceeding to make a decision. This rationale is supported by the higher performance score in the exam where participants were obliged to put in their best and carefully read and understand all information.

Hypothesis 2

The next hypothesis question was to test whether highly educated people faced with graphical dynamic effects, can successfully interpret these graphs. In order to test for this hypothesis, we added a multiple choice question based on the ‘learning effect sim’ to the examination (to ensure full effort). Table 4 shows the overall results with significant improvement in the performance as illustrated by a Wilcoxon signed rank test—comparing the game score to the exam score on a person to person basis. The test showed that there was indeed a statistically

Table 2 Results from a cross tabulation concerning percentage-wise differences between control and treatment game

	Version 1 (% of correct answers)	Version 2 (% of correct answers)
Treatment group (with graphical information)	17 % (rounded off to one decimal place)	27 % (rounded off to one decimal place)
Control group (without information)	11 % (rounded off to one decimal place)	15 % (rounded off to one decimal place)

Table 3 Results from a cross tabulation of the game performance in relation to the exam performance

Game Score * Exam_answer Crosstabulation

			Exam_answer		Total
			Incorrect	Correct	
Game score	Incorrect	Count	62	44	106
		% within game score	58.5 %	41.5 %	100.0 %
		% within Exam_answer	84.9 %	75.9 %	80.9 %
		% of Total	47.3 %	33.6 %	80.9 %
	Correct	Count	11	14	25
		% within game score	44.0 %	56.0 %	100.0 %
		% within Exam_answer	15.1 %	24.1 %	19.1 %
		% of total	8.4 %	10.7 %	19.1 %
Total		Count	73	58	131
		% within game score	55.7 %	44.3 %	100.0 %
		% within Exam_answer	100.0 %	100.0 %	100.0 %
		% of total	55.7 %	44.3 %	100.0 %

NB This table matches the number of people whom had played the correct and incorrect strategy in the game against the exam answers (correct/Incorrect). Here we used the percentage of total row for our analysis

significant increase in the number of correct answers at the phase of the exam as compared to the game ($p < 0.001$ with a medium effect size ($r = 0.27$)). Confirming that under exam Pressure/conditions students generally pay more attention to case descriptions and choices than in other conditions (learning environments included). Regardless of the better performances in the exam compared to the game, the overall results in the exam were still low optimal as seen in Table 3 (56 % incorrect and 44 % correct). This may indicate that even with a high level of education people faced with graphical dynamic effects still find it difficult to interpret such graphs.

Hypothesis 3

To test whether people show better performance after having made a model about the learning curve (specific modelling experience) we developed a cross tabulation matching modelling experience against game performance. The results were surprising and counter intuitive. For instance, it appears that those with experience in modelling learning curve still performed poorly in the game phase (78 %). About 22 % had it correct, whereas of those that had no modelling experience, 73 % performed poorly in the game and 26 % played the correct strategy as Table 5 shows. This means that about 5 % more participants performed better without

Table 4 Results form a Wilcoxon signed rank test—to compare the game score to exam score

	N	Percentiles		
		25th	50th (Median)	75th
Descriptive statistics				
Game score	131	0.00	0.00	0.00
Exam answer	131	0.00	0.00	1.00
Test statistics[b]	Exam_answer—Game score			
Z	−4,450[a]			
Asymp. Sig. (2-tailed)	0.000			

[a] Based on negative ranks
[b] Wilcoxon Signed Ranks Test

Table 5 Comparison of game performance and learning curve modelling experience in modelling learning effects

Game score * Model_Experience crosstabulation

			Model_Experience		Total
			No	Yes	
Game score	Incorrect	Count	41	11	52
		% within Model_Experience	73.2 %	78.6 %	74.3 %
		% of Total	58.6 %	15.7 %	74.3 %
	Correct	Count	15	3	18
		% within Model_Experience	26.8 %	21.4 %	25.7 %
		% of Total	21.4 %	4.3 %	25.7 %
Total		Count	56	14	70
		% within Model_Experience	100.0 %	100.0 %	100.0 %
		% of Total	80.0 %	20.0 %	100.0 %

NB This table matches the number of people whom had played the correct and incorrect strategy in the game against the modelling experience of the participants (‘yes’ means with experience and ‘no’ without experience). Here we used the percentage within model experience, as we want to know the score within this variable

prior experience modelling the learning curve than those with such experience. More research into these strange results is required for further analyses.

Given the overall performance of the participants across all the tests, there seems to be an urgent need for model-based decision support because people, when faced with (even simple) dynamic effects simply cannot make good estimations. Policy makers may perhaps need to be given the solutions to a problem (if possible) before they make decisions. Providing further assistance, for example [22] suggest the provision of a help navigation system or an animated pedagogical agent, which might have even greater impact than providing information like we did via information transparent interfaces.

Concluding Remarks and Future Steps

Although our results were not statistically significant, they were sufficient to suggest modifications to our methodology and research. Solutions may be provided to participants prior to the decision making phase and the learning environment may be incorporated into a serious examination environment for evaluation purposes. This experiment was part of a suite of simulation games to be carried out in phases. Our next goal with this experiment was to test for decisions under uncertainty and complexity; however in view of this results, as at the simplest level providing information about structural effects does not guarantee that learners perform better, it may not be wise to proceed to even more complex versions of the simulation, where uncertainty and other multi-player activities come in to play. We plan to further investigate more interactive strategies, which can help us to effectively test hypothesis related to inertia in the built environment.

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Boats and Bridges in the Sandbox: Using Role Play Simulation Exercises to Help Infrastructure Planners Prepare for the Risks and Uncertainties Associated with Climate Change

Todd Schenk

Abstract Climate change poses a range of threats to our various infrastructure systems. Among the myriad of hazards, increased precipitation and sea level rise may inundate transportation networks and heat waves may stress our electricity grids. These threats may require new ways of managing uncertainty and making decisions. Climate change adaptation planning is being proposed as an important part of infrastructure management and decision-making moving forward, but is not yet well developed or integrated as an area of practice. Various tools and approaches may be employed under the umbrella of effective adaptation—including scenario planning and multi-stakeholder decision-making—but they have not been fully embraced by stakeholders. Facilitating the uptake of new tools to effectively address nascent, complex and uncertain challenges by infrastructure-related institutions is no easy task. Role-play simulation exercises (RPS) offer one way in which we can explore issues and options with decision-makers and other stakeholders. These exercises provide safe spaces in which stakeholders that are not used to working together directly can interact and experiment with tools and approaches not traditionally employed. Simulations make it possible to zero in on the key issues while pushing those of less importance into the background.

Keywords Role-play simulation exercise · Serious game · Stakeholder engagement · Adaptation planning · Scenarios · Multi-stakeholder engagement

T. Schenk (✉)
Department of Urban Studies and Planning, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
e-mail: tschenk@mit.edu

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Introduction

The consequences of climate change—including sea level rise, more frequent and intense storms, higher temperatures and water shortages—pose a range of threats to our built environments, including key infrastructure [1–4]. Climate change adaptation planning has emerged as an area of practice and research, focused on helping planners and decision-makers better understand, prepare for, and respond to the risks and uncertainties associated with these threats [5, 6].

Efforts to address the risks and uncertainties posed by climate change, and advance sustainability in general, require working across traditional disciplinary, methodological and sectoral boundaries [7]. They require the effective integration of systems of knowledge and action [8–10]. They also require new ways of framing uncertainty and approaching complex and dynamic problems [11, 12]. Successful climate change adaptation requires cooperation and communication across traditional institutional boundaries, and effective means for making decisions in spite of significant uncertainty.

Actually achieving the necessary degree of collaboration and introducing new ways of managing risks presents substantial challenges. In the public sector, governance typically follows well-entrenched institutional norms, or patterns, that make systemic change and cooperation outside of established, discrete relationships difficult [13–18]. Politics and the tension between competing interests typically bound what is possible and highly influence the decisions made.

Institutional and political norms have evolved over time to more or less effectively manage persistent problems. However, environmental perturbations rife with uncertainty and complexity - like those associated with climate change—may go beyond what is possible under existing institutional arrangements. More flexibility and cooperation across boundaries is required. In addition, competing interests, jurisdictional jealousies, limits on professional expertise, and constraints on resource availability have to be overcome.

The problem is that changing governance paradigms to better account for dynamic and uncertain risks is no easy feat. It requires the collective realization that change is necessary, the identification and adoption of new and widely supported tools for framing uncertainty, and a commitment to take the results these new tools generate seriously in planning and decision-making. But where do we start? How do we explore this uncharted territory with decision-makers and other stakeholders? How do we experiment with possible tools and solutions that increase cooperation and help deal with uncertainty?

Role-play simulation exercises (RPS) offer one way in which we can explore issues and options with decision-makers and other stakeholders. *This chapter focuses on the use of RPS as tools for exploring complex issues like climate change in the context of multi-stakeholder decision-making environments, like those associated with the construction and management of major infrastructure*. The proposition is that these exercises provide safe spaces in which stakeholders that are not used to working together directly can interact and experiment with tools and approaches not traditionally employed. The fact that the simulations are abstractions makes it possible to zero in on the questions deemed central for consideration while pushing those of less importance into the background. It also obviates participants' reticence to talk about adaptation in their real world contexts.

The Problem

Every planning and decision-making process involves uncertainty and complexity. In planning a road, for example, traffic forecasts are based on a variety of assumptions about economic growth and future trends in transportation. Noise and air quality models incorporate many variables but cannot possibly account for every factor. The weather is even more uncertain; roads in continental climates must be constructed to withstand a wide range of conditions, from snow and ice to the hot summer sun. Politically, a range of stakeholders influence planning processes as they attempt to defend and advance their respective interests; a community might successfully fight to have a route altered away from residential areas, while commercial users lobby to have additional lanes built.

Yet decisions are made. Decision-makers and supporting experts get the technical data they need from existing standards, guidelines and officially sanctioned and generally trusted models and forecasts. The future can never be known in advance, but the assumption is that conditions will generally remain within certain ranges over at least the medium term. The weather may be particularly uncertain, but the probability of a one-in-a-hundred year flood is expected to stay constant at 1 % each year. Models and forecasts are inherently imperfect and sometimes disagreements around their veracity emerge, but they are generally accepted as *good enough* by decision-makers and other stakeholders.

When and how decisions are made, and how various interests and other factors are incorporated into complex decision-making processes is highly institutionalized. Which variables should be taken into account and how they should be modeled or forecasted is often codified in regulations. This is not to say that decision-making is always formal. In fact, a substantial proportion of the interactions that influence decisions are informal, whether they are between agency experts and decision-makers or involve external interest groups. Still, these interactions have generally become patterned, following institutionalized norms that have emerged and evolved over time. The various actors are aware of each other and have established both the means for communicating and particular shorthand for doing so.

Climate change may substantially increase the degrees of uncertainty and complexity, necessitating changes in the institutional status quo. It may also introduce new threats or variables that need to be accounted for. Existing policymaking frameworks and institutional arrangements are ill suited to dealing with dramatic uncertainties that cross existing institutional boundaries. Adequately assessing possibilities outside traditionally expected dimensions requires new levels of cooperation and an ability to tap multiple sources of knowledge. Such changes necessitate new ways of thinking and doing in our infrastructure planning and decision-making.

There are various ways in which climate change adaptation planning for infrastructure may be advanced. Two areas in which challenges lie and solutions are needed are the accounting of persistent uncertainties and the effective engagement of multiple stakeholders. Substantively, we need tools designed to help reconcile decision-making with substantial and potentially unresolvable uncertainty. Procedurally, we need effective techniques for bring various actors together to collaboratively identify and address emerging threats. We turn to these challenges, and possible solutions, next.

Reconciling with Uncertainty

Uncertainty may be resolved or managed in various ways. Traditionally, experts have attempted to remove, or at least reduce, uncertainty by conducting more research. This is an appropriate response when *the* answer can be known, or at least accurately estimated, after further analysis.

The problem is that it is typically impossible to resolve uncertainty completely. Reconciling with this fact, some have resorted to exploring the likely range of possible future conditions and making decisions based on *worst-case scenarios.* This is deemed particularly appropriate when the failure of the infrastructure in question is deemed untenable, and thus decision-makers have a mandate to invest significant resources *just in case*. For example, the primary dike network in Holland is designed to withstand 1 in 10,000-year flood levels. The probability of a 1:10,000-year event is highly unlikely, but this level of protection is deemed worth the cost for this low-lying region of the Netherlands. For less critical infrastructure, a middle-range forecast might be used in the establishment of design standards.

Climate change may complicate matters further, involving *deep uncertainty* in which future conditions are completely unknown [19]. One response to deep uncertainty is to increase flexibility in planning and decision-making. *Robust Decision Making* [20] and *Dynamic Adaptive Policymaking* [21] are two similar approaches that can be used to develop flexible policies that involve ongoing monitoring and amendments over time as conditions change and new information is revealed. Similar flexibility has also been called for in the design of infrastructure [22].

Whether for static or dynamic planning processes, having an explicit set of possible future scenarios in-hand can be valuable. The idea is not to predict the future, but to recognize that there are a range of possible futures in any situation, and layout what they might look like for the sake of better decision-making today [23]. In practice, the use of multiple scenarios in planning and decision-making is uncommon and not without its challenges. There is a relative dearth of academic evaluation of scenario planning, but various critiques have been leveled, including:

Scenarios are subjective in nature; the limited number of scenarios can be problematic; scenarios do not account for *deep uncertainty* and the diverse range of possible futures; the process is prone to political interference and constraints; users often focus on what they know or want to see in the future rather than on the uncertainty; and it is unclear how the scenarios connect and translate into better decisions in practice [19, 23, 24].

Despite the challenges and lack of widespread use in practice, some public-sector institutions are finding the explicit recognition of multiple possible futures to be invaluable in their long-range planning efforts [25]. Multiple scenarios provide opportunities for decision-makers to bracket the range of possible futures and make choices despite the lack of certainty. The use of scenarios and flexibility in planning are not mutually exclusive. In fact, many climate change adaptation measures do not require absolute certainty, but greatly benefit from an understanding of what seems possible, as this motivates flexibility and allows for the identification of various options that could be implemented as conditions change or become more apparent [26].

The question of whether or not the explicit identification of multiple possible futures (i.e., scenarios) makes a difference in how decision-makers advance with adaptation planning is important and insufficiently answered. If the use of scenarios—rather than single forecasts of possible future conditions—is found to make a positive difference, much more substantial work on improving the practice of scenario planning would be justified. Questions also remain around how scenario planning might be institutionalized into infrastructure planning in practice.

Stakeholder Engagement in Infrastructure Planning

Consensus-based collaborative planning (or governance) is normatively advanced as a powerful way to engage the range of decision-makers and other stakeholders associated with a particular problem or management challenge, bringing them together to collectively analyze the situation, solicit and evaluate information, and seek out solutions that are both robust and widely supported [27–29]. It is proposed as a way to overcome the barriers to effective and efficient interaction that are often present in institutions.

While notable criticisms of collaborative planning exist [30, 31], there is substantial evidence that it can lead to better outcomes when the conditions are right [27, 29, 32]. An important question is whether, and how, collaborative planning can make a difference in situations rife with complexity and uncertainty, such as those involving climate change. Can collaborative processes bridge the gaps between stakeholders and effectively help them to identify new ways to manage nascent and dynamic threats?

Margerum [29] suggests that collaborative processes are more successful when embedded within the institutional fabric of management and decision-making processes, and across networks of processes. An important corollary question is how to better embed multi-stakeholder collaboration into existing institutional regimes. The relative lack of up-take thus far suggests that this is not easy. Work remains to be done in better understanding the barriers and how they might be overcome.

The presence of competing interests cannot be ignored in the context of climate change adaptation. Each adaptation option is bound to garner support from some and opposition from others, depending on their interests. The construction of hard infrastructure, like seawalls and storm surge barriers has, for example, often faced opposition from environmental groups due to the associated ecological damage and disruption. In contrast, coastal landowners often champion such infrastructure projects due to the protection and relative stability they provide. Various political and citizen groups may oppose or support for a myriad of reasons. Environmental groups often favor allowing nature to run its course and reclaim areas vulnerable to sea level rise and storm surges, an option typically untenable to landowners with thousands if not millions of dollars of property and invaluable memories and emotional attachments at stake. Insofar as climate change may accelerate the extent and rate at which controversial adaptation-related projects are being initiated, the tensions among stakeholders are likely to increase. How can these tensions be managed as we adapt? This is a question of stakeholder engagement and collaborative management.

On a related note, it is quite possible that accounting for and responding to climate change is a *hot potato* that stakeholders are aware of, but that no one wants (or knows how) to handle. Because responsibility for newly emerging threats is often unassigned, it is all too easy for stakeholders to assume that someone else will take the necessary action.To what degree are stakeholders aware of the risks associated with climate change, but expecting others to take responsibility for them? Are processes being initiated to collectively identify the risks and apportion responsibility? These are questions of institutional design.

Role-Play Simulation Exercises for Research and Learning

The explicit use of multiple scenarios and structured collaborative planning are two of the many possible tools and approaches that may be employed in addressing the risks and uncertainties climate change poses to our infrastructure. Critical questions remain unanswered around the veracity of these particular instruments and how they may be implemented in practice. In general, there has been insufficient opportunity to experiment with various tools and approaches for adapting to climate change.

The challenge is how to effectively and efficiently introduce possible solutions to decision-makers and other stakeholders so that their efficacy and viability may be jointly evaluated. The relative nascence of climate change adaptation as an issue means that those engaged in infrastructure development and other forms of project planning and implementation have little or no experience incorporating the potential impacts of climate change into their analysis and decision-making. The dearth of cases in which climate change has been meaningfully integrated into project-level planning makes learning from others difficult.

Role-play simulation exercises (RPS) can help. They are powerful instruments for introducing scenarios, collaborative planning and virtually any other tool or approach to decision-makers and other stakeholders in a relatively low-cost simulated environment. RPS can present one or more possible futures and ask participants to work through how they might react. This can help researchers, advocates, and decision-makers to assess tools, prepare for the particular scenarios presented and, at a broader level, shed light on how they might respond so that plans, policies, and management and decision-making structures may be modified and capacity provided proactively. In other words, decision makers can experiment with alternatives around how to prepare and who should be responsible.

While traditionally discounted as merely entertainment or ice breakers, serious games are increasingly recognized for the value they can add to the public policy making process, providing safe spaces to explore information and alternative pathways forward. RPS can serve as *diagnostic tools* to help groups collaboratively explore how they can and do manage uncertainty and dynamic risks, like those associated with climate change. In fact, RPS—and serious games in general—may be all the more valuable when planning for climate change, as stakeholders enter uncharted territory facing greater uncertainty and increasingly volatile situations [33]. We have certainly found them very useful in prior climate change adaptation work with stakeholders at the Consensus Building Institute and the MIT Science Impact Collaborative [34].

When different stakeholders are brought together to play a simulation exercise, the experience helps them to understand each others' points of view, interpretations of data, and sets of interests around how to best adapt to projected climate change impacts. Decision-makers in complex environments with a range of stakeholders responsible for discrete pieces of the puzzle may not be aware of who the other players are, how they make decisions, or what their priorities are. RPS exercises force them to confront one another and experiment with collaborative decision-making. Effective exercises can help stakeholders to appreciate the value of engaging with each other to grapple with challenges that are not currently accounted for in decision-making processes, yet may impact everyone.

Conflicts around how data should be collected, analyzed and interpreted have often impeded decision-making on a range of science-intensive policy issues [35]. RPS exercises help stakeholders to understand where the data is coming from and how scientists are generating it, thereby increasing the credibility of the information in stakeholders' minds. Scientists play a key role in providing information, but it is only useful if others have confidence in it and are able to use the data appropriately. Technical information—real or simulated—can be provided in such a way that participants have the freedom to process it outside of their traditional roles and settings. Simulations also provide a *sandbox* in which decision makers can wrestle with situations or data that has not yet manifested or is not yet conclusive in their real-world situations, but that may have major implications down the road. As noted previously, they can also experiment with new tools for processing this data and making decisions, like scenario planning.

This *sandbox* environment also provides participants with the space to explore options without committing to things they may not be prepared for or politically able to do yet in their real world positions. Participants can discuss issues in reference to the fictional case presented rather than their real situations, which is less threatening. Once they have gone through this experience, they are often more willing to open up and put their real-world issues on the table in the debrief conversation. The hope is that this new willingness and ability to discuss these important issues with other stakeholders continues beyond the RPS exercise itself. Getting the right people in the room to start the discussion is contingent on having influential local conveners or project partners.

Reflecting on a fictionalized yet realistic situation as a group helps stakeholders to better understand potential adaptation options, and to start grappling with the choices they may need to make. RPS exercises force participants to deal with concrete decisions. They have to make difficult choices, or be creative in identifying potential *no regrets* options.

Addressing the risks associated with climate change is no easy task given the high degree of uncertainty, complex decision-making environments into which this new challenge must be inserted, and competing priorities. RPS exercises provide a powerful way to introduce decision-makers to the uncertain risks climate change poses and how they might respond in concert with other stakeholders. To be effective, exercises must acknowledge the institutional environments in which planning and decision-making takes place, the competing priorities of various stakeholders, and the fact that resources are limited. They should encourage stakeholders to work together and consider new ways of making decisions while recognizing existing decision-making structures and competing agendas.

Many of the aforementioned benefits of RPS are primarily educational and motivational in nature. That is, they highlight the value RPS can provide directly to groups initiating discussion and planning for climate change adaptation. For researchers, the benefits of RPS are twofold: First, observing how participants respond within the simulations can provide substantial insights into how they might respond, or at least some of the issues they may face, in analogous real-world situations. These insights can contribute to new theories on how actors will behave, and lead to new proposals on what support might be provided proactively. Second, RPS serve as inflection points with participants, creating powerful windows for both individual and collective reflection and analysis. Debrief conversations and follow-up interviews can be used to discuss experiences and reflections with participants, paying particular attention to how the insights gleaned from the RPS translate to or may reflect their real world situations. Established qualitative research techniques, including effective semi-formal interviewing and data coding and analysis can be applied to make the most of the information collected.

The employment of RPS for both education and research is certainly not new. Scholars and practitioners have been using RPS with a wide range of different groups in a variety of contexts around the world for more than sixty years [36–48].

Parson [43] identified four ways in which RPS may be used: As experiments to test what happens when certain dynamics are presented in a scenario; to teach particular skills to participants; to foster creativity; and to facilitate the integration of knowledge. These uses are not mutually exclusive—the game introduced below was designed as part of an experiment, but facilitating the integration of (new) knowledge is at its core. The hope is that it is also fostering creativity and potentially even teaching, or at least introducing, some new skills.

Surveying the literature and considering his own experiences with RPS, Najam [46] offers the following lessons on using exercises for research purposes in particular:

- They are good for theory-building, and less appropriate for theory-testing;
- RPS are particularly appropriate for novel, complex and high-stake problems that are difficult to explore via more traditional research techniques;
- They can be very useful in shedding light on possible process issues, and for soliciting insights and feedback from participants, but are not good for predictive research;
- Ideally, RPS should be used with other methods as part of any research project;
- To be effective, the RPS themselves must be well-designed and substantively accurate, while accepting that they are greatly simplified reflections of reality; and
- RPS are most effective when the participants come from, or at least are highly familiar with, the real-world situation that the scenario reflects.

In addition to the limitations embedded within these lessons Najam [46] drew, using RPS also presents other challenges. Preparing appropriate RPS can take a great deal of time and resources. While ideally usable in more than one situation, RPS are increasingly being tailored to the unique situations of the time and place for which they are developed, limiting their portability. There is inherently a tradeoff in any RPS between universality and particularity. When being used for research purposes, it is all the more important to lean towards particularity, including elements that reflect the analogous real-world situation that may influence the outcomes. On the other hand, any RPS is necessarily a simplification and not a perfect representation of reality. Both researchers and participants must acknowledge and work to understand the gaps and how they make what happens in the game different than what might happen in the real world. These gaps are precisely why RPS are better for theory building than testing, and are not ideal for predictive research. Finally, getting decision-makers and other stakeholders to participate in RPS can be challenging. They must be convinced that the experience will be valuable.

Despite these challenges and limitations, the existing literature and anecdotal experience suggest that RPS can be very powerful tools for both research and teaching. Yet, there is not a great deal of scholarship testing this assertion or identifying best practices for their development and application. This represents an opportunity for further research.

A Role-Play Simulation Exercise in Practice: A New Connection in Westerberg

The *Harboring Uncertainty: Exploring how decision-makers can prepare for uncertain climate futures* research project is engaging infrastructure planners, decision-makers and other stakeholders to explore how the risks and uncertainties posed by climate change might be more effectively managed. The foci include: Assessing if and how the uncertainty associated with climate change is posing any unconventional challenges, particularly to existing decision-making processes; discussing how new risks and uncertainty may be incorporated into institutions and streams of decision-making; discussing how the interests and perspectives of various stakeholders impacted by both climate change and proposed responses might be reconciled; and considering potential tools for decision-making in the face of risks, and scenario planning in particular.

The project is still underway, but so far interviews and surveys have been conducted and two versions of an RPS called *A New Connection in Westerberg* have been run with decision-makers in the Netherlands. *A New Connection in Westerberg* revolves around a proposal to build a new highway to address critical congestion issues in a coastal city with a major port. The highway would potentially serve both port users and the wider fictitious city the port is situated in. Money has been allocated and the project is on the cusp of proceeding when a new regional climate change assessment suggests that there may be vulnerabilities if certain route and design options are chosen. A group of stakeholders from both the local and national levels, and from both within and outside of government, have subsequently been brought together to consider the various options they have against the uncertain climate risks.

RPS participants may assess the climate change risks differently, and their particular interests inevitably shape their opinions, but the group's goal is to come to consensus on how to proceed. General instructions introduce the situation and options to participants. In addition, each player is given individual confidential instructions that provide background information and explain how they should fill the unique role they have been assigned. Participants intentionally do not fill their own real-world roles in the exercise, but rather are assigned those of other stakeholders. Interviews were conducted with real world stakeholders as the exercise was developed to make the case and roles as accurate as possible.

The *A New Connection in Westerberg* RPS will be run in at least two other cities around the world –New York and Singapore—in the coming months. Participant observation, pre- and post-exercise surveys, in-depth interviews, and debrief focus groups are used to collect data in each place.

These three different port cities are being used to test for variation across governance regimes. Governance (or policy) regimes, including their institutional norms and standards and how they relate to infrastructure planning, are not universal [18]. From an institutional theory perspective, these three cases are interesting because of their distinctive governance regimes: Rotterdam operates within a *neo-corporatist* framework of decision-making with a strong tradition of seeking broad consensus on issues, often known as *poldering* [49]. Decision-making in New York occurs within a *neo-pluralist* and *neo-liberal* governance paradigm with regular contention between interest groups and a strong market orientation. Singapore's decision-making environment is *top-down technocratic* in nature, with a strong civil service left to make many decisions unilaterally [50]. How the differences between these three governance models impact their approaches to adaptation planning, and use of scenarios in particular, remains an important open question. Insights are being gleaned from assessing how groups in the different cities perform and respond to the RPS.

Two separate versions of the RPS are being run with different groups in each city: One version provides a single forecast (or 'risk assessment') of probable future conditions under climate change. The other includes a set of four possible futures (i.e., scenarios). These parallel RPS are used to test for variation based on the presence or absence of explicit scenarios in adaptation planning processes, accounting for the variation in governance regimes. In addition to observing how participants respond differently, the surveys allow for pre- and post-exercise comparisons between those that use each of these versions.

Both versions of the RPS involve face-to-face collaborative multi-stakeholder engagement. For this element of the research, there is no control group against which participants' actions and reflections are compared. Participants are observed interacting in this format and asked afterwards to assess the influence and efficacy of this particular type of collaborative planning effort compared to the typical modes of collaboration and decision-making in their respective real worlds. The pre- and post-exercise surveys allow for limited analysis, but not against a control group.

The RPS exercises serve as critical interventions in the research agenda, but are not the only element. As noted previously, directly observing how each plays-out is important and should yield insights, but data will also come from debrief conversations with the groups post-exercise, in-depth interviews with participants, and pre- and post-exercise questionnaires. The RPS themselves serve as tools to introduce the issues and foster reflection among participants. The goal within the wider *Harboring Uncertainty* research project is to draw generalizable conclusions that can inform infrastructure planners and other stakeholders around the world, and that support or refute various theories around governance, decision-making and the use of tools like scenario planning. The expectation is that the exercises are also of direct value to the participants in each city, providing them with an opportunity to collectively grapple with the nascent challenge of incorporating climate change into their planning and decision-making.

Initial results indicate that those that participated in the *A New Connection in Westerberg* RPS in the Netherlands found it to be a useful experience. The two runs also provided valuable insights on the underlying research questions. Participants noted that the exercise helped them to think about the climate-related problems they may face in new ways and appreciated the opportunity to interact with other stakeholders around this nascent issue. Those coming from more technical backgrounds said it helped them to understand how the competing interests of various stakeholders influence the decisions made. Decision-making around infrastructure is not merely a technical process, but also a political one. Conversely, policy-makers appreciated the opportunity to explicitly explore questions of uncertainty, which are typically buried within the models and recommendations they receive from their technical counterparts.

The presentation of scenarios made uncertainty more explicit, which many viewed as useful yet also complicating and potentially paralyzing. Among other issues, those opposing action can use uncertainty as a stall tactic. In the end, the RPS group with the more traditional risk assessment reached a consensus recommendation on how to proceed while the group with multiple scenarios concluded that they would need more information before they can make a decision. Despite the explicit lack of probabilities, participants quickly found themselves arguing over which scenarios are more likely and thus should be designed for. This suggests that genuinely accounting for multiple possible futures can be difficult when planners and decision-makers are used to working with single sets of parameters and design conditions, or, at most, probability distributions.

Not all agreed that climate change involves an abnormal degree or particularly complex form of uncertainty. Some argued that we already know enough about what is happening to move ahead with adaptive measures. Conversely, others said that status quo infrastructure design and decision-making processes are already robust, and that there will be plenty of opportunity to adapt as the climate changes and particular problems emerge. A common view within the latter camp is that we have more immediate challenges to address in infrastructure planning and management than slow-moving climate change, although those with this sentiment still found this 'what if' exercise useful. No one doubted that climate change might be an issue at some point, if not today. Maintaining flexibility was identified as a viable way to start thinking about the impacts of climate change on infrastructure today so that future problems may be avoided, or at least are easy to mitigate, while putting off making expensive investments.

Other Experiences with Role-Play Simulation Exercises

Various organizations, including the Consensus Building Institute (CBI) and the MIT Science Impact Collaborative (MITSIC) have been using RPS exercises for decades to help decision-makers and other stakeholders work through a wide range of issues [34, 51]. Many of these exercises—which deal with a range of topics—are available via the Program on Negotiation at Harvard Law School Clearinghouse (*See:* http://www.pon.harvard.edu/store/*)*. CBI and MITSIC are now applying their expertise in the climate change arena [34, 52].

One CBI project involved developing and running a comprehensive RPS grappling with the risks and uncertainty climate change poses to the hydroelectricity sector in Ghana. The project was commissioned by the World Resources

Institute and brought together several high-level Ghanaian decision-makers (*See:* http://www.wri.org/node/40358). Data on climate change, including both hydrologic and meteorological projections, future energy sector plans and information on the decision-making environment was used to prepare the exercise. This information was gleaned from interviews with a wide range of stakeholders and a thorough literature review. The exercise introduced issues or questions that decision-makers may face in the not so distant future in light of climate change, but was abstracted to a fictitious place and situation similar to but not exactly the same as Ghana so that participants could engage without compromising their real-world positions or getting stuck in the minutia of what was and was not accurate in the instructions.

The scenario presented was that a new dam has been approved and construction is about to begin when a report by highly regarded experts is released suggesting that climate change may significantly alter the hydrology of the river on which the dam will be located. The questions participants grappled with included: Should the dam project be modified (or halted) in light of this new climate information? If so, how should it be modified? What data is necessary for making a decision? What degree of certainty is necessary? Who is responsible for collecting data and making decisions? Moving forward, how should monitoring, evaluation and decision-making in the face of climate change be institutionalized? Each participant was assigned a role (e.g. Energy Authority) and provided confidential instructions outlining their interests vis-à-vis these questions.

The exercise was facilitated in November of 2010 with a group of high-level decision-makers and other stakeholders in Ghana. An extensive debrief discussion was facilitated with participants to extract lessons learned from the experience. Participants were first asked a series of questions to engender reflection on the exercise itself. They were then asked to connect the exercise to their real-world situations. The challenges associated with balancing competing priorities and grappling with climate change-related uncertainty were very apparent. Participants struggled with the question of how to meet current development needs while protecting against uncertain future risks, fostering discussion around how much risk is tolerable, and how risk can be reduced and better understood. The question of how decision-makers can assess the veracity of data was also discussed. Participants also wrestled with the questions of how these climate change-related issues should be incorporated into the decision-making process, given that it is a complicated system with a variety of actors often unaware of how or why others are making decisions that have significant impacts on the overall outcomes.

In a different project, CBI and MITSIC partnered with the Maryland Department of Natural Resources and the National Oceanic and Atmospheric Administration to develop a role-play exercise exploring how Maryland's coastal communities might adapt to climate change (*See:* http://maryland.coastsmart.org*)*. The exercise was run with over 170 mayors, county commissioners, environmentalists, business leaders and state officials during an interactive summit in April of 2009. The exercise is quite comprehensive with nine stakeholders, plus a mediator, tackling questions in the areas of 'reducing vulnerability of the built environment'; 'water and waste water infrastructure'; 'protecting wetlands and wildlife'; 'farm and forestland preservation'; and 'public education'. How to deal with disagreements around information through *joint fact-finding* is an important element of this exercise.

CBI and MITSIC continue to use RPS exercises with decision-makers ranging from those engaged in local planning to stakeholders participating in international negotiations (*See:* http://cbuilding.org/blog/2011/building-national-consensus-international-climate-change-negotiations *and* http://cbuilding.org/publication/article/2011/adapting-climate-change-managing-tomorrow039s-risks-today039s-decisions).

Conclusion

Role-play simulation exercises offer unique opportunities to immerse decision-makers and other stakeholders in hypothetical yet realistic situations that present threats like climate change and ask them to make decisions. RPS can engage participants to introduce and explore issues and experiment with potential tools—like the explicit use of scenarios (i.e., multiple possible futures) and collaborative planning—in safe and low-cost environments. RPS can also help participants to assess, or even generate, potential concrete solutions to problems. RPS are particularly appropriate for nascent and complex threats like climate change for which there is not a great deal of previous practice to learn from and around which strong institutional norms have not yet emerged.

RPS can be invaluable both for teaching and research. Ideally, participants learn from their involvement while researchers glean valuable data. This chapter has introduced an RPS—called *A New Connection in Westerberg*—being used with infrastructure planners in three cities around the world for exactly this purpose; it is too early in the research project to draw substantial conclusions, but the work so far suggests that their use is promising. In general, the value of RPS in teaching is well established, but their use for research purposes is rare and not well understood. More work remains to be done here in assessing their efficacy in various situations and when different research questions are on the table.

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Game-Like Characteristic of Engineering Design

Sertaç Oruç and Scott W. Cunningham

Abstract Engineering design is conventionally regarded as a mono actor optimization problem and modeled accordingly. Decision-making, values and optimality are building blocks of conventional engineering design. However, with the advent of decentralized decision making processes, various actors are more likely to be involved in decision making processes in engineering design. As a response in this chapter, authors attempt to claim that engineering design is inherently multi actor and has game-like characteristics. Accordingly, a research agenda is put forward.

Keywords Multi actor systems · Engineering design · Game theory

Introduction

In the process of designing engineering components and systems, optimization approach has been the conventional choice. In this context, we regard optimization as formulation and execution of problems instead of the narrower use of the word as a mathematical technique. As a mathematical technique, optimization is a pragmatic tool and an important step to bring about the final design, although not in focus of our discussion.

In our context, engineering design refers to the plan for construction of an engineering artifact. It is a specification of the artifact intended to accomplish a certain designated goal. Moreover, optimization is the traditionally applied approach to guide this process. Engineering design, being based on optimization, is directly related to value paradigm and decision theory.

S. Oruç (✉) · S. W. Cunningham
Policy Analysis Section, Faculty of Technology, Policy and Management, Delft University of Technology, Jaffalaan 5, 5015 2600 GA Delft, The Netherlands
e-mail: S.Oruc@tudelft.nl

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Decision making, and therefore decision theory, is directly employed in the current theory and practice of engineering design. It is important to distinguish theory of engineering design and theory of engineering modeling at this point as the latter aims to asses and predict the performance of engineering artifact whereas the former is related to the total design of the artifact anew.

Multi actor engineering design refers to the engineering design that involves more than one actor. In our framework, we consider initially a customer who funds and utilizes the design artifact and a designer who actually designs the engineering artifact. However, the conceptual framework we consider here can be applied to other type of business models that involve various other types of actors.

In the following section, we give the engineering design in terms of optimization problem. A methodological review is presented in this section. Later game like character of engineering design is presented and it is formalized with a game theoretic model. In the subsequent section new approaches to engineering design is discussed briefly. Lastly, concluding remarks and reflections are presented.

Engineering Design Optimization Problem

Engineering Design is historically seen as a mono actor optimization problem. Here in this section, we present the conventional approach to engineering design and discuss a brief methodological review on this issue. Revisiting conventional approach makes it possible to extend the framework to equilibrium approach in the subsequent sections.

Conventionally engineering design is associated with giving the "appropriate" design decisions. Appropriateness in this context is determined by an optimization process, which is sometimes only intuitive and sometimes grounded on rational choices based on values and analytical techniques [1]. The decision making in engineering design process begins with the very basic components such as the kind of steel to be used or engine oil to be utilized. These basic component decisions permit certain measures for design characteristics such as engine power, machine weights etc. Then the design characteristics constitute various values that are considered to be maximized or minimized according to the "wishes" of the designer. Optimization of the engineering design may hold for the case where only one designer and accordingly one wish is at stake. How to handle the situation in case there are more than one designer or choice is the central question of this chapter.

Optimization Concepts

Consider the following linear program, where x are decision variables, c parameterizes the objective function, and A and b parameterize the constraints.

$$\min_{x} Z = c^T x \tag{1}$$

$$\text{subject to } Ax \geq b \tag{2}$$

$$x \geq 0 \tag{3}$$

The solution to this optimization problem can be expressed in terms of a set of algebraic equations; indeed, this is the core of the simplex algorithm. Investigation of the solutions to this set of variables reveals a fundamental insight that only the set of linear operations (addition and subtraction) are needed to find the optimum solution. Furthermore, the derivation of any solution can be exclusively expressed in terms of its slack variables. This fundamental insight leads immediately to the duality theory of linear programming. Furthermore, the use of the dual program is useful since it provides insight into the trade-offs at the optimum, without requiring extensive re-optimization of the problem from scratch [2].

The vector of decision variables x is an optimum solution to the problem if the vector is a feasible solution, and if there is a dual vector y. The vector y must satisfy the following optimization problem:

$$\max_{y} Z = b^T y \tag{4}$$

$$\text{subject to } A^T y \leq c \tag{5}$$

$$y \geq 0 \tag{6}$$

This linear optimization problem can be transformed, with no loss of generality, in various ways. The maximization can be reduced to a minimization, the constraint equalities can be transformed into inequalities, and the constraint boundaries transformed to various forms. There is an account of this point in [2], but also in [3].

Engineering Design Optimization

Consider the following model of the design process. A designer has i = {1, …, m} design options. A customer has j = {1, …, n} criteria for choice. The customer expresses a weighting of their preferred criteria, $w_1 \ldots w_n$. The designer has a score card, a matrix U which is dimensioned $i \times j$. Each element of the score card, u_{ij}, expresses the utility obtained by the designer for selecting a particular technological option. Utilities are a function of expressed customer satisfaction (w_j) minus the implementation cost (k_{ij}). Thus u_{ij} can be expressed using the following function.

$$u_{ij} = \left(w_j - k_{ij}\right) \tag{7}$$

The designer's choice is to combine or blend technological functions to achieve maximum utility. This involves playing a mixed strategy, $v_1 \ldots v_n$. The design problem is conditioned on the designer's knowledge of the game matrix U, the costs of implementation k_{ij}, and the preferences of the customer w_j.

This problem, given fixed preferences of the customer, reduces to the following classic expression of an engineering design problem.

$$\max_{v} Z = \sum_{i=1}^{m} \sum_{j=1}^{n} v_i u_{ij} \tag{8}$$

$$\text{subject to} \sum_{i=1}^{m} v_i = 1, \tag{9}$$

$$v_i \geq 0. \tag{10}$$

This optimization model implies a mono actor, monoobjective problem. This actor objective problem constitutes one side of the multi actor problem. Unilaterally formulated optimization problems from various actors constitute multi actor problem. Later we show how the above listed mono actor optimization model is fit into multi actor problem.

Methodological Review

The use of formal optimization modeling in engineering literature dates at least back to the early 1970s [1, 4, p. 13]. Most expressions of the problem involve non-linear optimization, although the use of linearization procedures as a means of approximation are common [3, p. 131]. Variant expressions of the problem include multi-objective optimization, as well as optimization under risk [5, ff. 164]. Others [6] question the engineering optimization paradigm on fundamental questions of value.

Infrastructure problems of design, planning, allocation and control all invite the use of optimization techniques [7]. Consider for instance the canonical example of optimization, linear programming. Despite the considerable usefulness of linear programming in decision-making, this technique depicts the system preferences of just a single actor. Arguably, the most apt use of linear programming has been in command and control environments such as planned economies, the military, and oligopolistic corporations. In these environments, there is less capacity for the system to rebound in response to decisions or tactics. Linear programming is one of the premier tools for computer modelling of decision-making under constraint. Linear programming, and its extensions, is widely applied across many fields of application. Dantzig discovered the principle computer algorithm for the technique in 1948, as reported in a memorandum of the United States Air Force [8]. Linear sensitivity analysis, and ultimately a full expression of a strategic theory of games, emerged organically from this initial research in linear programming [9].

Variant Statements of the Problem.

Research into engineering optimization has been productive, resulting in a burgeoning literature. Previous research, less than ten years old, provides a survey of multi-objective optimization in engineering [10]:

> This survey excludes many of the technical details and, instead, provides a road map of currently available continuous nonlinear methods and literature. General concepts are briefly described, and references are included for further investigation. In addition, this paper consolidates seemingly different concepts, methods, and terminology stemming from diverse applications (p. 369).

The fact that this work has been cited by more than 189 authors (Web of Science 2012) suggests that the question of multi-objective optimization remains of essential interest to designers, and is still subject to rapid progress. Further, the field requires multi-disciplinary surveys to keep abreast of the varied technical details from the various literatures.

Modern infrastructure supports the exchange of multiple kinds of goods and services. Flows are becoming multi-commodity, multi-modal, multi-sectoral and multi-faceted. For instance, the shipping industry has long been a multi-commodity enterprise. Multi-modal traffic is increasingly being considered, for instance, in the design of rail links. Multi-faceted infrastructure is leading to an explosion of new consumer options, and new concerns for decision-makers. For instance, consumers may choose "green" electricity: this formerly homogeneous good grows more diversified as consumers are presented with increasing amounts of information about the environmental impacts of their choices. Thus, network infrastructures are inherently multi-objective in character.

Multi-Actor Design Problems.

Despite this interest in formal models of multi-objective optimization, very little synthesis and review is available on the related but distinct question of multi-actor design. As evidenced by the multi-objective setting, there is a proliferation of specialized applications, rich in technical detail, in the multi-actor design setting. There however, has been little effort in consolidation. Two exceptions are [9, 11].

Infrastructure is inherently multi-actor in character. Infrastructure is commissioned, designed and built, and utilized by multiple stakeholders. There is no single objective function held in common between these stakeholders; rather, an expression of opposing economic, social or physical forces is a more useful paradigm for expressing network usage. This realization is often a better depiction of system behavior. In network infrastructures—such as highways, airports, water systems, electrical transmission and distribution systems—there are always multiple actors making multiple if interdependent decisions.

Our question concerns whether the classic design problem continues to hold in a multi-actor setting. Can design effectively be expressed as an optimization problem, even in the simplest of multi-actor settings? Can the design problem be reformulated to better encompass a fully multi-actor setting? If so, what are the consequences for engineering practice?

The Game-Like Character of Engineering Design

In this chapter, the game like character of multi actor engineering design is emphasized. Theory of games traditionally analyzes multi actor behavior in situations where individual interests conflict or coincide with each other. Actors in scrutiny are considered to be interested in their own pay off function and alter their strategies in order to maximize their utilities. Von Neuman and Morgenstern's seminal work *Theory of Games and Economic Behavior* [12] laid down the mathematical foundations of game theory, which triggered various theories around the idea of *equilibrium* instead of *optimum.*

In this section we hypothesize that engineering design could be considered as an equilibrium problem instead of an optimization problem unlike the conventional approach to the field.

Previous Work

Social choice theory stands as a prominent field in this regard. Collective decision making influence and determine various outcomes of formal institutions, i.e. laws. "Voting paradox" and Arrow's "impossibility theorem" are two generally acknowledged.

Arrow's impossibility theorem implies that when voters have more than two distinct options no voting system can convert ranked individual preferences into a collective ranking while also meeting a specific set of criteria [13]. These criteria can be listed as;

- **Non-dictatorship**: No single member's choices should prevail in every voting instance. The social welfare function should account for multiple voters' wishes.
- **Universality**: The function should yield a unique and complete ranking of societal choices.
- **Independence of irrelevant alternatives**: Changes in individuals' rankings of irrelevant alternatives of a certain subset should have no impact on the collective ranking of the subset.
- **Pareto efficiency (Unanimity)**: If every voter prefers a certain option to another then the collective preference must make the same preference.

Arrow's impossibility theorem points out that if the decision making group of individuals. Various formal and informal proofs follow in literature [14, 15].

Arrow's impossibility theorem showcase one particular case where social processes build up game like consequences. The implication of impossibility theorem in engineering design is that the different interests of different actors in a multi actor engineering design setting satisfaction of all individual choices of the actors is less likely than intuition may suggest. A thorough examination in this regard is usually required.

Following the formal modeling approach in game theoretical analysis in the next sub section we give an effort to present engineering design problem in formal model format. Creating a formal model of the problem would enable policy testing and operational insight into engineering design.

A Formal Model of Engineering Design

The first step in formulating the game-like setting of design activities is to specify the rules of the game. These rules may be presented by means of the "order of play" [16, p. 14]. The essential elements of a game, that is players, actions, payoffs and information should be attributed in the model.

A Game of Multi-Actor Design

Rules

1. The designer presents the customer a set $i = \{1,\ldots, m\}$ of technological options. Included in these options are one or more status-quo options (resulting in the use of alternative technologies), and a null option (resulting in a failure to adopt any technology at all). The customer knows their own utilities (X), as well as the costs of the designer.
2. The designer elicits preferences from the customer, requesting a set of weights or utility scores for each design criteria, w_j.
3. The designer completes the design, and the artifact is developed or implemented, thereby becoming available to the customer.
4. The customer then expresses their true preference for the product by choosing between the finished product and the null option.

Pay-Offs

The customer receives utility x_{ij} for objective j, under option i. The choice of the null option is set to zero for all criteria, with no loss of generality. The designer's pay-offs are as stated previously.

We offer two propositions concerning engineering design and an extended game between designers and customers. The first concerns the efficacy of engineering optimization in a multi-actor setting. The second concerns the capability of obtaining truthfully stated preferences from customers prior to the design process.

Proposition 1 *The multi-actor design game rarely results in an optimization problem.*

Proof The minimax theorem, which is closely related to the strong duality principal of linear programming, demonstrates that any zero-sum game is reducible to an optimization problem expressed in minimax form. The proposition restated is therefore the question of whether the multi-actor design game is inherently zero sum. This is tantamount to asking whether there must always be a proportional relationship between customer utility and the cost to the designer.

Corollary *In those cases where optimization is an effective expression of the design problem, there is a direct transfer of utility from the customer to the designer in proportion to technological performance. This can occur only in those cases where it is possible to fully and completely valorize product performance.*

Proposition 2 *Stated preferences, given the rules of the game, are rarely those actually expressed by customers.*

Definition (*Strategic Complements*) Strategic complements occur whether one player acts it encourages the other player to do more of the same.

Definition (*Last-Mover Advantage*) A last-mover advantage occurs whether taking the first action in the game benefits the player. Gal-Or [17] provides a generic result concerning the relationship between strategic complements and last-mover advantages. There are always last-mover advantages where there are strategic complements.

Proof Since the utility of the designer is proportional to the interests of the customer, there are strategic complements in this game. Since there are strategic complements, there must also be a last mover advantage for the customer. Since there is a last mover advantage, the initial expression of values by the customer cannot be in equilibrium. This follows directly from the definition of the Nash equilibrium.

Corollary *It follows from the revelation principal that it is not incentive compatible for the customer to fully reveal their preferences in the presence of the designer prior to the actual design of the product.*

The model can be expanded in various ways. It could be revised to be a game in continuous strategies. This would be more general, without reducing any of the findings. Also the model can deal with incomplete information situations such as the case when the customer knows about the engineering costs.

New Approaches to Engineering Design

In engineered systems equilibrium is ever present. Mechanical, thermal, electrical, fluidic—all these systems are engineered for a robustness requirement determined by some specifications. The specifications vary depending on the nature of the environment that the engineered artifact is built or utilized in. For instance, in construction sector requirement of resilience to external disturbances such as earthquakes is different in Japan compared to the Netherlands. However, in both cases some specifications are designed and propagated. The equilibrium concept that guarantees a certain specification is always employed in engineered systems. In addition, social equilibrium is an extremely useful concept that has seen application in both economics and the theory of games. Inarguably, network equilibrium is an important and useful concept for analysis and design. We do however, draw a cautionary note, in recommendations for future research, about the appropriate use of equilibrium analysis.

Conclusions

In this chapter, a new approach to engineering design is debated. The traditional approach to engineering design is contested with a multi actor approach that emphasizes game theoretical modeling. With this approach, the top down characteristic of engineering design optimization is challenged with a decentralized approach of equilibrium. Multiple actors (involving customers, funders, suppliers, and a designer) approach is considered as opposed to mono actor (i.e. designer) setting.

Engineering design is historically been considered as a mono actor multi criteria decision problem. Decision models, which most of the time emphasize optimization based approaches leave their place to equilibrium models where multiple actors take part in decision making process. Game theoretical concepts have increasing importance in analyzing such decision processes. In this chapter, authors attempt to formulate the game like characteristic of the engineering design problem.

New methods provide better insights as they encompass multi actor processes. Readily available multi actor theories can be applied in engineering design as opposed to traditional optimization modeling.

Finally, we see a pathway for continuation of laid down approach to engineering design. This work as presented here is to be expanded with an articulated model in continuous strategies form. The implications of the model for engineering design is also to be articulated and discussed. The model could be articulated within incomplete information settings, which is a widely encountered case in engineering design.

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Part VI
Governance

System Governance: Emergence of Practical Perspectives Across the Disciplines

Behnido Y. Calida and Charles B. Keating

Abstract As the eventual concept of governance has yet to emerge, traditional sources of power and authority symbols will always be at risk of falling short or even failing catastrophically. This is a daunting challenge since the actual governance landscape have dynamically evolved far more sophisticatedly than the usual well-framed "control" models that are embedded within traditional domains of administrative, public administration and political theories. The purpose of this paper is to articulate an alternative analysis of governance-relevant themes based on systems theoretic principles. This study utilizes a system-of-systems (SoS) conceptualization of governance that relates (1) a 'governed' system—the target of governance, with (2) a 'governing' system—the direct controller of the 'governed' system, (3) a 'metagovernance' systems—a metasystem that strategically influences the 'governing' system directly and the 'governed' system indirectly, and (4) its contextual environment—as anything external to the supposed SoS boundary. The paper will discuss how the symbols of governance that perpetuate "myths of control" thinking within the emergent infranomics discourse will be better understood incorporating for instance pluralist perspectives, role of the observer, and information—a few example of concepts and principles that are well-articulated in systems-based theories and approaches. The main contribution of this study is a set of systems-based ideas representing governance that will continue to remain relevant in spite of emergent problems and increased complexity.

Keywords System theory · Governance · Infranomics · Transdisciplinary · Clustering analysis

B. Y. Calida (✉) · C. B. Keating
Department of Engineering Management and Systems Engineering,
Old Dominion University, Kaufman Hall, Rm. 241, Norfolk, VA 23529, USA
e-mail: bcalida@odu.edu

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Introduction

Keeping in mind the context of infranomics, in what ways should the governance of a complex system change? The body of knowledge has shown that the answers to such questions varies and are as diverse as the held meanings of governance either in the context of research or in practice. Established 'old-fashioned' disciplines have attempted to reinvent their take on governance while upcoming multi-disciplinary initiatives suggest a somewhat radical transformative take of governance. The challenge therefore is to attempt to clarify the ambiguous nature of ideas relevant for a precise articulation of system governance. This entails an investigation at the conceptual level of ideas that broadly embraces mental images, memories, concepts, propositions, theories, inferences, problems and many more.

This research will focus primarily on the exploration of the concept 'governance' from a system view. There is increasingly some regularity in the body of knowledge that criticizes how existing notions of governance have been perpetuating the "myth of control", such belief which over a period of time has determined current forms and distributions of power and authority across different levels of society. Before dispelling any myth, it would be useful to describe what the 'myth of control' refers to in the first place. Bijlsma-Frankema and Koopman [1] regard the 'myth of control' as "a barrier that has to be shattered to open the way in the direction of more optimal mixes between commitment and control" (p. 211). In general, the 'myth of control' refers to pretentious attempts by entities to impose their capacity to control in enormous proportions all organized activity. These entities can vary from individuals to groups, to organizations and to governments. If only one can guarantee a complete grasp of a myriad of possible control factors to ensure goals are always met, then we can call it a perfect world—a closed-loop world. From the management paradigm that closely reflects and helps perpetuate the current views on control, Mintzberg [2] reflects on the assumptions that he claims to rarely apply in practice and argues for a normative control model that supports Bijlsma-Frankema and Koppman's view towards a new rationality of governance. In a much mature view of reality, the world as everyone experiences it is far from perfect in as much the same ways reflected in the social artifacts produced by human societies throughout its history. Complete control is not readily achievable, if not entirely unrealistic, given that we try to impose closed-systems constraints on an open-system world [3]. The purpose of this paper is to articulate an alternative analysis of governance-relevant themes based on systems-based principles. The analysis of governance is facilitated by a system-of-systems (SoS) conceptualization of governance that relates (1) a 'governed' system—the target of governance, with (2) a 'governing' system—the direct controller of the 'governed' system, (3) a 'metagovernance' systems—a metasystem that strategically influences the 'governing' system directly and the 'governed' system indirectly, and (4) its contextual environment—as anything external to the supposed SoS boundary.

The Complex Domain of Infranomic Governance

Limitations of Current Forms of Governance

The limited conceptualizations of governance are fast becoming a daunting challenge in an transdisciplinary domain like infranomics. Reasons for these can be interpreted as likely due to several factors among which include: (1) an unrealistic interpretation of governance based on ideal-types; (2) a natural fixation on hierarchical notions of authority; (3) a simplistic theoretical depiction of power, and lastly, (4) unerring resolve or determination to preserve non-compromise seeking solutions. These different reasons will each be elaborated in turn.

One suggested limitation of contemporary understanding of governance can be traced back to its original interpretation based on ideal-types, which is specifically framed using Weber's bureaucratic versus patrimonial administration and charismatic leadership concepts [4]. Such seminal work by Weber has afforded distinct explanations of authority and administration that relied on formal contrasts using ideal-types. Traditionally, governance as a "bureaucratic administration" has remained dependent for its effectiveness in realizing goals on the degree of congruence between authority and power. Ideal-types are but imaginative constructs with varied implications to governance. As a result an understanding of reality emerged that interprets human events in terms of relationships and regularities but not to necessity, i.e. it is governance by meaning, not by laws (p. 200). Likewise, as an ideal-type, authority is: "… in administrative structures, is based on adherence by participants to the expectations associated with their formal roles, that is, on the assumption that incumbents' motives and orientations will be sufficiently congruent with formal role expectations, and relationships are re-cast in terms of power." (p. 198); "… exists when participants do what is required of them by virtue of their organizational roles." (p. 206). However, this preeminent ideal-type explanation of authority may be challenged by instances where power may emanate from outside of existing "administrative structures" (p. 198). That is, administrative structures are human as much as they are mechanical contrivances. Participant's performances are affected by the variability in an individual's purposes, will, and capacities, organizational effectiveness will vary over time. Formal rationality (and technology) may help but can lead to inefficiencies themselves.

Unlike authority (that is constant and calculated within formal rationality), new concepts of power indicate that it is variable and mercurial where its amount and distribution vary over time as a function of (1) purposes and interests of participants, (2) distribution of power relevant resources, (3) participant's control of uncertainty and discretion, (4) participants' willingness to apply or withdraw efficiency and effect, and (5) unstable and conflict-based power relationships. (p. 206). Power struggles then ensues where a power struggle is a general phenomenon resulting when individuals, isolated groups, and alliances attempt to realize values, interests and goals of their own choosing that conflict with those of the administrative structure. Events that unfold as a part of its history are viewed as an evolutionary process of adaptation that was at least universal, inevitable, and accessible to human understanding and explanation. From Weber's original conceptual frame (i.e. rational-legal authority and formal rationality), there exists the inability to account for existence and use of power within and outside organizations and of the persistence of patrimonial features. Without a clear basis for understanding power, abuse of power may easily end up in conflict and problematic pathologies. Conflict situations result when what is good for organizations is not necessarily good for their participants and for society. Even much disconcerting is the possibility of resulting to a pathological tendency where even if participants serve the legitimate values and interests of participants and actors in the organizations environment, 'unintended consequences' can still have benign consequences. That may provide the impetus to instead adopt patrimonial features in promoting administrative effectiveness by mitigating conflict and promoting organizational loyalty, discipline and efficiency (i.e. Godfather effect). Beyond these ideal-type concepts, instead, there is a need to consider an alternate and "modest" conception of power based on formal rationality. For instance, new concepts of governance should consider Simon's system's view of 'satisficing' invoking a recognition of reality that is imperfect, limited, high-cost nature of information, variability and uncertainties of commitments to 'strict obedience', organizational goals (p. 210). Further, there has to be an inclusion of an environmental dimension as imperative for a new view of power (p. 211). Formal organizations are profoundly affected by environmental forces that try to influence or control their goals, policies, and resource allocations, and by the participants' efforts to use environmental forces to benefit the organization or their own positions within it. Dilemma in the environment is heterogonous and pluralistic. In other words a hybrid solution is necessary, or at least a "differentiated view" (p. 217) as a viable alternative.

Moving on to the next limitation is that of a natural fixation towards hierarchical notions of authority. This is at odds with recent non-hierarchical aspects of modern day cooperative roles and relations with respect to citizens that are meant to be serviced by such authority. The underpinning involved is such a conceptual switch may possibly undermine actual epistemological and political foundations [5]. That is, in public administration, various capacities are endowed with authority to carry out specific functions to do the people's business (p. 86–87). These capacities may come in either by personality or by institutional structure. However, once endowed with that authority, same capacities can lose sight of what the people want and are in positions where they can do damage. Also, institutions are single-minded and rule-bound in focus, thereby insulating from continuing critique and oversight. There is a thin line between formal authority and extreme authoritarianism. Lesson is, authority structures should be breathable (and not impervious to change; p. 95) and able to think outside of the hierarchy, … a case for a self-aware public administration. How do we implement such measures? These can be integrated into a governance approach by (1) strengthening public life and institutions such that citizens can reduce reliance on authority; (2) synthesize truth with others (authority is collective rather than hierarchical), and (3) adapt a lens of a higher ethical standard beyond self as truth claims are always revisable, contestable, and potentially democratic (p. 99).

The next limitation pertains to a simplistic theoretical view of power that cannot take into account non-formal and emergent forms of power. Unlike in some instance where simplicity is preferentially targeted, the resulting trade-off is that 'simplistic' accounts of power have an insufficient analytic propensity to explain power that may have different sources in organizations. Astley and Sachdeva [6] and Salancik and Pfeffer [7] have previously insisted separately in their analysis on a need for a conception of power that is meaningful beyond social interaction and organization. In their analysis, they have also alternatively observed a proliferation of multiple subtypes of power is also a problem (p. 105). Hence, their works have suggested an analysis of power in organizations as a function of (1) hierarchical authority, (2) resource control, (3) network centrality. Furthermore, these also suggests that even as we understand that power needs to be linked to structures of intra-organizational nature, the power structure needs to also include the role of the wider environment itself (p. 111).

Finally, the last limitation of current forms of governance can be broadly categorized as the inherently built-in tendency of existing governance forms to resist changes themselves. That is, despite the growing pressure and acknowledgement of weaknesses attributed to their current form, a negotiating process promotes non-compromise seeking solutions that allow administrators to retain power and authority, while encouraging collaboration and decision making [8].

The Challenge of Synthesis Across Practice and the Different Disciplines

It will not be surprising that the scope of governance literature just about covers any problem as a problem of governance. For instance, one account of the problem of governance in modern society suggests that it is a problem of adaptation, capacity and scale [9]. Under the paradoxical reality of globalization and devolution, terms used to refer the simultaneous internationalization and in parallel localization of traditionally government-centered decision processes (pp. 490–492), the agenda for modern governance must find ways to address these problems. The problem of adaptation, specifically in government, refers the need for non-traditional structured and staffed bureaucracies to support newer strategies and tactics, suggesting the role as "fitting traditional vertical systems to the new challenges of globalization and devolution, and integrating new horizontal systems to the traditional vertical ones" (p. 495) The problem of capacity is a call for effective management and accountability as enhancing government's ability to govern and manage effectively in this transformed environment. This is uncharted territory not accounted for in traditional intellectual foundations supporting hierarchical authority, bureaucratic exchange mechanisms and delegation of power practices.

Closely related to the problems of adaptation and capacity, there is also the problem of scale that makes issues harder to address, as it remains unclear as to which levels of governance are best suited or best fit to address it. In other words, the problem of scale implies sorting out the functions of different levels of governance and finding better alternatives of channeling available expertise and machinery rather than relying on ad hoc mechanisms most of the time.

Though examples of these problems were found in very distinctly different disciplines and problem domains, the rhetoric sounds all too familiar and almost resounding very similar themes.

Need for a Systems Perspective on Governance

Theorizing system governance would imply an attempt at formulating an acceptable multilevel abstraction of the system. This allows for the accommodation of underlying worldviews to be made explicit and perceived governance situations to be accurately depicted. To help confront this issue, a systems based approach is the primary study lens where perceived systems of interests will provide the focus to study generalizable aspects of governance situations. The process of governance and the system of interest themselves exist as independent societal entities and are embedded within the society at large. As such, they are easily captured conceptually as complex systems, as system-of-systems (SoS), or just simply, as systems. Motivated by several system-based principles, certain anticipated paradoxical divergences of perspectives helps in resolving the practical difficulties in theorizing about governance. Keating [10], similarly by Baldwin et al. [11], promoted the use of system-based articulations of context and its associated boundaries as the key tools in resolving such paradoxical perspectives. Whereas several definitions were available, Lycan [12] suggests a definition of paradox as "an inconsistent set of propositions, each of which is very plausible" where its resolution is a matter of deciding, on principled ground, which of the propositions are to be abandoned. This is the usual case and the domain of complex system governance. Paradoxes can be traced to propositional inconsistencies arising from philosophical, methodological, axiological, axiomatic and even application logical levels of divergence (Keating p. 2). Without a way to study these paradoxes, it would be impossible to even begin to understand how to design or embark on development of a system governance platform that would make sense with the vast array of other relevant theories and/or frameworks. Any resemblance to replicable governance phenomena, though interesting and novel, is coincidental and, at best, existential in the context of time, place and prevailing logic of someone else's decisions and actions. In other words, while there are examples of the utility in examining particular accounts of governance, the main argument in this dissertation is towards an attempt for a well-articulated universal governance concept. It is a grand and complicated effort but it should be attempted nonetheless because of its greater relevance to resolving paradoxical dead ends that confound day-to-day practice related to governance.

Hence, moving forward it would be convenient to explore the notion of the concept of governance in greater depth. Current understanding of governance is either conceived too broadly or too narrowly, limiting the recognition of the paradoxical phenomena that carries over to conflicting approaches of implementation.

Diverse Understanding on Governance

The literature is replete with studies that are about governance but are totally standing on very dissimilar conceptual bases. To date, there is still no comprehensive conceptual account of "governance" Kjaer [13, 14]. This does not imply a shortage of well-thought rigorous scholarly studies at all. In fact, several works on the usual "what" question has have been articulated quite sufficiently and extensively [15–17]. Multidisciplinary literature would reveal two prevailing perspectives in the practice of "governance". Either governance is deployed supposedly for a system of interest for purposes of (1) maintaining its operation despite any recurring problem, and/or (2) adapting its capabilities in anticipation of future challenges. While it is the contention in this study that existing governance systems were predominantly designed towards either one of the previously mentioned perspectives, new and existing governance systems will benefit from a step back analysis that reaches back to of basic concepts and approaches supporting such perspectives. In reality, most governance systems will have to merge both perspectives given their underlying purposes. Such an appreciation is starting to emerge as evidenced by many studies about governance within the specific topical contexts of the internet [18], urban culture [19], knowledge [20], enterprise information systems [21], networks [22], resilience and vulnerability [23] to name a few.

In some general sense, all these initiatives seem to converge on governance as either the last resort solution or as the ultimate cause of failure. There are several successful realizations where resulting outcomes can be evaluated against some theoretical backdrop of "governance". In each of those instantiations, however, the claims will not allow for enough comparison to suggest similar conceptualizations of 'governance'. In some instances, one implicitly assumes that "governance" is viewed not as the problem but the solution. Conversely, the problem perspective is stated in terms of the "lack of" where new efforts towards correct "governance" will progress towards improvement. There is also the difficulty to clearly draw out what is being governed and to what end. Presumably, a system is assumed at the receiving end where governance reflects the effort to realize a system's purpose. However, each one unique system state often invariably requires its own unique kind of governance. The current state is described by an internal differentiation of dynamics and complexity residing within the system in relation to its environment [24]. There are of course several available ways to reveal the state of a system by way of systematic classifications or typologies [25–29]. These have been instrumental in advancing understanding that are useful for application in real-life complex systems. Therefore, the rich diversity of interpretations for governance brings to life like a key systems notion concept, specifically the notion of multiple perspectives. This consideration has implications to for anyone responsible with for the design, development or transformation of governance systems. They will have to utilize these perspectives in order to comprehensively allow the system to accomplish their underlying purpose.

Increasing Relevance of Governance: Perception or Fact

There are now several examples of existing governance systems that are said to be unprepared for the practical difficulties of increasing complexity, change, emergence or uncertainty. Another set of suppositions hint on the need for governance within the context of the system. That is to say that there must of course be a priori an established awareness of a system in the first place. The focal question becomes, "Was the system developed with governance in mind?" And inextricably related to it is the question, "When exactly was governance conceived with respect to a system's own conceptualization and development?" As one possible starting point, one may hold that no attempt of governance was conceived to begin with. For such a conceptual case, a complex organismic philosophy is adopted where a system, as it is starting out, evolves without any notion of governance similar to natural, biological and ad hoc network systems, making it likely that such systems (simple or complex) can exist without any form of governance. On the other hand, as another starting point, a mechanistic philosophy adopts the prevailing view of purposeful, carefully planned systems. The base assumption for such a technical view, whether tacit or implicit, is that governance is in fact present, and pre-planned during the conceptualization, design and development stage of the system. In either case, both assumptions can thus be simply a matter of how the system boundaries are being perceived, studied and established, whether naturally or by purposeful design.

Governance is dependent on how one draws the respective boundary regarding the exact state of the system by looking at one's experience with the system or any relevant documented or historical accounts. If one considers a system without any pre-conceived notion of governance, the main task is to design, develop and implement a suitable governance system. If governance is already built-into the system, then the argument shifts into how to proceed towards "good" or "effective" governance as a system response to recurring system problems.

Irresolvable Conflicts of Perspectives

Several reasons for conflicts in perspectives on governance are traceable to the multiple "levels" and roles of different actors and their associated interests in implementing governance. Because each perspective held by every actor are important in the actual implementation of governance, blurring of traditional "functional" boundaries (i.e. political, administrative, public, private, etc.) is inevitable. Having no clear delineation presiding over practice, the active 'governance' concept is a tenuous implementation of overlapping and often conflicting hierarchical and network/collaborative paradigms. We can draw perspectives based on both assumptions from a single very recent real-life example—the US financial market collapse that triggered damaging effects throughout the global economy. Depending on how an individual's epistemological stance or knowledge boundaries are drawn, one can make a good case either way that some form governance already exists or was in fact absent. Before the financial collapse, the financial market is a good case example of sophisticated layers of governance. Governance in the financial market can be described as a dizzying array of regulations, policies, laws, standards through a complex interaction between public, private and government sectors [30]. Shortly after the collapse, everyone was insisting on better governance as a pressing concern since taxpayers' money was used for bailout or stimulus money. However, if one is a keen fan of Adam Smith's genius, the financial market as it was conceived was one that can function without any individual's awareness of obvious governance, whether minimal or if any at all. Hence since then, free markets are famous for the "Invisible Hand" metaphor [31]. This shows that no matter which assumption is held, governance is perceived sometimes as a solution and sometimes as the problem.

Uncovering Underlying Philosophical Debates

Undoubtedly, there are much larger philosophical roots underlying the debates that feature these differing perspectives. This goes back to the great debates between philosophers like Plato, Aristotle and much more recently Kant regarding the very nature of existence, of reality, of knowledge and of truth, of wholes and of entities [32]. It is not the intent of this dissertation to offer a resolution to these debates as they are expected to persist irrespective of any ongoing scholarly deliberation of governance. Instead, it is supposed that to have a good foundational understanding of governance, an integrative philosophy should be adopted that is appreciative of the different ontological, epistemological and axiological perspectives found in the literature. While governance can mean very different things based on which philosophical strand dominantly persists, it will be helpful to establish the preliminary conceptual boundaries before going any further in this study.

As such, the body of knowledge introduced here highlights the multidisciplinary lens to investigate system governance. Having implemented a thorough literature review process, an overview of the body of knowledge (BoK) was produced to help narrow down the key literature boundary themes on system governance. Both systems and governance are well studied terms with each having undergone advanced conceptual development and a long history from the purview of multiple independent disciplines and practice domains [33]. System governance, however, is not an easy transition from both key ideas (e.g. systems and governance), although there were already a few recent studies which used the compound notion of 'system governance' [34]. The difficulty was in the heterogeneous paradigms and plurality of conceptions expected when associated ideas were cultivated from the diverse world of traditional disciplines and practice [35, 36]. These were evidenced by a set of systemic themes emerging from the literature.

Approach to Extracting Governance Themes

An Overview

Content analysis is "a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use" [37]. It has several advantages, chiefly, its objectivity. Governance and systems related research, in possessing strong grounding in values and attitudes, and havings social science derivatives, must employ repeat methodologies which avoid subjective biases [38]. Specifically, properly use of content analysis tends to avoid recall biases [39]. Furthermore, it can be performed utilizing unstructured input data, a feature which was very useful given the diverse nature of scientific input likely to be employed in a given literature review process. Dealing with diverse input was one promising feature of content analysis as it is often highly utilized to obtain otherwise unavailable information [40].

Content Analysis Process

To begin with the quantitative phase of this research, the textual data sets were made ready for use in the modified content analysis procedure, which employed a novel clustering text analysis method. The novel method employed a clustering technique that helped to extensively discover any important concepts and interrelationships that are reflected in frequently recurring themes. The methodology, shown in Fig. 1 first proposed in Calida and Hester [41] and employed in this research study utilized a modified three-stage approach.

Stage 1 consisted of data generation and pre-processing. A literature review process was typically undertaken by performing a search in a library database using research relevant keywords, thereby identifying a set of potentially relevant articles from only peer-reviewed journal sources. In depth process and other details of the content analysis as part of the literature review is further discussed in Appendix 1. Peer-reviewed journal articles feature the intellectual hallmarks for validated forms of knowledge [42, 43] that may eventually impact and shape the

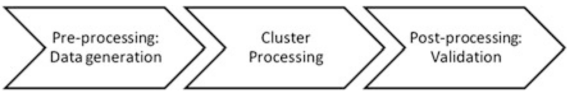

Fig. 1 Simplified 3-stage method overview

research field. In this regard, the ISI Web of Knowledge social science citation index (SSCI) and science citation index (SCI) was the selected database since it was the most comprehensive database of peer-reviewed research work for both the social sciences and sciences. All material available in the database for years available up to the time of the research: from 1992 through 2011 was used. Another key consideration was the determination of the relevant keywords to be used for the search. Given the plurality of meanings attached to the word 'governance' and 'systems', the search query employed was intentionally crafted to be as broad as possible, as a general selection requirement, to maximize the inclusion of all the relevant studies. The initial search of the SSCI and SCI database was performed using the basic keywords: 'governance' and limiting to descriptive 'systems' and its derivatives of systems-related research work (i.e. Title = (governance) AND Topic = (systems OR system OR systemic)); document type 'article' and 'review' (not including book reviews); language as 'English'. The search was further delimited to include only articles that also mention 'systems' (and its derivatives) in the relevant topic search fields. This was an important reduction step that significantly narrowed the search field and yet still remained inclusive to relevant works that write about governance within the context of a system. The system delimitation was an important distinction to other research available on governance that often specifically talks on a rather narrow view of the concept.

A digital copy of each identified full text of each article was then retrieved, excluding those that were identified as irrelevant (e.g. a book review or editorial). This pool of articles was considered the text for proceeding to the literature review process. All baseline articles were then converted to ASCII text files. This pre-formats the articles in order to enable the next step in the clustering process.

In stage 2, each ASCII text file was subjected to cluster analysis. Cluster text analysis was performed through the use of computer software. Articles were automatically processed using computer software in a textual analysis program. Stage 3 ensured the subsequent proper validation of the identified common thematic elements present in the articles.

The textual network clustering established conceptual linkages between different literature sources using textual frequency, location and relevance within the text. Clustering results were verified and validated by comparing the two modes of clustering undertaken in Stage 2. In Stage 3, clustering results were compared in terms of the themes identified and membership of the themes. In line with the earlier discussions, validation at this point was achieved in terms (1) obtaining well-structured clusters, (2) agreement with existing literature results and expert intuition, and (3) demonstrated stability robustness of the clusters found. Not involving any expert inputs in the validation steps, this enabled the advantages described earlier in the study to be fully realized, namely, the analysis and synthesis of large amounts of information, unable to be analyzed by a human-only system.

Content Analysis: The Emergent Themes

Governance Noun-Phrase Networks

Despite the broad reach of the concept, governance is not necessarily articulated consistently in theory and much more so practice. The content analysis method realizes the added value in determining the common coherent linkages of disparate concepts. Derived common conceptual threads were useful in articulating the thematic basis needed to produce a rigorous conceptual understanding of a meaningful "system governance" theory, framework and application development. This section present the results of the content analysis phase of the research.

The preliminary stage of the content analysis methodology consisted of generating noun-phrase information networks for the entire sampled set of literature as a whole and their aggregation into categorized groups (Groups 1 through 3). The results for the entire data set and those at the group level were found in Table 1 where the table only shows the top 25 words for clarity. The combined articles appearing in multidisciplinary publications within the 1992–2011 timeframe revealed a number of interesting features. First and foremost, the number of nodes—herein referring to the number of noun or noun phrase in the network—was 27,912. The density score was ~ 0.001 (the density score was determined by calculating the ratio of the number of network connections that directly links the nodes compared to how many linkages were possible within the network). The group influence score, which signifies the level of coherency of the entire network of noun phrases, was 0.069. Note that the density and group influence scores were standardized measures with minimum–maximum score ranging between [0,1].

When segregating the results according to different article categories (Groups 1, 2 and 3), the specific noun phrase network similarly demonstrate loosely connected networks. Moreover, it also demonstrated having a slightly higher level of group influence or focus for all groups with the exception of Group 2. In particular, the density of the texts segregated by group was similar to those for the "All Groups Combined" dataset (Table 1). For Group 1 articles, the number of nodes was 11,170. The density score and group influence score were 0.0014 and 0.074, respectively. In comparison, Group 2 has 16,007 nodes, 0.0013 density score and 0.05 group influence score. Rounding out the category, Group 3 has 13,500 nodes, 0.001 density score and 0.078 group influence score. The density scores range from a high of 0.00143 for Group 1 to a low of 0.0013 for both Groups 2 and 3. The Group influence values range from a high of 0.07789 for Group 3 and a low of 0.05102 for Group 2 ($M = 0.0947$, $SD = 0.014179$). These density and group influence scores suggest that the article texts selected are composed of fairly diverse discussions.

In addition to the descriptive node, density and group influence calculations of the selected dataset, the top influential words for all the groups of text were produced. As previously mentioned, the influence score is normalized and ranges from [0,1]. The higher the influence score, the more influential the word is.

Table 1 Noun phrase network summary information

All groups combined		Group 1—perspectives, reviews and meta-analysis		Group 2—highly cited		Group 3—recent articles from high IF journals	
Nodes	27,912	**Nodes**	11,170	**Nodes**	16,007	**Nodes**	13,500
Density	0.00086	**Density**	0.00143	**Density**	0.00131	**Density**	0.00133
Influence	0.06873	**Influence**	0.07483	**Influence**	0.05102	**Influence**	0.07789
Word	**Influence**	**Word**	**Influence**	**Word**	**Influence**	**Word**	**Influence**
System	0.04806	System	0.07503	System	0.05115	System	0.0549
Governance	0.03332	Governance	0.04446	Governance	0.04314	Governance	0.04619
Policy	0.0239	Management	0.0416	Policy	0.02553	Policy	0.02891
Management	0.02371	Fishery	0.03463	Management	0.0221	Management	0.02531
Change	0.01411	Policy	0.03222	State	0.0203	Food	0.01946
State	0.01275	Health	0.02465	Corporate	0.01832	Public	0.0178
Public	0.01211	Change	0.02309	Change	0.01742	Forest	0.01747
Social	0.01156	Social	0.0193	Firm	0.01709	Research	0.01636
New	0.01057	Ecosystem	0.01794	Industry	0.01341	State	0.01538
Research	0.01003	Process	0.01422	Company	0.01323	Social	0.01534
Process	0.01003	Environmental	0.01312	Director	0.01322	Change	0.01345
Resource	0.01002	Public	0.01295	University	0.01282	Resource	0.01312
Firm	0.00946	New	0.01206	Process	0.01197	Development	0.01184
Fishery	0.00897	Resource	0.01171	Environmental	0.01176	Model	0.01132
Environmental	0.00896	Development	0.01167	Economic	0.01174	University	0.01132
Forest	0.00885	Information	0.0116	Market	0.01174	Local	0.01094
University	0.00873	Climate	0.01148	Public	0.01166	Information	0.01043
Food	0.00859	Political	0.0112	Social	0.01163	Global	0.01023
Corporate	0.00847	Level	0.01084	Global	0.01122	Analysis	0.01005
Global	0.00836	Science	0.01071	Research	0.01102	Government	0.00966

Specifically, influence score of 0.10 or higher imply that the words are *significantly influential* which further implies of its tendency to become the center point tying together thoughts and meanings of the diverse text sampled. The more influential words across all the dataset and within each group include *system*, *governance*, *policy*, *management*, *change*, *social*, and *process*. Other influential words appearing denote specific domains or context of governance including *economy*, *market*, *fishery*, *health*, *ecosystem*, *environmental*, *corporate*, *food*, *forest*, *research*, and *water* to name a few. Still in others, influential words like *public*, *organization*, *government*, *director*, *organization*, *industry*, *firm*, and *university* highlight the diversity of entities involved in the process of governance. The influence of these words was interesting particularly because of the fact that it comes from multidisciplinary sources reflecting on separately distinct issues and problems. Although it should be expected that *system* and *governance* as the top influential words from the sampled dataset, it is still interesting to note that there were unanimous even though the context or perspective may be different. In particular, the results highlight *policy* and *management* as jointly important perspectives when it comes to the topic system governance. While the top influential words may present some interesting narratives and insights of themes characterizing the system governance literature, further thematic analysis was pursued to derive a refined perspective of the field.

Emerging Governance Themes

All literature identified and categorized in the previous section where further analyzed deeper for much more refined themes. Themes were identified based on state-of-the-art computer-assisted clustering Crawdad software [44]. Given the large-sized clusters detected across the scholarly literature sampled, several relevant system governance themes emerged and were discussed accordingly in this section.

A software built-in exploratory factor analysis (EFA) using the 250 most influential words appearing across three (3) or more articles within the sampled dataset of articles and publications was performed. Having computed the influence values as score values for each of the variables, EFA used principal components analysis (PCA) with varimax rotation to assess the underlying thematic structure of the body of abstract texts. Having designated an eigenvalue cutoff of two (2), those factors having values greater than the cut-off were extracted. As a result, we determined forty-eight (48) as the final number of factors to extract from the resulting factor solution. Using the top factor components identified, the EFA process provided a first look at emerging themes and provided a good basis to develop system governance themes. The eigenvalue cut-off resulting in 48 factors represents a combined explained variance of 82.63 %. As shown in Table 2 after rotation, the top 15 resulting factors accounted for 30.66 % of the dataset variance.

Table 2 Breaking down EFA % explained variance per factor component

Component	% of variance explained	Cumulative %
Factor 1	3.33	1.33
Factor 2	7.10	4.17
Factor 3	5.52	6.38
Factor 4	7.98	9.58
Factor 5	5.37	11.73
Factor 6	7.25	14.63
Factor 7	3.63	16.08
Factor 8	5.03	18.09
Factor 9	4.39	19.85
Factor 10	5.28	21.96
Factor 11	3.59	23.40
Factor 12	4.45	25.19
Factor 13	4.97	27.17
Factor 14	3.67	28.64
Factor 15	5.05	30.66

Note 1 Remaining factors 16 thru 48 accounts for 51.96 % of explained variance

The remaining component factors (Factors 16 thru 48) accounts to a combined explained variance of 51.96 % that brings the cumulative variance to 82.63 %.

Recall, from the first study objective which was to identify generalizable elements of governance. In relation to this, recall too the research question posed as *What are the distinctive characteristics of governance?* The preceding objective and research question provide the basis for further elaboration of themes as suggested from the sample of articles collected. The analysis of the relevant themes continued by using the rotated factor loadings to provide a preliminary basis for evaluating the emergent themes for the first 20 factors where only the highest loading components were included for clarity. As shown in Table 3, the first factor reflected strong factor loadings on influential words *performance*, *shareholder*, *investor*, *finance*, *firm*, *control*, and *market* (0.715, 0.714, 0.559, 0.539, 0.469, 0.400, and 0.390, respectively). For comparison purposes,

Table 4 shows the same factors but omitting the most influential list of words that appear in previous noun phrase information (as shown in Table 2). The comparison allows for thoroughness by also increasing the possibility of identifying useful terms other than the most influential ones. For instance, omitting the most influential words for the first factor introduced into the analysis more descriptive terms such as *corporate* (0.356) and *executive* (0.335). Moving to the second factor, the results show strong loading on the words *press*, *large*, *university*, *change*, *new*, *problem*, *international*, and *system* (in Table 3); add to that *human*, *institution*, *stakeholder,* and *theory* (in Table 4). The same process was performed for all the different factors thereby producing the rest of the tabular data presented in Tables 3 and 4. Together with the examination of the factor loadings, the texts from the dataset were reviewed. Additionally, a secondary latent coding analysis was performed to "logically connect words to themes and strengthen the face

Table 3 Factor loadings for the rotated factors

Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading
1	Performance	0.715	6	nsmd	0.992	11	Fishing	0.946	16	Stockholder	0.988
				Audience			Commission			Director	
	Shareholder	0.714		Pragmatic	0.984		Stakeholder	0.941		Reform	0.947
				Legitimacy			Stock			Investor	
	Investor	0.559		Environmental	0.959		Reform	0.489		Corporate	0.784
	Finance						Process			Board	
	Firm	0.539		Certification	0.512		Community	0.435		Law	0.714
	Control			Forestry							
	Market	0.469			0.445			0.397			0.449
		0.400			0.426			0.252			0.350
		0.390			0.318			0.248			0.267
2	Press	0.166	7	Transnational	0.964	12	Coordination	0.600	17	Product	0.961
	Large			Accountability			Assessment			Safety	0.434
	University	0.157		Global	0.946		Organizational	0.406		Information	
	Change			Network			Learning			Data	0.418
	New	0.154		International	0.621			0.401		Good	
	Problem			Actor			Commission			Environmental	0.239
	International	0.145		Governance	0.469		Cost	0.315			
							Pragmatic			Shareholder	0.236
	System	0.137			0.292		Level	0.262		Carbon	0.129
		0.134			0.284			0.236			0.125
		0.122			0.279			0.213			0.119
		0.117		National	0.253			0.155			

(continued)

Table 3 (continued)

Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading
3	Adaptive	0.847	8	Press	0.135	13	Theory	0.110	18	Governance	0.132
	Socio-ecological			Approach			Human				
		0.733		Management	0.130		Governance	0.098			0.105
	Resilience			Different							
		0.681		Problem	0.107			0.098			0.104
		0.630		Governance	0.105			0.078			0.100
		0.577			0.102			0.078		Control	0.097
										Data	
	Management	0.457			0.099		Business	0.077		Approach	0.095
							New			International	
					0.095		Institutional	0.077		Market	0.093
	Change	0.413		Institution			Change			State	
	Social										
	Ecosystem										
4	Emission	0.941	9	Executive	0.842	14	Urban	0.987	19	Incident	0.989
	Policy			Performance			City			Case	
	Federal	0.612		Company	0.506		Energy	0.986		Network	0.687
	Carbon			Innovation			Local			Federal	
								0.456		Control	0.605
		0.585		Board	0.425		Scale			Theory	
	Energy			International			New				
	Government	0.543		Business	0.412		Change	0.440		Research	0.495
	State	0.507			0.368			0.349			0.202
		0.422			0.332			0.263			0.163
		0.382			0.311			0.239			0.151

(continued)

Table 3 (continued)

Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading
5	Approach	0.136	10	Large	0.113	15	System	0.142	20	Press	0.139
	Public			Problem			Governance			University	0.119
		0.126		Stakeholder	0.104			0.126		Level	
	Group			Financial						Governance	0.111
				Stock	0.100			0.125			
	Business	0.106		Market							0.106
	Information			Action	0.094			0.100			
	Bank	0.102			0.093			0.095			0.106
							Press				0.105
	Board	0.100					Control	0.095			
					0.090		Change			Institutional	0.100
		0.097					National	0.094		Process	
		0.089			0.086		Large			Social	

Note Including words from influential list (first 20 factors only for clarity)

Table 4 Factor loadings for the rotated factors

Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading
1	Performance	0.715	6	Nsmd	0.992	11	Commission	0.941	16	Stockholder	0.988
		0.714		Audience	0.984			0.489			0.784
	Shareholder	0.559		Pragmatic			Stakeholder			Reform	
								0.435		Investor	0.714
		0.539		Legitimacy	0.959					Board	
							Stock	0.397		Law	0.350
							Reform			Executive	
	Investor	0.469		Certification			Community	0.248		Rule	0.267
	Finance	0.356			0.512		Rule				
	Control	0.335		Case				0.202			0.247
	Corporate			Organization	0.426		Control				
	Executive				0.196			0.162			0.239
					0.193						

(continued)

Table 4 (continued)

Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading
2	Press	0.166	7	Transnational	0.964	12	Coordination	0.600	17	Product	0.961
	Large	0.157			0.946			0.406		Safety	0.434
	Problem			Accountability			Assessment			Data	
	International	0.134			0.469		Organizational	0.401		Good	0.239
	Human									Shareholder	0.236
	Institution										0.125
	Stakeholder										0.119
	Theory									Carbon	0.078
										Law	0.049
								0.315		Standard	
								0.262			
								0.236			
				Network				0.213			
		0.122		International	0.292						
					0.284		Learning				
		0.112			0.253		Commission				
				Actor			Cost	0.112			
		0.102		National			Pragmatic				
				Legitimacy	0.245		Agency				
		0.098		Approach	0.105						
		0.097									

(continued)

Table 4 (continued)

Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading
3	Adaptive	0.847	8	Press	0.135	13	Theory	0.110	18	Data	0.104
	Socio-ecological	0.733		Approach	0.130		Human	0.098		Approach	0.100
				Different			Business			International	
	Resilience	0.681		Problem	0.105		Institutional	0.078			0.097
	Human			Institution	0.102		Control	0.077		Stakeholder	0.061
		0.297		Society			Data			Institution	0.061
	Group			Study	0.095		Stakeholder	0.072		Performance	
	Learning	0.248		Data							0.058
	Society				0.095		Model	0.072		Value	
	Agency	0.243			0.093			0.068		Service	0.056
		0.207			0.090			0.68			0.054
		0.196									
4	Emission	0.941	9	Executive	0.842	14	Urban	0.987	19	Incident	0.989
	Federal	0.585		Performance	0.506		City	0.986		Case	0.687
	Carbon						Energy			Network	
	Energy	0.543		Innovation	0.412		Scale	0.456		Federal	0.605
		0.507			0.368			0.349			0.495
										Control	0.202
										Theory	0.163
							Institutional	0.190		Actor	0.126
					0.332		Emission	0.165			
		0.422		Board	0.311		Problem	0.150			
				International	0.196						
		0.151		V							
	Government			Ownership							
	National	0.124									
	International										

(continued)

Table 4 (continued)

Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading	Factor	Component	Loading
5	Approach	0.136	10	Large	0.113	15	Press	0.125	20	Press	0.139
	Group	0.106		Problem	0.104		Control	0.100		Institutional	0.106
	Business			Stakeholder			National				
	Bank	0.102			0.100		Large	0.095		Control	0.080
	Board			Financial			Group			Area	
	Human	0.097		Stock	0.094		Action	0.094		Society	0.076
	Organization			Action			Theory			Executive	0.075
		0.089		Scale	0.093			0.089		Theory	0.073
		0.088			0.086			0.074			0.070
		0.081			0.073			0.071			

Note Excluding words from influential list (first 20 factors only for clarity) validity of the theme" (Tate et al. [45], p. 25). These two data considerations were synthesized to express the dataset themes. Starting with the rotated factor solution, descriptive labels in each factor was generated. The labels indicated the themes that were logically inherent in the texts (or components) associated with each of the factors. The emergent final themes were then presented in Table 5.

The first theme emerging from the dataset was concerning open-system issues and combined factors 2 and 7. Although the texts were reflected from different contexts (international development and global environment), some of the consistent key terms referenced to this theme (and as reinforced by its associated factors) were *legitimacy*, *accountability*, *deliberative*, *discourse* and *public*. An implication would be that the assumed boundaries need to be enlarged to include those beyond the traditional notions of an organization or a system in general. Unlike in closed-systems where boundaries are more definite, decision making in this new context need to be deliberated in discourse (with the public as an additional stakeholder) and also with enlarged new concerns for legitimacy and accountability of authorities as it applies to their decision making processes.

The next theme, *Operational quality standards*, is another resonant research topic reflected by Factors 6 and 12. Strong loading on the following components represent this theme including: *quality*, *service*, *improvement*, *standards*, *safety*, *assessment*, and, *external certification*. The related articles that strongly emphasize these themes reveal a deeper context of large complex systems, specifically in pertinent areas of healthcare, clinical practice, and hospital systems among others. In closer review, the needs for quality and safety system practices are highlighting current challenges to service-intensive and publicly-scrutinized aspects of the health care system. This is consistent with the domain of contemporary governance systems where the larger involvement of external stakeholders (e.g. the public) in a healthcare practice would require certain incorporation of quality and service standards to appease the plurality of interests that are entangled within the operation-level decision-making processes.

Closely related to the previous theme, the next theme *New regulatory tools* highlight a different set of themes as reflected by strong loadings (Factors 17 and 18) on the components as follows: *standards*, *policy*, *traceability*, and *certification*. Whereas the previous theme reflects the clamor for solutions to problems at the operational level, this current theme reflects the needs for enhanced regulation at the higher levels of policy which does not necessarily exists within the influence or control of an organization or system. It is also a reflection of the interconnectedness of multiple systems. Articles reflecting these theme reports on the importance of recognize higher level systems in addition to the current level system at issue. External standard, traceability and third-party certification was meant to regulate processes and interactions between disparate large systems involved in food or agricultural supply value chains, for instance between the global food markets, the consumer, the private and public enterprises, and the state.

Recognizing multiple perspectives is the next dominant theme emerging from the dataset. It shows strong loading on components like *adaptive*, *management*, *governance*, *policy*, *local*, *global*, and *scale* (Factors 3, 10, and 14). The specific context

Table 5 Emerging themes on system governance

Emergent themes	Descriptive components	Factors
Theme 1. Extending boundaries beyond the organization	Legitimacy, accountability, deliberative, discourse, public	2, 7
Theme 2. Operational quality standards	Quality, service, improvement, standards, safety, assessment, external certification	6, 12
Theme 3. New regulatory tools	Standards and policy, traceability, certification	17, 18
Theme 4. Recognizing multiple perspectives	Adaptive, management, governance, policy, local, global, scale	3, 10, 14
Theme 5. Enhanced performance monitoring	Financial, value, incentive, corporation, control, ownership, board	1, 9, 16
Theme 6. Evolving governance structures and organization	New, change, network, industry, corporate, school, company, organization, market	10, 13, 19, 20
Theme 7. Advancing analytic tools	Ostrom, rules, economic, game, theory, institution, analysis, common, resource change, management, information, research, process, social, public	11, 13, 14
Subtheme 7a. Institutional analysis		4, 5, 8,15, 20
Subtheme 7b. Group policy development		
Theme 8. Implementation modeling	Complex, adaptive, systems, levels, resilience action, coordination, learning, organizational, pragmatic	3, 13
Subtheme 8a. Conceptual approaches		6, 11, 12
Subtheme 8b. Action learning-based approaches		

of articles that reflect the theme focuses on bridging the gap between diverging views of governance like policy versus management, social and ecological, local versus global, and scalability from human to institutional resource levels. Frequent terms associated with this theme is the need for adaptive measures—to enhance resilience and to improve the learning capacities with regards the relevant changes. This is another closely familiar theme to systemic thinking which also considers incorporating multiple perspectives to large, complex problem situations.

The fifth theme, *Enhanced performance monitoring*, is one theme that emerged within the context of system governance. Although most of the articles that capture this theme emanate from the wider context of financial markets and related industries, the strong loading on the components: *financial*, *value*, *incentive*, *corporation*, *control*, *ownership*, and *board* (Factors 1, 9 and 16) signify the much more general need for specific governance performance mechanisms (e.g. incentives, board structure, and ownership influence, etc.) to ensure greater value is promoted. Performance monitoring is indeed a very important governance theme whilst to embed control in the design of any system of interest.

Another emerging theme is *Evolving governance structures and organization* which at its core reflects the need for better governance structures within and beyond any organization or initiative. It recognizes that whereas existing structures are acknowledged to exist, new or better changes to its governance structure have to take place. These themes highlight strong loadings on the factor components: *new*, *change*, *network*, *industry*, *corporate*, *school*, *company*, *organization*, and *market* (Factors 10, 13, 19 and 20). In particular, the component *network* strongly implies a structural dimension to system governance and is in itself an increasingly strong topic in governance, having its own body of multidisciplinary literature (e.g. network governance) that broadens the scope of any system of governance across traditional governance disciplines and areas of practice.

Several factors combined to create the major theme of *Advancing analytic tools* which comprised of factors 4, 5, 8, 11, 13, 14, 15, and 20. After reviewing several of the texts associated with the influential words from this theme, the sub-theme *Institutional analysis* became apparent within the major theme of *Advancing analytic tools*. Another sub-theme that seemed to reveal itself from the *Advancing analytic tools* was *Group policy development*. For the *Institutional analysis* sub-theme, the texts highlighting the sub-theme include: *Ostrom*, *rules*, *economic*, *game*, *theory*, *institution*, *analysis*, *common*, and *resource* (Factors 11, 13 and 14) which appear to index Nobel-prize winning work by Elinor Ostrom's and her colleagues on an integrated framework to analyze institutional rules at work in common-pool resource governance problems. From this theme, it highlights the importance of advanced analytical frameworks incorporating into governance practice the latest in game theory and economic modeling approaches. *Group policy development* is the second sub-theme of the *Advancing analytic tools* theme and the words found in factors 4, 5, 8, 15, and 20 ways to engage and manage group initiatives through collective, collaboration, and coordination in the texts. The components *change*, *management*, *information*, *research*, *process*, *social*, and *public* all provided perspectives about this theme; some of the articles were directly related to various complex system issues pertaining to forestry governance, climate change, emergence of nanotechnologies, energy and innovation policy to name a few. In all of these discussions, it highlights the need for new analytic approaches to collectively analyze and inform the mobilization of group-based multilevel efforts to address the complex issues involved. All together these two sub-themes comprise the larger theme of developing or introducing new enhanced analytic approaches to analyze and guide a governance system.

Lastly, the final theme (e.g. *Implementation modeling*) that emerged from the dataset is again comprised of two subthemes. The words associated with rotated factors 3 and 13 all reference a major subtheme, *Conceptual approaches*, and the texts that the influential words (*complex*, *adaptive*, *systems*, *levels*, *resilience*) of each factor point to support it. Breaking down the *Implementation modeling* theme further, the texts associated with the influential words of factor 6, 11, 12 supports a sub-theme of *Action learning-based approaches*. In this sub-theme, the specific component indicate strong loading on the terms *action*, *coordination*, *learning*, *organizational*, and *pragmatic*. Although the theme, *Implementation modeling: Conceptual approaches*, addresses articles discussing the trend of adopting new concepts terms not traditionally associated with the practice of governance and outside its own disciplines, the sub-theme *Implementation modeling: Action learning-based approaches* recognizes articles discussing result-driven approaches that need to be adopted within involved organization or components of governance systems. Altogether, both subthemes comprise an emergent complementary schema to model and implement governance systems. It entails the necessity to engineer a pragmatic approach that encompasses new conceptual theoretical advances but still firmly implanted on delivering results through action and collective engagement.

Conclusion and Recommendations

The content analysis phase of the research yielded several interesting themes relevant to system governance. In relation to the first study objective, the earlier discussed themes is an identification of the different generalizable elements of governance which was in response to the research question posed as “What are the distinctive characteristics of governance?” Since the research purpose was for an integrated articulation of the philosophical, theoretical, axiomatic and methodological basis for system governance, and the research objectives attempts for a comprehensive theoretical formulation, the content analysis results have produced a set of closely interrelated themes (8 major themes with 4 sub-themes in 2 of the major thematic categories). These themes are broad and multidisciplinary in order to take into account the wide range of definitional, conceptual, operational and theoretical similarities and differences pervasive in this “governance” research domain. Each of these themes will help to inform and properly contextualize the system framework development phase that follows next in the research agenda.

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Capacities and Governance in Kenya: Lessons in Technology Transfer

J. Otto Kroesen and David J. Ndegwah

Abstract First, the authors set the scene by exploring the main lines of the present development debate. They take a nuanced stand, not only looking at failures of Western development initiatives, but also going into the internal dynamics of African societies that stand in the way of social and economic development. Next, authors present some case studies of entrepreneurial development initiatives in Kenya. These cases show the difficulties in terms of organization and capacities such initiatives have to deal with and they take into consideration the bigger picture in terms of sector development, regulation, and finally civil society and governance issues. Kenya is caught up between a value set of traditional values adapted to small-scale ethnic societies, which doesn't exercise its cohesive function like it once did and the modern large-scale and open civil society values, which are not yet fully in place. Authors contend that progress must involve a mutual reinforcement involving combination of entrepreneurial skills and capacities (i.e. initiatives from below and adequate institutionalization and regulation from above).

Keywords Technology transfer · Entrepreneurship · Cultural and institutional transition · Civil society

Introduction

In 2007 the board of the TU Delft decided to give cooperation with, and technology transfer to Africa a high priority on its agenda. Lustrum activities were devoted to Africa. Since that time, especially within the framework of the minor

J. O. Kroesen (✉)
Department of Values, TPM, TU Delft, Jaffalaan 5 2628 BX Delft, The Netherland
e-mail: J.O.Kroesen@TUDelf.nl

D. J. Ndegwah
Jaramogi Oginga Odinga University of Science and Technology, School of Education and Social Sciences, P.O. Box 210Bondo, Kenya

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'International entrepreneurship and Development', many internships were completed in technology transfer, innovation and sustainable entrepreneurship in Africa. Besides that a number of master theses combined with entrepreneurial internships were completed.

This contribution especially focuses on Kenya, where an extensive internship program has been developed in cooperation with NGOs, entrepreneurs and universities, especially with teachers from Jomo Kenyatta University, Tangaza College and Jaramogi Oginga Odinga University of Science and Technology. Some case studies from Kenya will be reported and experiences, both in terms of obstacles and opportunities will be evaluated with a view on further steps to be taken. Before going into these case studies the reader will be introduced to the development debate and its different and competing positions, as well as the socio-cultural dynamics of the sub-Saharan countries in order to set the scene.

Both opportunities and obstacles have been discovered. Among the opportunities are the discovery of many relevant partners and initiatives: entrepreneurial, from NGOs, vocational training and higher learning institutions. Among the barriers are the strong compartmentalization of the African society, insufficiently universalistic governance, a relatively weak civil society interaction, insufficient development of skills and capacities.

The Development Debate Focused on Sub-Saharan Africa

What is it in the African culture that stands in the way of modernization? We echo some voices from the debate without aiming at completeness. Sachs [1] mentions the poverty trap as a self-perpetuating vicious circle; while Collier [2] adds other traps like the land lock trap (say, being surrounded by badly functioning neighbours, without opening to the sea), the civil war trap (once a civil war has happened it is very difficult to build up the economy, because of lack of trust; which, in the end, leads to more civil wars), the natural resources trap (revenues from natural resources make it possible for autocratic leaderships to evade democratic elections). Easterly [3] adds the Western habit of making big plans to the list, which mostly are designed to suit the Western electorate ('We are doing something about it!') and show no accountability to the poor they claim to help. He further mentions insufficient professionalism with the donors, who want to be involved in everything and refuse to specialize and professionalize in anything. Chang [4] primarily criticizes neo-liberal economic policies of the 'unholy trinity' of the IMF, the World Bank and the WTO, constantly calling for a 'level playing field' [4] between unequal forces. In effect such neo-liberal policies, following the *ad hoc* streams of capital, prevent developing countries from installing effective long-term industrial policies and building up productive capabilities. And yet such capabilities need a long-term investment in order to flourish, even though this requirement doesn't meet the demands of present-day neoliberal economy, which claims that immediate profitability is more important and that capital streams should merely follow the highest revenue. If, however, capital flows only go after short-term gains, no long-term productive capability can ever be built. Instead, it is often destroyed if a short-term competitive advantage robs existing technicians and professionals of their jobs, making their capacities useless.

All of this may be true, also true in Africa, but nevertheless experts in development are also increasingly pointing the finger at the African actors and stakeholders, especially the leadership, as causes of persistent poverty. Robert Calderisi mentions mismanagement of the political leadership, high production and distribution costs, a poor investment climate and lack of unified policies among African states [5]. He also criticizes the political correctness, due to colonial history and slavery, of the West, as giving 'a final touch to Africa's misery'. On his part, Roel van der Veen gives an insight into the tribulations that Africa has faced right from the time of the Cold War; the economic decline the continent went through, the many civil wars, of which some amounted to genocide (as it happened in Rwanda, in 1994) and finally the disintegration of some states: as witnessed in Somalia, twenty years after the overthrow of Mohamed Siad Barre [6]. He points out that the failure of Africa to develop can be blamed on internal as well as external factors, as most people have always done, but he insists that external factors are not the overriding cause. He has finally blamed this state of affairs on misappropriation of funds from the donors, selfishness and greed, among the leaders; all of which can be summed up in one word—corruption [6]. Maybe one of the most radical solutions for development has been proposed by Dambisa Moyo by arguing that development aid as such should stop, especially government to government aid [7]. That, in her perspective, would force African governments to be more accountable to their populations. Although this last point may be true, at least in some cases, nevertheless, merely stopping all development aid doesn't solve the aforementioned capacity problem either. If untrained and uneducated masses have to compete on the international market with a well-trained and well-educated labour force elsewhere in the world the division of losers and winners is quite predictable.

Looking at the broader picture of development approaches Gasper [8] gives an overview of five decades of development; he criticizes the emphasis on development in purely economic terms of the early years. Some large projects involved conscious sacrificing of the well-being of certain groups like indigenous peoples whose land and resources were taken from them. The structural adjustment programs of the World Bank often made things worse; because the concentration on the Gross Domestic Product (GDP) growth does not say much about the distribution of welfare and general employment. Merely cutting the budgets enlarges the gap between those who have access to state services and those who haven't. The so-called efficient development aid is not helpful, either, because it often did not answer the question: 'efficient in what respect'? Efficiency also implies certain assumptions and beliefs concerning what can be considered as valuable and what cannot. He, therefore, welcomes the broadening of the ideas on development in the 1990s; including matters of personal security and societal peace. This broadening of the development approach became necessary, to a large extent, due to the neoliberal so-called economic 'reforms', which have set in motion a process of socio–political decay. The reason for this is that cutting budgets mostly also means cutting productive power and capacity.

Whereas, during the 1980s, comparative economics was in the driver's seat, in the 1990s the many conflicts, in Africa and around the world, in developing countries, led to new views on development. People should at least be able to exercise their humanity. The rights-based approach and the capabilities approach entered the scene of the development debate. The capability approach makes us look at a set of life options that every person has, or should have. Des Gasper values the approach of Amartya Sen, in the sense that he emphasizes positive freedoms and capacities to achieve things, which one has reason to value [9]. The 'good life' in this approach, a life which is worth living, once more becomes part of the development debate. Interestingly, Des Gasper also calls attention to the so-called 'significative values'. Only if people feel they need a meaningful life, do they find inspiration to work hard and get disciplined. These 'significative values' give meaning to life and are often religious, in origin. And yet, he laments that 'Despite the pre-eminence of religions historically and still in the lives of vast numbers of people, development discourse has largely ignored them' [8]. This brings us to the role of culture.

Traditional African Values

We would like to call for attention to the original unity of religious and social or cultural values; which, in the African context, are one and the same thing. Traditionally it was impossible to separate respect for the elders from belief in the authority of the ancestors, the first being a social value, while the second is a religious belief. We, however, see that this is not always the case any longer; in the name of being enlightened or developed (often put pejoratively—we are not backward!). And yet in the traditional African culture these two dovetail into each other, and are not separable. The word culture itself is derivative of another English word, 'cult', signifying the religious origin of the so-called cultural values; as it does in other languages of the Western society too. For this reason, we would like to analyse the deeper meaning giving cultural layers and mindsets. Religious or not, people in Africa as elsewhere are driven and motivated by strong values which are seated in deep existential layers.

Calderisi gives a short survey of the African values, attributing the typical communal values of Africa to its harsh natural circumstances. Traditionally, he says, only harmonious groups, families and tribal relationships could help to surmount the obstacles thrown up by nature [5]. In addition Africans live in the here and now and enjoy life as it is; which can lead to remarkable paradoxes. An international survey, in 2003, found that Nigeria, despite its dictatorship and corruption, had the highest percentage of happy people in the world. Authority is venerated; people do not easily speak out in a group, while a large group of uneducated Africans are fatalistic, and feel there is little they can do to control events. In general Africans are patient and endure long periods of suffering—a quality without which Africa could not have survived its tribulations, according to Calderisi.

Traditionally indeed, Africa, throughout history, has been mainly organized in tribal societies. These tribal formations showed delicate equilibriums in power and jurisdiction between men and women and between old and young. There was authority, difference in status and power, but there also were countervailing forces. For instance, the age groups would come to power, rule for a limited time, and then abdicate. This system worked well in the sense that it created equilibrium of powers and promoted internal cohesion of social groups coming to power the one after the other. This was important in a vast continent, like Africa is, where in case of disagreement and conflict it was always possible to flee and join another tribe or start a new one. This system also met the requirements of the small scale of a nomad or agrarian society, organizing groups between 300 and 3,000 people. It cannot be expected that this social system can also serve the needs of a society of millions of people, mixed and organized by modern institutions and sophisticated technology. An important question, at this juncture, is: how much of the old mentality of autocratic chiefs (ruling over 300 to 10,000 people) has gone into the mentality of modern dictatorial leaders like, Amin, Ngueso, Mobutu and Mugabe, among many others; now ruling over millions of people and doing so with the help of sophisticated institutions and technology?

This is, however, not to say that other parts of the world have not produced their share of bad leaders. It is not a matter of bad or good leaders. In the present situation the checks and balances of the old system are gone; and yet new ones, suitable to present needs, are not yet in place. On the one hand, without modern technology, serving the centralized administration, such dictatorial political units would not have been possible. The autocratic rule of the old chiefs is transplanted into a context of modern communication, transportation, and, not to forget, military technology. Originally the power of the chiefs was kept in check by the age group system, by which in general a closely knit together group of men of about the same age would come to power and devolve their office after about 15 years [10]. At the high point of colonialism there were still no more than a thousand British civil servants administering the whole of Africa. They ruled by means of the chiefs they appointed, and beckoned at will by their military force. By this system colonialism reinforced the autocratic authority of the African chiefs, because the English administration used the chiefs as intermediaries [3], who could now bypass the old-time delicate system of equilibriums and checks and balances. However, the patriarchal community values, by which these chiefs ruled small political units turn into dictatorial control, if transplanted to bigger and modern political units, especially if they are, thanks to mineral resources or outside support, not dependent on consent of their own population in order to maintain power. The authoritarian paternalism of the old tribes can easily turn into dictatorial despotism in the new situation, which is provided with a powerful government bureaucracy and making use of modern technology. The devil—so to say—does not change the label if he changes the content of the bottle.

Civil Society and Governance

Although traditional values underwent such deformation institutional checks and balances, like a free press, independent judiciary, independent accountancy of expenditures, a strong civil society and so forth, are often not functioning. Old checks and balances disappeared, while new ones are not yet in place. At the background of this scenario is the complex relationship between state and society [11–13]. Good governance requires a strong state, setting rules and standards, as well as accountability towards its citizens. These are in themselves opposing forces; and yet, both the citizens and the state should act according to universalistic rules and roles, also without thirdly granting privileges and promoting particularistic relationships [14]. An open civil society can only function if a strong and accountable government enforces such universalistic rules, so that particularistic mindsets and patronage systems cannot obstruct an open process of constantly regrouping of social actors [14, 15], which is indispensable for innovation. If collectivistic political parties, which only serve their own ethnic or regional constituencies, conquer the state bureaucracy, they easily destroy the delicate system of equilibrium between a strong state, on one side and strong universalistic rule on the other side, which is supposed to maintain equal access to the state power for all citizens. In line with this analysis Gyekye [16] sees development bottlenecks in Africa within cultural practices that do not help in building a modern society. These are: (1) a negative attitude towards science; (2) ethnicity over and above humanity; (3) apathy towards public service and (4) primacy of the community over the individual. For him, an emphasis on educational and training programs in science and technology can go a long way to help and turn round cultural attitudes. A substitution of the bottlenecks related to extreme communitarianism with a stronger focus on individual responsibility and equality could obtain a credible dialogue with modernity. Indeed, as Nyasani [17] observes, '…Africa which is hankering after the attainment of the Western model of development cannot actually achieve it without changing its reveterate habits and attitudes in the most radical and deliberate manner possible in tune with the West's development fervour, pace and rigour.' Museveni [18] is even more pessimistic on the continent's economic survival: 'Societies that do not master science and technology will either be slaves, surviving at the mercy and sufferance of others, or will perish altogether.' In this regard we need to note that technology and large scale cooperation have implications on each other. New technologies can only become affordable if they are produced on a large scale, which implies cooperation of many different actors. It also implies a standardization of institutional, logistical and technical procedures. The history of Europe shows a complicated process in which technical development, large-scale governance, and an open civil society came into existence in such a mutually reinforcing process [19].

Entrepreneurial Activities and Their Context

The attention for rights, capacities and social values in development theory has grown along with the emergence of another development approach, i.e., development by entrepreneurship. For a long time the development debate has been dominated by a community approach. Local communities were to be organized to take responsibility for their development by means of participation and involvement in community-based programs and community committees [20]. In this approach institution building and a common support base for the creation of equal access to basic services were of primary importance. However, in recent years the emphasis shifted towards entrepreneurship. The millions at the bottom of the pyramid were considered as consumers and producers [21]. Where Prahalad initially focused on large-scale enterprises producing cheap commodities for mass consumption in developing countries, others came in with the idea of bottom to bottom business ventures. They put more confidence in many small-scale initiatives, since markets at the bottom of the pyramid are difficult to penetrate by large scale one-size-fits-all entrepreneurial approaches. If productive capacities and business skills are lacking small enterprises which are thoroughly contextualized can have a bigger impact [22]. As will be corroborated by the case material presented below, however, such small-scale initiatives need to be embedded in larger scale policies, visions and therefore within the framework of complete innovation systems [23] in order to be effective. They also will have to take the cultural specificities into account in their management system and capacity development, including cross-cultural learning processes [24]. Some cases will be put forward as illustrations of this complicated process, and to show the links between small-scale entrepreneurial initiatives and the large-scale analysis of governance and civil society. They will also help to underline the importance of a well ordered regulatory framework as a necessary precondition to make those local initiatives flourish.

Solid Waste Management in Nairobi

In Nairobi students from the Technical University Delft studied the business model of different solid waste recycling companies [25]. It appears that a business in the recycling of solid waste has to operate in a challenging and complex environment. The defunct Nairobi City Council (NCC) charged every area in Nairobi for waste collection. But NCC did not have enough equipment itself to pick up all the waste. Since the 1990s the quantity of waste increased, whereas the number of trucks to collect it decreased. There were 1,000 tons of waste per day and 100 trucks in the 1970s and 1980s, but in the 1990s the waste increased to 1,600 tons per day and the number of trucks decreased to 40. During the research there was 2,400 tons of waste per day. For that reason 80 % of all the waste was picked up by either community-based organizations or small and medium enterprises.

Although there were a lot of laws and policies related to solid waste management, actually and effectively a broader policy framework is lacking. Targets were set for the amount of waste to be collected and the amount of trees and public gardens in Nairobi. Every quarter there was an evaluation of these targets and new targets were set for the next quarter. Besides that NCC has divided Nairobi into different zones for waste collection. Officially the collectors could only pick up waste in the zones that were assigned to them, but due to lack of law enforcement in practice the collectors could collect wherever they want. Most collectors, especially the smaller ones, collected waste only in their neighborhood. Plastic was the most valuable product to be recycled. Occasionally it occured that the competition had already picked up all the plastic and the collectors had to go to another place. A lot of areas in Nairobi were partially or completely not served by the NCC or any other collection company. Nevertheless competition in the solid waste sector was really stiff, exactly because it was not regulated at all. Illegal dumping was not prevented and not controlled by NCC, although it was one of the causes of unfair competition. Companies were sometimes afraid to invest also because of the uncertain future in view of the legislation on waste collection companies and truck requirements. Other complaints about NCC were that sometimes plastic recyclers had to pay a corruption (dubbed 'protection') fee; moreover, NCC made top-down decisions without consultation of collecting companies, which led to legislation and statistics based on theory instead of practice and experience. In the long run, there was no cooperation between the collection companies and the NCC.

After collecting the solid waste the companies started separating the plastic. Sometimes this was already done during transport. In order to add value plastics were sorted by color and type. Then it was washed in a big tank and cut to pieces by a machine and finally it is put in bags. It could be sold in a minimum amount of one and a half ton. At another project bones were also reused and toxic waste was dealt with by means of incinerators and the rest of the waste, which is useless, was dumped.

There were many companies working together with community-based organizations, which collected the waste and brought it to the collection place. Most of the companies also had a goal to help the community and create jobs. This was a reason for them to employ street boys. One of the biggest challenges for solid waste management was insufficient organization so that waste is piled up at the source. In addition there were other challenges for small companies, like pay delay of customers, the high cost of the operations, poor infrastructure, harassment by NCC, high costs of operation licenses, obstacles to recycling and the insecurity of the dump site. Then there was lack of protective gear as well as equipment and limited space.

The students came up with some suggestions for a start-up company. Their advisory business plan proposed to start on a small scale, not to buy land and to sort the waste in the truck by which it is collected. To that end a truck should be bought (cheaper than hiring) and besides the manager and the driver two sorters should be hired. With a number of 85 residential and commercial clients such a company would be able to realize modest positive revenue. Included in their final advice was a small amount of payment to the street boys in the neighborhood in order to prevent the truck from being damaged and also such provisions as buying not worn out but secondhand tires for the truck, because that would be less expensive and more reliable than buying new ones, of which the quality is not guaranteed.

The Case of Wind Energy

The main focus of this project carried out in Nanyuki region, was on transferring Western-based knowledge to Kenyan stakeholders so that Small Wind Turbine (SWT) activities would continue after departure of the Western internship students [26]. The NGO where the students worked was interested in a working wind turbine for own usage, but was not eager to learn about the technology itself. The student groups succeeded in collaborating with a local welder (popularly referred to as *Jua Kali*, Artisan) from Naro Moru to manufacture a small wind turbine. Despite the rather straightforward technology and the welder's enthusiasm to cooperate, it took some effort for the welder to build a small wind turbine all by himself. The reason was not only that the technology was new, but also his lack of confidence and a dependent attitude towards what he considered as the experts. For example, in the beginning, the welder was over-reliant on the students' opinion and lacked initiative, despite the students' efforts to support rather than control the welder in the SWT manufacturing. Furthermore, once the welder had succeeded in building an SWT with little external help, he handed in a project proposal to NGOs for generating funds for continuing his SWT activities instead of approaching a bank for a loan. So much was it out of his scope to implement the technology in a businesslike way.

Although the primary determinant for sector growth is entrepreneurship [22], only a few retailers are actively selling imported SWTs, and only recently a second local SWT manufacturer has entered the market. This lack of entrepreneurial activities has its reasons. For many years political uncertainty and corruption were the main obstacles for individuals to engage in, or start a new business. Bribery was a common practice, and only those with good political connections were able to successfully venture into business. For example, tenders did not go to the best proposals, but to the one which was part of the right circle or patrimonial system. Since the demise of the Kanu regime in 2002 and especially after the promulgation of the new constitution of 2010, corruption has significantly reduced. However, fraud is still ingrained in the Kenyan society, and still commonly occurs in both the public and private sector. Furthermore, despite the improvements mentioned, the government still has a bad reputation regarding corruption. In particular, the removal of the immediate director of Kenya Anticorruption Authority (KACA), P.L.O. Lumumba and his deputies, is seen as a case of corruption fighting back. Still, people do not trust the government, and would rather avoid government officials than work with them.

A practical manifestation of this attitude is the attempt by one of the interns to get market information and wind data, which are two crucial pieces of informationrequired to carry out SWT experiments or start a business, from the government. Unfortunately, she could not access such data because she was required to pay for it. It is clear that such a policy puts obstacles in the way for the promotion of wind energy instead of supporting it. Later a government official confirmed that actually such wind data are supposed to be available for free, which apparently confirms that existing practices do not meet the standards of official policies. Furthermore, universities and companies, which are, or have been, involved in small wind turbines all have collected their own wind data sets and have fragmented market knowledge. This information is not shared amongst the industry players and the individual actors are left with insufficient data to develop appropriate products or successfully commercialize them. Even though the SWT companies also lack financial resources to set up a public awareness campaign, they have not marshaled forces for launching anything like that.

As previously mentioned, the high upfront investment is a key barrier for end-users to purchase a small wind turbine. The majority of the financial institutions have unfortunately been reluctant to support the purchase of SWTs, since there is lack of awareness of the technology and the business opportunities of energy products in general are not recognized. Consequently, no appropriate financing mechanisms for SWTs have been developed so far.

Generally, there are hardly any linkages between the different Kenyan SWT actors; and there is no common knowledge or database on the SWT technology and user experiences. Thus every time a new actor initiates an SWT experiment, he or she is starting from scratch instead of building upon gained experiences.

The Case for Solar Energy

Another internship student, Max Tack, conducted a master thesis study in Kenya on the implementation of solar energy technology and the impact of cultural characteristics on that [27]. He did an internship at Sunrays Solar, a medium-sized solar energy technology company in Kenya, and conducted many expert interviews, concentrating on the creation of stakeholder networks. This is difficult in Kenya because of a general lack of cooperation and a climate of selective trust, whereby one can only invest in a selected few that one knows all too well. He connected his analysis and findings to theories on culture from Hofstede [28] and Trompenaars [29].

Specific cultural characteristics, which have a long tradition in tribal Africa, may explain the situation. These cultural characteristics also play their part in the other cases put forward already. In the first place there is a strong *collectivist* attitude, which means, that generally people are part of closed ‘we’ groups. This can be the tribe or clan, or a patronage or clientele system, but also a company or a governmental organization, or even an NGO. There is competition, but no cooperation. The consequence of this attitude is that competing companies do not cooperate in efforts to enlarge the market, say, by organizing an advertisement campaign together. In addition there is no cooperation within the sector, to put in place regulations and agreements in order to maintain the quality of the products. On the contrary, the recently founded sector of solar energy organization has set high fees for membership, thereby making it difficult for new companies to enter the market. Lack of regulation also makes it easy for 'crook companies' to spoil the market by selling bad products, which become idle after a while. This is detrimental to the reputation of solar energy in general, because the technology itself gets blamed instead of the bad organization and management.

Secondly, in Kenya there is strong *particularism*, which means that generally not rules but relationships are important and, therefore, affective relationships, likes and dislikes, preclude neutral and role dependent behavior. People of high status, or of the same group, or simply people who know and trust each other, receive a preferential treatment. This also affects the regulatory body of the government (Kenya Bureau ofStandard – KEBS), which has been called into being recently. It is important to have access to high status government officials, in order to keep the company going, because it is easy for the bureaucracy to create obstacles for companies, for instance, by postponing their license, or simply delaying some important papers for the operation of the company. This means that some big players, who are well connected to politicians, actually control the market. Customers too find their way to companies via personal relationships. They do not trust a company, but they trust a person. If this person moves to another company, his customers will follow suit. There is no anonymous trust like one can expect in a situation where everybody plays by the rules, and treats everybody on an equal footing.

Thirdly, *status* usually is derived from the position within a company or group, not by achievement or by labor. Usually this also means that employees work on their status within the group and their relation with the boss more than concentrating on performance and on work and labor. Not much attention is given to maintain good relationships with the users.

In the fourth place, *sequential* dealing with time, i.e., planning and looking forward, is not strongly developed. From their side users too do not bother about a maintenance contract. Of course it costs money and their hope is that future days will take care of future problems. Apart from lack of cooperation and of networking between users and companies, there is also lack of cooperation with knowledge institutes. There is strong *traditionalism* which means that things remain as they are and as a consequence, even if there are problems, nobody takes the initiative and everybody is inclined to remain waiting. People recognize that there would be much benefit in having knowledge institutes, like universities, involved in the development of solar energy, if asked. But they are inclined to wait for the other party to start.

Traditionalism and *fatalism,* to accept things like they are, like rain and sunshine, are closely connected. These attitudes are part of a collectivist mindset that prevents people from going against the group and start something new. *Creativity* means loneliness, but also initiative. In this regard, another cultural characteristic is also involved, i.e. *uncertainty avoidance*. Facing uncertainty of course means to face an unknown future and often implies to go a lonely way forward into novelty. Generally, people are inclined to avoid situations they do not know for certain how to deal with, lest one does something wrong. Generally, the cultural characteristics summarized here, and described by our master student in his interview reports, are typical of closed in-group societies like tribal and agrarian societies, not to open markets and to open civil society oriented societies [13].

Conclusion

The state of affairs, described above, leads to a situation in which it is difficult to implement sustainable technologies, because an important first step, network formation, is slow. This has its origin in the compartmentalization of the Kenyan civil society: companies, government bodies, NGOs—often—are not very accessible to each other and tend to maintain a culture of closed "we" groups. This prevents learning experiences to take their course, and finally it does not stimulate the growth of expectations. It is to be mentioned, however, that a continuous struggle is going on to create a more open society, open cooperation and anonymous trust, regulated by law and rules, involving a culture of egalitarian relationships and personal initiative. This is happening both at the national level and at the societal level; and it is reflected in many projects and partnerships. Kenyan society is moving in the direction of modernity and in this process modern technology and modern organizations play a key role.

In general, as the cases confirm, Sub-Saharan Africa appears to be caught up between two competing sets of cultural values and institutions: a set of small-scale oriented values and institutions derived from its tribal and collectivist past, which do not function anymore in a time, where large-scale politics and technology creates one system of socio–economic interaction; and a set of large-scale civil society oriented values and institutions, like free association of individuals, universalistic rule of law, checks and balances on governance, an entrepreneurial spirit etc., which is not fully functioning yet.

The challenge lying before us is to integrate technology and policy transfer into a strategy for cultural transition, in which an equilibrium and also a courageous step forward is taken by a creative combination of old and new values and policy approaches. Africa has to face a conscious cultural transition from a tribal/hierarchical clientelistic society, with selective trust towards a stable government and a strong and open civil society [15]. Such a society is characterized by pluralistic cooperation, and competition of many stakeholders; based on anonymous trust and judicial checks and balances. This cultural transition should be explicitly part of the development agenda, and be conducted in a path dependent way: preserving valuable parts from the past, but courageously entering upon a new socio-political and economic dispensation. This can address the issues of poor investment, skewed distribution of available resources, underproduction of civil servants and poor exploitation of natural resources, surfacing corruption and grinding poverty, among many other challenges. Entrepreneurial initiatives from below and consistent regulation from above together with multiple coalitions within all layers of society may create a flourishing civil society and a growing economy.

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The Structural Dimensions in the Security of Power Transmission Systems

Tao Huang, Ettore Bompard, Marcelo Masera and Fei Xue

Abstract This chapter discusses the security of power transmission systems from a structural perspective. It introduces a systematic concept of structural analysis for power grids security assessment applying extended topological approaches based on an adaptation of the theory of complex networks modified to capture the physical behavior of transmission networks as "flow networks". The concept of structural analysis is introduced as an alternative approach for discussing the relation between structure and state of power grids. A general review of complex networks applied to power grids security serves as introduction to a discussion of the shortcomings of pure topological approaches. Finally, authors describe the proposed systematic extended topological approach. In this chapter, "entropic degree" and "T-betweenness" are used to provide a measure of the criticality of buses and lines of transmission networks. Then, authors proceed with a dynamic way to rank critical components. Third, integration the previous concepts as metrics for distinguishing important components from critical ones, and for indicating their correlations are done. Finally, taking an overall perspective, and departing from net-ability, authors discuss the concept of path-redundancy as a new metric for survivability.

Keywords Power system security · Power grid · Complex networks · Extended topological approach · Structural dimension

T. Huang · E. Bompard (✉)
Dipartimento Energia, Politecnico di Torino, Corso Duca Degli Abruzzi, 24, 10129 Turin, Italy
e-mail: ettore.bompard@polito.it

E. Bompard · M. Masera
Joint Research Centre, Institute for Energy and Transport, 2 1755 NL ZG Petten, The Netherlands

F. Xue
Siemens Eco-City Innovation Technologies (Tianjin) Co., Ltd., Eco Business Park, Tianjin Eco CityBinhai New Area, Tianjin, China

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PWRS Security Analysis Approaches and Practices

The contemporary society increasingly relies on a high integration of different interdependent systems [1]. Electricity, as a main energy source to other infrastructures, stands in the center and is essential to the operation of all other systems. Therefore, as a critical and fundamental infrastructure, power system's security problem is a global concern strongly associated with social stability and economic development. Hence, priorities for the secure operation of the power system have always been given by different authorities, organizations, and utilities at all levels.

As the power system is evolving in many directions, such as network interconnections between nations or regions, utilizations and deployment of new technologies and controls, and operation in highly stressed conditions, different academic/industrial organizations proposed various terminological definitions based on the scenarios of their own interest. For example, Table 1 lists definitions relevant for power system security from four academic/industrial organizations, namely the International Electrotechnical Commission (IEC), IEEE (the Institute of Electrical and Electronics Engineers), ENTSO-E (the European Network of Transmission System Operators for Electricity), and NERC (the North American Electric Reliability Corporation).

In order to unify the understanding of security issues to be addressed in this chapter, we propose our perspective on these terminologies.

Reliability refers to the ability to supply loads with a high level of probability for a certain time interval. It can be described by two attributes: security and adequacy. *Security* means the ability to withstand imminent disturbances or contingencies, such as electric short circuits or unanticipated loss of system elements, without interruption of customer service; and *adequacy* means the ability to supply power to customers in various conditions, taking into account operational constraints. As a sub-item of security, *stability* refers to the ability to maintain or to regain a state of equilibrium after disturbances or contingencies. Here *disturbance* refers to an unplanned incident producing an abnormal system condition; and *contingency* refers to an unexpected failure or outage of a system component. In addition, *vulnerability* and *robustness* are frequently used to qualify the low reliability and the high reliability of the power systems, respectively. Moreover, similar to the concept of reliability, availability refers to the ability to be in a state to perform a required function under given conditions, and is measured as the proportion of time the power system is in operable and committable condition over a given time interval.

In contemporary system operational practices, to verify the aspects of the above mentioned securities issues, simulations are employed to assure the secure operation of the power system as well as to devise and validate emergency planes after contingency. Security is commonly analyzed by using methods completely based on operational data and physical models such as static security assessment [13, 14], and dynamic security assessment [15] for different purposes. For example, steady state analysis is called every 15 min to conduct contingency analyses with "n − 1"

Table 1 Definitions of security related terminologies from academic/industrial organizations

	IEC	IEEE	ENTSO-E	NERC
Reliability	Probability that an electric power system can perform a required function under given conditions for a given time interval [2]	The probability of its satisfactory operation over the long run [3]	A general term encompassing all the measures of the ability of the system, generally given as numerical indices, to deliver electricity to all points of utilization within acceptable standards and in the amounts desired [4]	Able to meet the electricity needs of end-use customers even when unexpected equipment failures or other factors reduce the amount of available electricity [5]
Security	Ability of an electric power system to operate in such a way that credible events do not give rise to loss of load, stresses of system components beyond their ratings, bus voltages or system frequency outside tolerances, instability, voltage collapse, or cascading [6]	The degree of risk in its ability to survive imminent disturbances (contingencies) without interruption of customer service [3]	The ability to withstand sudden disturbances, such as electric short circuits or unanticipated losses of system components or load conditions together with operating constraints. Another aspect of security is system integrity, which is the ability to maintain interconnected operations [4]	The ability of the bulk power system to withstand sudden, unexpected disturbances such as short circuits, or unanticipated loss of system elements due to natural causes [5]
Adequacy	The ability of an electric power system to supply the aggregate electric power and energy required by the customers, under steady-state conditions, with system component ratings not exceeded, bus voltages and system frequency maintained within tolerances, taking into account planned and unplanned system component outages [7]	A system's capability to meet system demand within major component ratings and in the presence of scheduled and unscheduled outages of generation and transmission components or facilities [8]	The ability of a power system to supply the load in all the steady states in which the power system may exist considering standards conditions [4]	The ability of the electric system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements [9]

(continued)

Table 1 (continued)

	IEC	IEEE	ENTSO-E	NERC
Stability	The ability of an electric power system to regain or to retain a steady-state condition, characterized by the synchronous operation of the generators and a steady acceptable quality of the electricity supply, after a disturbance due, for example, to variation of power or impedance [10]	The ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact [3]	The ability of an electric system to maintain a state of equilibrium during normal and abnormal system conditions or disturbances [11]	The ability of an electric system to maintain a state of equilibrium during normal and abnormal conditions or disturbances [9]
Availability	The ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided [12]	–	A measure of time during which a generating unit, transmission line, ancillary service or another facility is capable of providing service, whether or not it actually is in service [11]	–

criteria, verifying that for each configuration no line flow limits or voltage violations are expected. It is also used to check the adequacy of the system with the 4 typical operational scenarios (summer peak/off-peak, winter peak/off-peak) per year. In addition, when new plants or transmission lines are planned, it is called on demand to test the static security impacts on the system. In contrast, the dynamic state analysis is often used as an off-line resort to understand the dynamic cascading mechanisms after a severe failure or blackout happened. More often than usual, it is conducted to assess the dynamic impacts of new planned units on other rotating components in the system in terms of angle stability, oscillation, etc. Yet, although rarely, dynamic simulation is performed online when the system is very close to violate the constraints provided by the steady state.

As mentioned, these traditional methods evaluate the security relying on a given contingency and operating condition. It is computationally infeasible to check all possible combinations of contingencies that could cause serious blackouts in practical power grids; on the other hand, operating conditions of power systems change along time due to load variations, switching actions, etc. Therefore it is difficult to prevent the collapse of electrical power grids due to unforeseen operating conditions. Besides, due to the size of large-scaled power systems, physical behaviors and the interaction among many operators over power grid add difficulty to perform a comprehensive analytic analysis and simulation of the electromagnetic processes over the whole grid. Hence, in practice, reduced systems or some simplifying hypothesis are applied to these conventional methods to simulate the network's response to various external disturbances, yet the simulation results cannot reflect the exact response of power systems.

As a result, frequent blackouts occurred all over the world although advanced technologies and huge investments have been used in assuring the reliability and security of power systems. To deepen the insight into power systems, it is necessary to develop and complement the conventional analysis technology with new points of view and analytic capabilities.

Structural Analysis in Power Transmission Networks

Relation Between Structure and State of Power Grids

In the assessment of power system security, we need to distinguish the influence of two different aspects, structure and operating states. If we only consider the vulnerability caused by structural factors or operating states, they will only represent a part, although important, of the problem. To explain the relationship between the two aspects, we give a conceptual example in Fig. 1.

As shown in Fig. 1, the cup can be considered as the transmission network, the water inside can be considered as the exact power flow depending on operative states of generators and loads. The volume of the cup can be considered as the

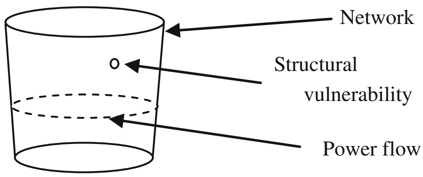


Fig. 1 Conceptual example for structural vulnerability

aptitude of the network and indicates the capacity of the cup to take water. This capacity is fixed even there is no water inside the cup. A small hole as shown in the figure is a structural vulnerability for the cup. The outbreak of a problem (leaking water) induced by this vulnerability also depends on the level of water. Only when the level of water is higher than the hole, this vulnerability will affect the function of the cup. Similarly, structural vulnerabilities in power grids are caused by the network structure and may threaten the function of the network and power system. However, the outbreak of security problems will also depend on the operative states of generators/loads and corresponding power flow. For example, if currently there is no power flow in the network, there would of course be no security problem.

Complex Networks on Power Grids Structural Analysis

A new approach, based on recent advances in the understanding of the structure of large complex networks, provides an emerging perspective to consider power grids security issues. By investigating the network model of the power grid from a topological perspective, it is possible to find properties and behaviors that have not been identified in traditional detailed model and analysis.

In Ref. [16], the authors built a network model based on data stored in the POWERmap mapping system developed by Platts [17]. This mapping system contains information about every power plant, major substation, and 115–765 kV power line of the North American power grid. The power from a generator is considered able to reach a consumer if there exists at least a path composed of transmission lines between them. In practice, the existence of a path between two substations does not always imply that power can be efficiently transferred through it by taking into account capacity or other constraints. Without consideration of the latter, the model only provides an idealized view.

As in general theory of CN, the node degree is a good indicator of topological importance (maybe not enough suitable for power grids, to be discussed later), the degree distribution of the power grid has been studied. Comparing the grid in Ref. [16] to scale-free and random networks (with the same number of nodes and edges), its cumulative degree distribution indicates that the probability of high-degree buses is less than in a scale-free network model, but higher than in a random network model [16].

In Ref. [18], the reliability of electric transmission systems is examined using a scale-free model of network topology and failure propagation. The topologies of the North American eastern and western electric grids were analyzed to estimate their reliability based on the Barabasi–Albert network model. A commonly used power system reliability index was computed using a simple failure propagation model. The results were compared to the values of power system reliability indices previously obtained from some standard power engineering methods, and they suggested that scale-free network models are unable to estimate aggregate electric grid reliability.

In Ref. [19], with the September 2003 actualization of the Union for the Coordination of Transport of Electricity (UCTE) power grid, the authors made an analysis of this topological structure and static tolerance to errors and attacks. Though every power grid in the study has exponential degree distributions, most of which without typical small-world topology, they were found to show patterns of reaction to node loss similar to those found in scale-free networks. Their observations stipulate that at the node removal behavior could be logarithmically related to the power grid size.

In Ref. [20], a cascading model was applied to the electrical power grid of the western United States. As a result, it was derived that global cascades are prone to be more probably triggered by load-based intentional attacks than by random or degree-based removal of nodes. The attack on a single node with large load may make the largest connected component decrease to less than half of its initial size, though the network is highly tolerant.

In Ref. [21], another cascading failure model was applied to the North American Power Grid. The model of the power grid used its actual topology and plausible assumptions about the load and overload of transmission substations. It was observed that the loss of a single substation can lead to a 25 % loss of transmission efficiency caused by an overload cascade in the network. A systematic study of the damage caused by the loss of a node suggested that the disruption of 40 % of the transmission substations may lead to cascading failures. While the loss of a single node can inflict primary substantial damage, the following removals have only incremental effects.

In Ref. [22], another cascading failure model was applied to the Italian power grid. The authors neglected the details of the electromagnetic processes and only focused on the topological properties of the grid. The objective of this study was to demonstrate that the structure of an electric power grid may provide important information about the vulnerability of the system under cascading failures. The Italian electric power grid network was built from the data on the 220 and 380 kV transmission lines of the GRTN web-site [23]. The network model has 341 nodes (substations) and 517 edges (transmission lines). Different kinds of nodes have been distinguished.

The network robustness is usually measured by the size of the largest connected component or by the average geometric distance as a function of the percentage of nodes/links removed. In the former works mentioned, the main attention has been on the number of removals needed to observe the serious decrease of system performance measured by these metrics. Nevertheless, in practical security analysis, it would be also meaningful to find what the critical components of the network are, i.e., the vertices/edges really crucial for the functioning of the network [24].

In Ref. [25], based on the general assessment of network performance in terms of efficiency, the drop of efficiency by cutting singular lines was applied to high-voltage electrical power grids to locate critical lines and best improvements. In Ref. [26], the topological properties of also high-voltage electrical power transmission networks of the Italian 380 kV, the French 400 kV and the Spanish 400 kV networks have been studied from available data. An assessment of the vulnerability of the networks has been implemented by analyzing the level of damage caused by a controlled removal of links. Such topological studies could be useful for the assessment of vulnerabilities and for designing specific actions to reduce topological weaknesses. As the analyzed grids are the same as the former case, some of their results are consistent.

Pure Topological and Extended Topological Approaches

Power grids have been widely acknowledged as a typical complex network because of both their huge sizes and the complex interactions among components. However, former works only apply the methodology and metrics of CN directly to power grids and consider them from a pure topological perspective. Some specific physical properties and constraints of power grids not taken into account have serious impacts on the power systems security problems. Here we will introduce the main shortcomings of the pure topological approach we found for power system security assessment.

The distance between two vertices and the length of a path are critical concepts in the definition of several important metrics in CN, such as average distance, betweenness and global efficiency. In unweighted, undirected graphs, the number of edges in a path connecting vertices i and j is called the length of the path. A geodesic path (or shortest path) between vertices i and j is one of the paths connecting these vertices with minimum length; the length of the geodesic paths is the distance d_{ij} between these two vertices [27].

However, from the perspective of engineering, distance should have a more practical meaning and should be a metric for the “cost” involved when a physical quantity is transmitted between the two nodes through the network. For electrical power grids, the cost of power transmission between two buses can be described from both an economic and a technological point of view, such as transmission losses or voltage drop. Therefore, in power system engineering, the description of distance by a pure topological approach cannot effectively reflect these related features and must be replaced by the description of “electrical distance” from an extended topological perspective.

In the general theory of CN, all elements are treated identically to avoid difficulties involved with their differentiation and dynamical behavior characterization [19]. Correspondingly, vertices are considered identical in the definition of several metrics, such as betweenness and global efficiency, where transmission of physical quantity was considered from any vertex to any other one, even for power grids [25].

Nevertheless, the essential function of power grids is to transmit electrical power from any generator bus to any load bus with eligible quality. Generally, we can classify the buses in power transmission networks as generation buses B_g, transmission buses B_t and distribution buses B_d. From the point view of extended topological perspective, power transmission should only be considered from generation buses to load buses.

In the pure topological approach, edges are generally described in unweighted ways in the definition of several related metrics, such as distance, degree and betweenness [27].

However, in power system engineering, transmission lines have a very important feature that is a line flow limit, which restricts the ability of lines for power transmission according to several economic and technological factors. As this feature is critical for the network to perform its essential function, it cannot be neglected in the analysis related to security issues. In the extended topological view, different lines may have very different values of this parameter and therefore its distribution may also be important for security assessment.

As in the definition of distance, betweenness and global efficiency, the physical quantity transmission between two vertices is always supposed to be through the shortest path [27]. This assumption is still kept in some works on power grids [16, 22, 25].

This is the most unrealistic assumption from the point of view of power system engineering. Power transmission from a generator bus g to a load bus d will involve most lines or a huge number of paths with different levels of contribution. In a power flow linear model, the different contributions of lines in power transmission can be described by the Power Transmission Distribution Factors (PTDF). PTDF is a matrix that reflects the sensitivity of the power flow on the lines to the change in the injection power of buses and withdrawn at a reference bus. For a network with N nodes and Y lines, the matrix of PTDF can be written as:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1N} \\ & & \vdots & \\ a_{Y1} & a_{Y2} & \cdots & a_{YN} \end{bmatrix} \tag{1}$$

where a_{ij} is the change of power in line i for a unit change of power injection at node j. The columns corresponding to node g and node d can be written as $\{a_{ig}\} i = 1,\ldots,Y$ and $\{a_{id}\} i = 1,\ldots,Y$. Then the distribution factor a_i^{gd} of the ith line corresponding to power injection at node g and withdrawn at node d can be calculated as:

$$a_i^{gd} = a_{ig} - a_{id} \quad (i = 1 \ldots Y) \tag{2}$$

The network model in the pure topological description of CN is unweighted and undirected. The identification of possible paths connecting two nodes is based on graph theory where transmission lines are assumed bidirectional [22], whereas, as we have discussed, the power transmission behavior between two nodes completely depends on physical rules that can be reflected by the PTDF. As PTDF has signs, the lines connecting to one node should be classified as input or output lines. Therefore, some paths in the undirected model may be not valid in the directed power transmission networks.

With the shortcomings of pure topological approaches discussed above, it is obvious that new extended topological approaches with consideration of specific physical features in power system engineering would be necessary and promising.

Metrics for Assessing the Criticality of the Network Components

Entropic Degree

The connectivity of a node is traditionally measured by the degree in the unweighted topological model or strength in the weighted model. In an unweighted and undirected network model, according to traditional graph theory, the degree of a vertex i is the number of edges connected to it (or the number of vertices adjacent to it), we rewrite it as:

$$k_i = \sum_{j \in B} c_{ij} \tag{3}$$

In a weighted graph, connectivity can also be described by strength as the sum of the weights of the corresponding edges, we rewrite it as:

$$s_i = \sum_{j \in B} w_{ij} \tag{4}$$

where w_{ij} represents the weight of line connecting i and j.

As a measurement of connectivity for a vertex, the definition of degree in a weighted network model should reflect the following factors:

- The strength of connections in terms of the weight of the edges;
- The number of edges connected with the vertex;
- The distribution of weights among edges.

It is obvious that the definition in (3) loses the information of the first factor and the definition in (4) loses information of the second factor. None of them can reflect the third factor.

For example, in Fig. 2, the results of (3) and (4) would be very different:

$$k_i(A) = 1; \quad k_i(B) = 2; \quad k_i(C) = 3$$
$$s_i(A) = s_i(B) = s_i(C) = 1$$

In Fig. 3, the results from (3) or (4) are all the same for both cases:

$$k_i(A) = k_i(B) = 2$$
$$s_i(A) = s_i(B) = 1$$

However, for case (A), both edges have the same importance for the node. For case (B), it is obvious that one edge is more important than another as it takes 90 % of the connection. Under a failure of the most important line, case (B) is more vulnerable than case (A).

We resort to the concept of entropy to define degree with consideration of all the three mentioned factors.

First, we consider p_{ij} as the normalized weight of the edge between vertices i and j for each edge l_{ij} connecting nodes i and j:

$$p_{ij} = w_{ij} \sum_{j \in B} w_{ij} \quad (5)$$

It is obvious that $\sum_{j \in B} p_{ij} = 1$

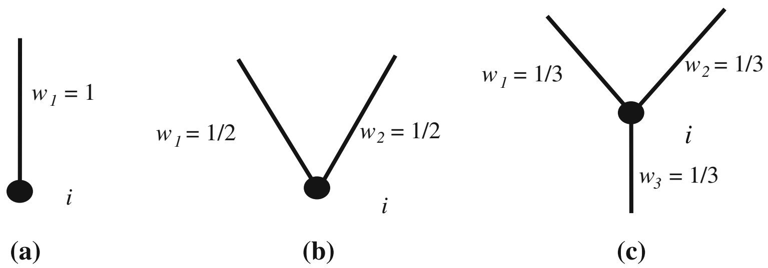
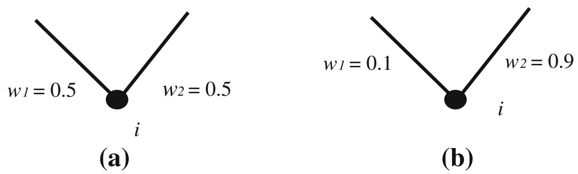


Fig. 2 Same total weight with different connections

Fig. 3 Different distribution of weights



Then, the entropic degree g_i of vertex i can be defined with entropy as:

$$g_i = \left(1 - \sum_{j \in B} p_{ij} \bullet \log p_{ij}\right) \sum_{j \in B} w_{ij} \quad (6)$$

As degree is a traditional concept in graph theory and widely applied for the analysis in complex networks, the proposed entropic degree may be a good replacement for research in weighted network models which include not only power grids but also other weighted networked systems. For power grids, it may directly give a quantitative measurement to indicate the importance of buses and their difference. The most important buses may need more resource to be protected or be more likely to be selected as targets of intentional attacks. If measured with the pure topological concept of degree, the corresponding results may be far from reality. Therefore, this entropic degree can give more reasonable evaluation of the importance of buses by taking into account not only the total strength of the connection but also the distribution of strength that may be sensitive for malicious attacks.

T-Betweeness for Buses

In the traditional unweighted and undirected model, the betweenness of a component u in the network Y has been defined as the number of shortest paths traversing the component u; we rewrite it as:

$$\Gamma_u = \sum_{\substack{i,j \in B \\ i \neq j}} \sigma(i, u, j) \quad (7)$$

where $\sigma(i, k, j)$ is the number of shortest paths between vertices i and j.

This definition has several shortcomings for the application in power grids:

In the traditional definition, the flow in the network has been considered from whichever node i to whichever node j. However, the essential function of power grids is to transmit electrical power from any generator bus to any load bus with eligible quality. Generally, we can classify the buses in power transmission networks as generation buses B_g, transmission buses B_t and distribution buses B_d. Power transmission should be only considered from generation buses to load buses.

In the traditional definition, the transmission between any pair of nodes i and j or g and d is considered equally. However, since each transmission line has its own specific power flow limit, the capacities of the network to transmit power from i to j and from g to d may be quantitatively different due to the configuration of all lines with different power flow limits and to the distribution of the power flow among the lines.

In the traditional definition, the physical quantity transmission between two nodes is always supposed to be through the shortest path. This is the most unrealistic assumption from the point of view of power system engineering. Power transmission from a generator bus g to a load bus d will involve most lines or a huge number of paths with different extents of contributions.

When we consider power transmission from one generator bus g to one load bus d, as PTDF has sign, we can divide the set of edges L^b connected to bus b ($b \neq g$, $b \neq d$) into two subsets: L^b_{in} inputting power flow into b and L^b_{out} outputting power flow from b. According to the theory of electrical circuits, as the total power injected into b must be equal to the power output from b, we have:

$$\Gamma_b^{gd} = \sum_{l \in L^b_{in}} C_g^d \left| a_l^{gd} \right| = \sum_{l \in L^b_{out}} C_g^d \left| a_l^{gd} \right| = \frac{1}{2} \sum_{l \in L^b} C_g^d \left| a_l^{gd} \right| \tag{8}$$

where C_g^d is the power transfer capacity of the transmission network from generator g to load d.

If b is only connected by one single line, it is obvious that $\Gamma_b^{gd} = 0$ in such situation since b is neither a source nor a destination of power flow.

The new T-betweenness of bus b can be defined as:

$$\Gamma_b^E = \sum_{g \in B_g} \sum_{d \in B_d} \Gamma_b^{gd} \tag{9}$$

T-Betweeness for Lines

When we consider power transmission from one generator bus g to one load bus d, as PTDF has sign, if we specify a reference direction for line l, the PTDF value a_l^{gd} should be positive, negative or zero. Then we define the positive T-betweenness of l as:

$$\Gamma_l^p = \sum_{g \in B_g} \sum_{d \in B_d} C_g^d a_l^{gd} \quad \left(\text{if } a_l^{gd} > 0\right) \tag{10}$$

If there is no $a_l^{gd} > 0$, then $\Gamma_l^p = 0$.

The negative T-betweenness of l can be defined as:

$$\Gamma_l^n = \sum_{g \in B_g} \sum_{d \in B_d} C_g^d a_l^{gd} \quad \left(\text{if } a_l^{gd} < 0\right) \tag{11}$$

If there is no $a_l^{gd<0}$, then $\Gamma_l^n = 0$.

The T-betweenness of line l can be defined as:

$$\Gamma_l^E = MAX\left[\Gamma_l^p, \left|\Gamma_l^n\right|\right] \quad (12)$$

As the power system can work at different configurations in terms of generation and load distributions, the positive power transmission and negative transmission along the same line l may not happen at the same time, so we use their maximum absolute value.

Topological Approaches for Component Ranking

Efficiency

Efficiency has been first introduced for small world networks, in which the average distance and the clustering coefficient define this property. Efficient networks are both highly clustered and closely connected averagely. The average geodestic distance is defined as:

$$D^Y = \frac{1}{B(B-1)} \sum_{\substack{i,j \in B \\ i \neq j}} d_{ij} \quad (13)$$

The definition of characteristic path length (or average distance) is valid only in a completely connected network Y where at least one path, composed by a finite number of edges, connecting any couple of vertices must exist; if two vertices i and j are not connected the relative distance $d_{ij} \rightarrow +\infty$, and the corresponding average distance, as defined in (13), tends to infinity [28]. In studying the network security, the removal of vertices and edges as a result of a failure is often considered and this may likely produce a non-connected network.

The concept of efficiency is closely related to that of distance. The distance, as we discussed, is generally assumed as a measure of the difficulty, cost or effort needed to transfer physical quantities over a network and so an efficiency ε_{ij} can be associated to a pair of vertices i and j and defined as:

$$\varepsilon_{ij} = \frac{1}{d_{ij}} \quad (i,j \in B,\ i \neq j) \quad (14)$$

If no path exists between vertices i and j, $d_{ij} \rightarrow +\infty$ and, therefore, $\varepsilon_{ij} = 0$.

By averaging the efficiencies we can define the *global efficiency* E^Y of the network Y as [29]:

$$E^Y = \frac{\sum_{\substack{i,j \in B \\ i \neq j}} \varepsilon_{ij}}{B(B-1)} = \frac{1}{B(B-1)} \sum_{\substack{i,j \in B \\ i \neq j}} \frac{1}{d_{ij}} \quad (15)$$

The concept of efficiency can be used to assess the possible impacts of a fault or failure onto a network and its resilience; local efficiency is to quantify the performance of the connections of the vertices in the neighborhood of i after a failure of i and is a measure of the failure tolerance as well [29].

Resorting to the new metrics, small world network can be characterized by high global and local efficiencies that basically individuate the same situation pointed out by small average distance and high clustering coefficient.

The loss of a component would affect the global efficiency of the network and so the detection and ranking of the most critical components can be undertaken assessing the drop of efficiency E_q^{Δ} that each failure would cause.

$$E_q^{\Delta} = \frac{E^Y - E_{-q}^Y}{E^Y} \tag{16}$$

where E^Y is the global efficiency of the original network and E_{-q}^Y is the global efficiency after the removal of the component (vertex or edge) q.

A global metric for the network vulnerability is the maximum vulnerability for all of its vertices:

$$E_M^{\Delta} = \underset{q \in \mathcal{B} \cup \mathcal{L}}{MAX}\, E_q^{\Delta} \tag{17}$$

From Efficiency to Net-Ability

The concept of distance within a network may be explained as the difficulty or cost to transfer physical quantities between a pair of nodes. Distance in general depends on the length of the path between the two nodes and thus should be defined as a function of the characteristics of the lines in the path. The economic and technical difficulties, which eventually amount to some sort of costs, for transmission of electrical power through a path depend on both the power flow through the lines and their impedance: with the same impedance, more power flow causes higher costs; with the same power flow, a bigger impedance causes higher costs. Consequently, the length of path k from node g to node d is related not only to the impedance of each line of the path but also to the power flows through the lines of the path. As a result, we define the electrical length of a path k as:

$$L^k = \sum_{l \in k} a_l^{gd} Z_l \tag{18}$$

where a_l^{gd} is the Power Transmission Distribution Factor of line l in path k and Z_l is its impedance.

Therefore, the net-ability based on topological efficiency with consideration of contributions from all paths (not only the shortest path as in pure topological approach) can be defined as:

$$A_{\mathscr{Y}} = \frac{1}{B_g B_d} \sum_{g \in \mathscr{B}_g} \sum_{d \in_d} C_g^d \sum_{k \in \mathscr{K}_g^d} p_k^{gd} \frac{1}{L^k} \tag{19}$$

where B_g is the number of buses in B_g and B_d is the number of buses in B_d, p_k^{gd} is the proportion of contribution in transmission of path k, C_g^d will be defined later as the transmission capacity from g to d. K_g^d is the set of all paths between g and d.

In the DC power flow equation, the definition of length for a path between g and d is just equal to the voltage angle difference between g and d when transmitting one unit power from g to d. Therefore, as the voltage angle difference is fixed, the length L^k is the same for any path k in K_g^d between g and d. Hence, Eq. (19) can be developed further as (with consideration of $\sum_{k \in \mathscr{K}_g^d} p_k^{gd} = 1$):

$$A_{\mathscr{Y}} = \frac{1}{B_g B_d} \sum_{g \in \mathscr{B}_g} \sum_{d \in \mathscr{B}_d} C_g^d \frac{1}{L^k} \tag{20}$$

Then L^k is just the electrical distance between g and d.

We can define the generator bus g together with all the involved paths K_g^d from it to the distribution bus d as an efficient power supply scheme $h(g, d)$ for power consuming on d. Then the capacity of scheme h can be defined in the following way: the injection from g is increased from zero to C_g^d when the first line among all involved paths reaches its maximum power flow limit. C_g^d is the capacity of the power supply scheme $h(g, d)$.

$$C_g^d = \underset{l \in L}{MIN} \left[P_l^{\max} \Big/ \left| a_l^{gd} \right| \right] \tag{21}$$

where:

L is the set of all lines
P_l^{max} is the power flow limit of line l
a_l^{gd} is the PTDF of line l for a power injection/withdrawal at buses g/d

We used the equivalent impedance to calculate the electrical distance L_k from the point view of power system engineering. The definition of net-ability A for a power grid Y is:

$$A_Y = \frac{1}{B_g B_d} \sum_{g \in B_g} \sum_{d \in B_d} C_g^d \frac{1}{Z_t} \tag{22}$$

B_g is the number of buses in B_g and B_d is the number of buses in B_d.

$$Z_t = \frac{U_{gd}}{I_g} = U_{gd} \Rightarrow Z_t = (Z_{gg} - Z_{gd}) - (Z_{gd} - Z_{dd}) \tag{23}$$

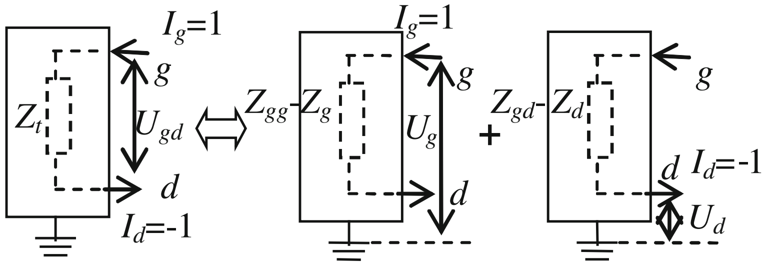


Fig. 4 The computation of equivalent impedance

Z_t is the equivalent impedance from generator bus g to load bus d as described in Fig. 4. Z_t is an extended concept of electrical distance between g and d to reflect economic and technical cost for power transmission.

According to the DC power flow equation, the value of Z_t is just equal to the voltage angle difference between g and d with one unit of power injected at g and withdrawn at d. Then the value of Z_t is just the value of L_k.

Ranking by Drop of Net-Ability

In Fig. 5, for the ideal 1-bus case (A), all generators and loads are connected by an ideal bus with infinite capacity and zero impedance (distance) and the net-ability is infinite. In case (C) where all generator buses and load buses are isolated, the connecting impedance or zero-power transfer capacity makes the net-ability null. In real cases (B) the net-ability, as defined in (22) is between infinite and zero.

Similar to the approach from efficiency, where critical components were identified according to the relative drop of global efficiency caused by the failure of each component, we can consider the failure of each line l (removed one by one) and calculate the relative drop of net-ability, caused by each failure:

$$\Delta A^r = \frac{A_Y - A_{Y-l}}{A_Y} \tag{24}$$

The relative drop of net-ability will indicate which lines are the most critical ones for the operation of the network under current normal conditions. Furthermore, by locating critical transmission lines, it may also be useful to indicate how the performance of the network can be improved by re-enforcing its structure.

However, for a large power transmission network with real size of buses and lines, the calculation burden would be a critical issue. For calculation of net-ability, it has to calculate B_gB_d times of PTDF between any generation bus and load bus. To calculate the relative drop of net-ability by removing each transmission line, if the total number of lines in Y is L, generally the calculation for

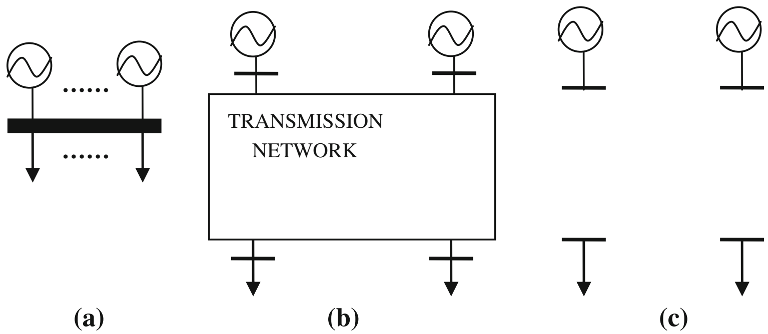


Fig. 5 Reference cases

net-ability needs to be repeated for $L + 1$ times. For large-scale networks, such as the network of UCTE, the corresponding calculation burden may be unacceptable. Therefore, it is necessary to find valid methods to decrease the burden as later discussed.

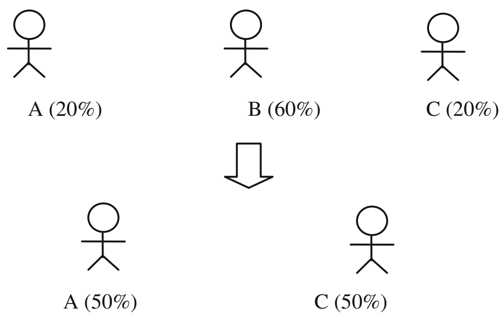
Important and Critical Components in Transmission Network

What is Different Between Important and Critical Components?

To give a clear definition and description between important and critical, we begin with an example about a team composed of a group of members as shown in the Fig. 6.

As we can see from Fig. 6, in the team, the member B takes sixty percent of the work of the whole team which is much higher than the work of the other two as twenty percent respectively. So we can say that the member B is an important

Fig. 6 Example for important but no critical member



member for the team since he is responsible for most part of the work in the whole team. However, if the member B is removed from this team and the other two members have enough ability to take the work left by the member B as shown in the figure, the performance and the function of the team could be as the same as before. In such situation, although we can say that B is important, but we may not consider him as critical.

Another situation can also be described by this example where we change to another different scenario as shown in Fig. 7.

This time, the situation before removing B is the same as the last example, therefore we consider B still as an important member. However, if B is removed from this team, due to any reason (ability, resource or configuration), A and C can only take very small part of work left by B, only sixty percent of the work of the whole team can be done as shown in the figure. The absence of B can impact greatly on the performance and function of the whole team. In such situation, we would say that B is both important and also critical.

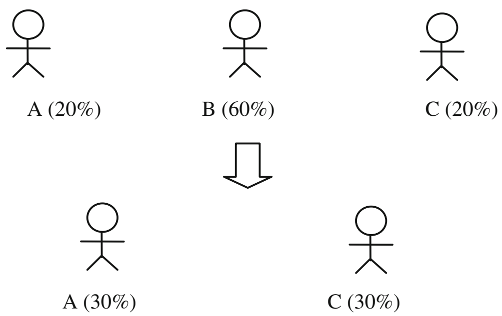
This logic can be easily transferred to the contexts of complex networks where we can give clear definitions as:

A component of the network is *important* if it takes remarkably higher proportion, quantitatively defined by the users, of responsibility for function of the whole network lying on the current configuration of the network compared with other components.

A component of the network is *critical* if its absence can have remarkable impact, quantitatively defined by the users, on the performance and function of the whole network lying on the change of the network configuration compared with other components.

From the discussion before, we can see that betweenness is a typical metric to measure how much responsibility a component takes for the function of the whole network in an unweighted and undirected pure topological model. This is a static measurement since it only depends on the current configuration of the network. The relative drop of global performance is to measure the impact on the network performance by the absence of a component. This is a dynamic measurement since it depends on the network configurations both before and after the failure of the component. Therefore, important and critical components all have their own specific definitions and meaning, and should not be confused.

Fig. 7 Example for important but also critical member



Important and Critical Components in Power Grids

According to the definition and analysis above, we can generally get a further conclusion in the contexts of complex networks: an important component may not necessarily be a critical component, however, a critical component must be an important component otherwise its absence cannot make serious impacts; or we can say that the critical components should be a subset of the important components. In a complex network, the quantity of important components may be more than the quantity of critical components.

With former definition of important components in CN, T-betweenness is an ideal indicator to reflect the responsibility of a component for the function of the whole power transmission network.

According to the definition proposed, a metric of performance is necessary to identify critical components in complex networks. Efficiency has been widely used as this type of metric in many research works, however as indicated in [30–32], it fails in describing specific features of power grids. Therefore, based on an extended topological approach, we have to resort to the concept of net-ability as the performance of power transmission networks.

The relative drop of net-ability in (24) will indicate which components (line and bus) are the most critical ones for the operation of the network under current normal conditions. Furthermore, by locating critical transmission lines, it may also be useful to indicate how the performance of the network can be improved by re-enforcing its structure.

According to what we have discussed, the important and critical components in power grids are respectively identified by their T-betweenness and relative drop of net-ability. Although T-betweenness and net-ability are two different metrics, they have deep interrelation caused by PTDF and equivalent impedance. As we can see from former definitions, both T-betweenness and net-ability depend greatly on the power transfer capacity C_g^d which are exactly defined in the same way by PTDF and transfer capacity of the lines in the two metrics.

Furthermore, the PTDF in T-betweenness depend on the relative relation in impedance of transmission lines among the whole network. Therefore, suppose that the influence from transfer capacity C_g^d can be neglected, we can generally judge that an important line should have relatively lower impedance or an important bus should connect to lines with relatively lower impedance, which cause higher PTDF compared with other lines. Meanwhile, if the absence of a critical component can cause incredibly decrease in equivalent impedance between many pairs of buses, this component must be related to lower impedance itself which may take them higher T-betweenness. However, conversely, the failure of an important line or bus described by absence of one or several lines with relatively lower impedance may not necessarily cause a serious drop in equivalent impedance between many pairs of buses because it also depends on the value and distribution of impedance in other lines. In summary, a critical component must be important, but an important component may not necessarily be critical.

Therefore, from the discussion above, we can generally conclude that the critical components in power grids should be a subset of their important components. This is important to decrease the calculation burden in ranking critical components by the relative drop of net-ability as we discussed in the last section. As the calculation burden for T-betweenness of all components is similar for calculation of net-ability for one time, we can make ranking of important components by the results of T-betweenness. Since the critical components are in subset of important components, limited top components in ranking of important components can be selected to perform calculation of (24) for relative drop of net-ability to identify critical components. In this way, the calculation burden can be greatly reduced.

Metrics for the Overall Topological Assessment of the Grid

Introduction to Path-Redundancy

Net-ability is originated from efficiency to indicate the aptitude of a network to perform its function in transmitting physical quantities between specified vertices based on current structure and physical conditions of the network. However, when we consider security, we may take care of the performance of the network after component failures or intentional attacks. Although to calculate the relative drop of net-ability in (24) can provide some detail information related to specific components, we still need a global metric as general assessment for ability of networks to survive from failures or attacks.

In a meshed system, for a given couple of buses, at least one path, composed by a sub-set of the lines of the system, can be identified. Higher is the number of paths connecting whichever couple of buses in the system higher would be the system resistance to attacks or failures.

As the PTDF indicates the contributions of all lines in power transmission from bus g to bus d, it is possible to calculate the contribution of each path (the PTDF of a path) in power transmission according to the PTDF of the lines composing the path. If we consider the PTDF values of lines as DC power flow when transmitting one unit power from g to d, we can get the power flow (i.e. PTDF) of a path by traversing the whole paths. The general procedure can be explained with the following steps:

1. Starting from the source bus g, follow an output line as the beginning of a path p and consider the PTDF of the line as the initial PTDF of path p.
2. When path p arrives at a new bus i and if i is not bus d, then partition path p into multiple new paths according to the output lines of i and recalculate the PTDF for each of them.
3. Continue to follow one of the new paths and repeat step 2 until the current path arrives at d.

4. Repeat to follow all possible paths until they all arrive at d.

In step 2, the recalculation of the PTDF should consider the three different cases shown in Fig. 8. As the path is a different concept from the line, multiple paths can go through the same line; we indicate paths by dashed lines and lines by solid lines.

For case (a), no matter how many input paths, since there is only one output line from node i, the PTDF of path p still keeps unchanged. For case (b), since there is only one input path p, it would be partitioned as multiple new paths corresponding to the multiple output lines. Therefore, the PTDF for each new path is just equal to the PTDF of the corresponding output line. For case (c) where we have multiple input paths with multiple output lines, in a linear model, we suppose the power injected from different paths should be mixed completely uniformly at bus i. Therefore, we can summarize the three cases as: if node i has U output lines ($l_1, l_2, \ldots, l_U$), each input path p with PTDF f_p would be partitioned as U new paths. The PTDF f_p^k of the new path from p through line l_k ($k = 1,\ldots,U$) can be calculated as:

$$f_p^k = f_p \bullet \left(a_{l_k}^{gd} \Big/ \sum_{s=1,\ldots,U} a_{l_s}^{gd} \right) \tag{25}$$

Assume that K_g^d is the set of all valid paths from g to d, we can get:

$$\sum_{p \in K_g^d} f_p = 1 \tag{26}$$

f_p can be considered as a weight indicating how much path p contributes to the power transmission from g to d. According to Eq. (26), the paths redundancy R_g^d from bus g to d can be defined as the entropy of the contributions (PTDF) of all paths involved in power transmission from bus g to d:

$$R_g^d = -\sum_{p \in K_g^d} f_p \bullet \log f_p \tag{27}$$

The paths redundancy between two buses is related to the number of paths and the proportions for the power to be routed through those paths. The average paths redundancy of the whole network Y can be defined as:

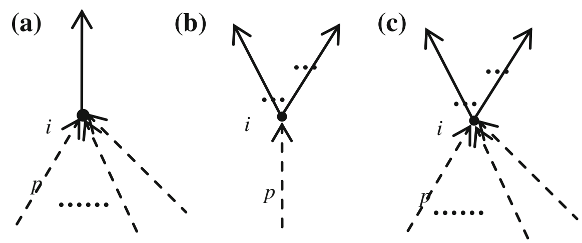


Fig. 8 Different cases for recalculation of PTDF for paths

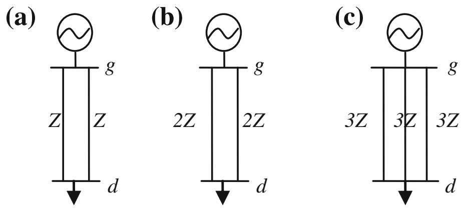


Fig. 9 Comparison for net-ability and paths redundancy

$$R_Y = \frac{1}{B_g B_d} \sum_{g \in B_g} \sum_{d \in B_d} R_g^d \tag{28}$$

Paths redundancy is a concept independent of net-ability. In Fig. 9, assuming C_g^d is the same for all cases, cases (a) and (b) have different net-ability due to different impedance. However, since for each case there are two paths with equal share of power transfer (50 %), their flow paths redundancies measured by (27) are same. The cases (b) and (c) have the same net-ability due to the same capacity and equivalent impedance. However, they have different paths redundancy defined in (27). The higher paths redundancy of the case (c) results in higher resilience to attacks or failures in transmission network. Even with the same number of paths, a more averaged distribution of the PTDF in paths causes higher entropy in (27), which means more resilience to malicious attacks to the most loaded path.

As shown in Fig. 5, the ideal 1-bus case (A) can be considered as composed of infinite paths with infinite capacity and zero impedance (distance) from whichever generator to whichever load. Obviously, the paths redundancy for this case is infinite. For the opposite extreme case (C), it is obvious that the paths redundancy is zero, since there is no path. Definition in (27) can give a quantitative measurement for case (B) between these two extreme cases.

From Net-Ability and Path-Redundancy to Survivability

To make a new assessment of structural vulnerability for power grids with consideration of not only current static performance but also possible resilience to failures or attacks, we define here a new metric, called survivability, to indicate the capability of a network to keep on performing properly its function in the presence of limited attacks or failures on transmission paths. Therefore, this survivability depends on both net-ability and paths redundancy:

- With equal net-ability, more paths redundancy means higher survivability.
- With equal paths redundancy, more net-ability means higher survivability.

The survivability for a transmission network Y is defined as:

$$Sr_Y = \frac{1}{B_g B_d} \sum_{g \in B_g} \sum_{d \in B_d} R_g^d C_g^d \frac{1}{Z_t} \tag{29}$$

In Fig. 9, the survivability of case (a) is higher than that of case (b) since the former net-ability is higher and their paths redundancies are the same. The survivability of case (c) is higher than that of case (b) since the latter paths redundancy is higher and they have the same net-ability.

As shown in Fig. 5, the ideal 1-bus case (A) can be considered with infinite net-ability and infinite paths redundancy. Alternatively, since the survivability is only considered with reference to attacks and failures in transmission networks, the survivability of this case is infinite because there is no transmission network. For the opposite extreme case (C), with no net-ability and no paths redundancy, it is obvious that the survivability is zero. Definition in (29) can give a quantitative measurement for case (B) which is between these two extreme cases.

The relations among net-ability, paths redundancy and survivability can be explained still considering the cup in Fig. 1 as an example. While the volume represents net-ability, paths redundancy is corresponding to the strength of the cup (a cup being made of glass is more fragile than a cup being made of steel). The ability of a cup to survive from a crash (an attack) to continuously perform its function (holding water) depends on both its original volume and its strength. Therefore, survivability should take into account both net-ability and paths redundancy together to consider the both aspects.

An important problem in the calculation of survivability and paths redundancy is the calculation burden of PTDF of all paths for a transmission network of real scale. For a network with several hundred or several thousand of nodes, there may be millions of paths between two nodes. This may make the time of calculation unacceptable in practice. However, the distribution of PTDF in paths is very uneven in power transmission networks. Even with millions of paths, only a very small part of these paths (e.g. hundreds of) takes most of the power flow.

Therefore, for the calculation in (25), we can define a threshold θ. Only when $a_l^{gd} > \theta$, line l can be considered in calculation of (25). In this way, it is possible to get meaningful results within an acceptable time.

Conclusions

Power systems play a pivotal role, as fundamentally critical infrastructures, in assuring the proper functioning of our societies. Therefore, the security of power systems has drawn attention since their inception. As a consequence, analysis approaches and tools have been developed to simulate the system response against any change, either internal or external. However, due to the Newtonian assumptions, they always depend on the given contingencies and operating conditions, which makes them not only computationally impractical but even impossible. As a fundamental change of ideology to combat the security problems in power systems, complex network theory, more specifically, topological analysis, was applied as a pioneer attempt. By abstracting the power system as a graph, the transmission network becomes the decisive factor. The trial showed some promising potentials in the arena, such as providing indices for overall characteristics of the system and identifying important structural components independent of the operating conditions. In any case those approaches showed some drawbacks. As the fact that, irrespective of the physical laws governing power systems, they ignore the engineering peculiarities of the system under study. All these shortcomings prompt the needs to reinforce the approach by considering aspects ignored by pure topological analysis.

We proposed a comprehensive framework composed of a set of metrics based on extended topological analysis derived from pure topological ones. The framework provides promising tools to analyze the general and overall security and identify vulnerabilities of the system determined by structural factors. More specifically, based on static assessment, "entropy degree" and "T-betweenness" can be used to measure the importance of a single component; while by ranking the drop of "net-ability" from dynamic assessment, the criticality of components can be observed. By considering both the static and dynamic results together, the correlations of the important and critical components can be revealed. In contrast, "path-redundancy" provides a global index indicating the ability of the network to survive from components failure. In light of considering the system resilience to limited failures on transmission paths, "survivability", depends on both net-ability and path-redundancy was proposed.

Although progress and improvements have been made with respect to pure topological analysis, the extended topological analysis still faces many challenges when applying to power systems.

The first and foremost problem is how to validate the results in real systems. As the topology is only one of the two dimensions of the security problem, comparisons with system data or references that are strictly connected with features other than structure may not provide satisfactory feedbacks. Also, due to the statistical property of results given by the extended topological analysis, the vulnerable points spot by them may not show in real cases used as benchmark to evaluate the results. Therefore, it seems reasonable to compare the results with statistics from system operation. However, blackouts are not so frequent enough to build up meaningful statistic results for the comparison.

Another issue involves a more complicated consideration: dynamics. In the vocabulary of power systems, dynamic refers to the quantities (e.g. voltage/angular behaviors) changes over time with stability concerns rather than topology changes and corresponding power flow changes over transmission lines. A bad news to the topological analysis, including the extended one, is that most of the blackouts happened due to voltage, frequency, or angular instability rather than overloads. Therefore, new engineering features should be incorporated into the extended topological analysis to reflect the mechanism of blackouts in reality. However, it may force us to consider the operating conditions to reveal dynamic instabilities. Moreover, to consider the dynamic behaviors of rotating components (e.g. generators) and discrete elements (e.g. FACTS) will create mathematically and computationally dimensional disasters when facing large scale systems. Efforts then should be made to strike a balance between the details and usefulness of the extended topological analysis.

Last but not the least, complexity of power systems comes from the hectic interactions among different technical layers and various operational players. The network itself can hardly be a complex system. Although the proposed framework simply considered the interactions between power supply and demand, others are still missing, such as multiple heterogeneous decision makers at national levels and international level: policy makers, regulators, market participants, TSOs, etc. The most important revolution of intelligent grids (i.e. smart grids, super grids) in power systems pose a great challenge to the extended topological analysis to consider multiple levels of dependent systems.

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Investigating the Surrogate Worth Trade-off Method to Facilitate Technology Selection for New Systems

Aria Iwasawa, Naohiko Kohtake, Nobuaki Minato and William Crossley

Abstract When designing a new system, engineers must often select from a set of discrete technologies available for use. Once the engineers select these technologies, they subsequently determine the value of continuous variables (e.g., lengths, thicknesses, other dimensions) that describe the new system. This mix of discrete and continuous choices can make it difficult to identify the best design. Additional difficulties arise when—as for most new systems—a trade-off exists between multiple, competing objectives. From a design optimization perspective, the resulting problem is a Multi-Objective, Mixed-Discrete Non-Linear Programming (MO-MDNLP) problem. The solution to an MO-MDNLP problem is not a single design; it is a set of non-dominated designs. In this set, the performance of one objective cannot improve without degrading performance in the other objective(s). However, the design process requires that a single design emerge as the best candidate; this best design needs to reflect the decision-maker's preferences. The Surrogate Worth Trade-off (SWT) method is one approach that provides an interface between the decision-maker's preferences and the mathematical models. This paper applied the SWT method to a simple example MO-MDNLP problem to determine how this might support a decision-maker in selecting new technologies during the early phases of design.

Keywords Technology selection · The surrogate worth trade-off method · Multi-objective design

A. Iwasawa (✉) · N. Kohtake · N. Minato
Graduate School of System Design and Management, Keio University,
4-1-1 Hiyoshi, Kohoku-ku, Yokohama, Kanagawa 223-8526, Japan
e-mail: aria.iwasawa@gmail.com

W. Crossley
School of Aeronautics and Astronautics, Purdue University, 701 W. Stadium Ave,
West Lafayette, IN 47907-2045, USA

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Introduction

Decision-making occurs throughout any project life cycle. The design of engineered systems require decisions about which technologies to use, how to obtain the desired technologies, and where to acquire the technologies. The tension of cost, risk, schedule and performance in engineering design makes decision-making a paramount issue. The quality of decisions made during the early life-cycle phases determines product success.

Decision-making for technology selection can be difficult for three reasons. First, constructing new systems often deal with satisfying constraints while optimizing conflicting objectives, necessitating trade-off studies. Second, technologies involve both discrete and continuous variables; there is a discrete choice of technology type and a continuous sizing of parameters or variables associated with the design. Viewed as an optimization problem, the problem is a constrained Multi-Objective, Mixed-Discrete Non-Linear Programming (MO-MDNLP) problem, which are difficult to solve. Third, the solution to a problem with multiple, competing objectives is not a single design; rather, it is a set of designs representing best-possible trade-offs. Decision-makers (DM) must choose the "best" solution from this set.

This paper investigates a systematic and quantitative approach to select suitable technology for an engineering design that has competing objectives. Such an approach can be effective in several ways: (1) it may measure the effectiveness of decision-making, (2) it allows for collection of data and analysis of success and failure mechanisms, (3) provide justification to the project, (4) ensure feeling of stakeholder security in the selections, (5) make possible evaluation of the technology selection by a third party, and (6) raise the reliability, performance and productivity of systems.

The approach here uses the Surrogate Worth Trade-off (SWT) method [1] to help choose a preferred solution from the set of solutions to a constrained MO-MDNLP problem. The discrete technology(ies) associated with this preferred solution is (are), therefore, the preferred technology(ies) for the new design. A simple benchmark design problem provided the example; this is a constrained, multi-objective three-bar truss optimization problem in which the material used for the elements is a discrete selection or, in the context here, a technology selection.

The chapter attempted to address three questions: How can design optimization facilitate selecting technologies for new systems? How can we support the DM in choosing new technology? What are the thresholds for DM to adopt technologies that are new to systems?

Multi-objective Decision Making

The DM involved in Trade-off Studies

In dealing with conflicting objectives, a designer has to clarify the trade-off among the objectives; however, the relative importance of the objectives is often ambiguous. A goal in multi-objective decision-making is to incorporate the DM's judgment with the mathematical model that provides quantitative values for the trade-offs available in the problem. A DM holds the responsibility of decision-making, selects the compromised solution from multiple alternatives and is involved in other actions related to the decision-making process. The DM may be the analyst who generates new information based on the input information, processes the information, and takes part in final decision-making. The DM could be an individual other than the analyst, a group of individuals, or perhaps a combination of human and computer. A role of the DM is to check the validity of the computational result, which will compensate for the limits of the calculations; this check may also incorporate subjective or qualitative factors that the mathematical problem model did not incorporate.

Divergence of Decision Making Theory

The theory of multi-objective decision-making can be tracked back into the 1950s. Utility theory appeared in the 1960s; this includes the DM's preference *before* optimization, combining all the objectives into a single mathematical objective. Well-known approaches include Multi-attribute Utility Theory, Goal Programming and Analytic Hierarchy Process (AHP). During the 1970s, new methods began to treat the objectives separately, making it possible for the DM to compare objectives paired two at a time, which made it easier for the DM to express one's preference towards the conflicting objectives. Hwang and Masud [2] classified the existing decision-making methods into three categories: *a priori*, *a posteriori*, and progressive articulation of preferences; each category depends upon the time when the DM assigns preferences. Utility theory belongs to the *a priori* articulation and SWT to the *a posteriori* articulation of preferences.

Solutions to Multi-objective Problems

In multi-objective decision-making, the DM must choose the "best" solution from multiple alternatives. When simultaneously minimizing two competing objectives, the designs providing the minimum possible values of the two objective functions are different. Engineering design problems generally have multiple objectives and constraints. The feasible optimal solutions to a constrained multi-objective problem are called "Pareto-optimal solutions". The Pareto-solutions are always on the border of the feasible solution space; they are also known as the "efficient solutions". Mathematically, these are "non-dominated" or "non-inferior" solutions. A design is "Pareto-optimal" if there is no feasible alternative that will improve one objective without degrading at least one another objective.

The Surrogate Worth Trade-off Method

The Surrogate Worth Trade-off (SWT) method provides an interface between the mathematical model of the problem and the DM. SWT consists of four steps: (1) generation of non-dominated solutions, (2) obtainment of relevant trade-off information for each generated solution, (3) interaction with the DM to assign preferences expressed in terms of worth, (4) finding of the best-compromised solution from the information obtained [3].

Rationale of Choosing the SWT Method

SWT has appeared in the areas of water resource planning and management, pollution control, power resource planning, and contract negotiation [1, 4, 5]. However, the SWT method does not appear to have had applications that involve technology selection. The fact that the SWT is an *a posteriori* method that can select from a set of non-dominated solutions motivated this investigation of how SWT might facilitate technology selection in the context of an MO-MDNLP problem.

Steps of SWT Method

Step 1: *Generation of non-dominated solutions*. The SWT method requires a set of non-dominated solutions from which the DM chooses the preferred solution. There are a number of ways to generate Pareto-optimal designs. Given the simplicity of the problem in this paper, the ε-constraint method generates Pareto-optimal designs. The ε-constraint method defines a master objective f_k and converts the other objectives f_j into inequality constraints of a single-objective optimization problem:

$$\text{minimize } f_k(\mathbf{x}). \tag{1}$$

$$\text{subject to } g_l(\mathbf{x}) \leq 0 \quad l: 1, \ldots, n_{con} \tag{2}$$

$$\mathbf{x} \in \mathbf{X} \tag{3}$$

$$f_j(\mathbf{x}) \leq \varepsilon_j \quad j: 1, \ldots, n_{obj} \quad j \neq k. \tag{4}$$

Here, $g_k(\mathbf{x})$ are constraints on the problem, and $\mathbf{X}$ is the bounded region. Varying the values of ε_j and solving the problem for each new value of ε_j provides non-dominated solutions, without particular restrictions.

Step 2: *Obtain relevant trade-off information*. Each λ_{kj} represents the partial trade-off rate between f_k and f_j. Using the ε-constraint method, the Lagrange multipliers of the constraints $f_j(\mathbf{x}^*) \leq \varepsilon_j$ are the partial trade-offs at the non-dominated solution $\mathbf{x}^*$:

$$\lambda_{\mathrm{kj}} = \frac{\partial \mathrm{f_k}(\mathrm{x}^*)}{\partial \varepsilon_{\mathrm{j}}} \tag{5}$$

when $\lambda_{kj} > 0$, there is degradation in objective j for any improvement in objective k.

Step 3: *Interaction with the DM*. First, the analyst prepares a table listing representative non-dominated solutions. The DM is asked: "*Given a design* $\mathbf{x}^*$ *with objectives* $\mathbf{f}(\mathbf{x}^*)$, *what is your assessment of how much an improvement of* λ_{kj} *units in* f_k *is worth in relation to an degradation of one unit of* f_j, *while all other objectives remain fixed at* f_l, *for* $l = 1$, k *with* $l \neq j$, k?" The DM provides the assessment on a scale of +10 to −10, where +10 means the greatest desire to improve f_k by λ_{kj} units per one-unit degradation of f_j, 0 means indifference about the trade, and −10 means the greatest desire to degrade f_k by λ_{kj} units per one-unit improvement in f_j. Values between −10 and 0 or between 0 and 10 show a proportional desire to make the corresponding trade-off. The DM's response becomes W_{kj}, the "surrogate worth" of the trade-off between f_k and f_j.

Step 4: *Finding the best-compromise solution*. A particular non-dominated solution $\mathbf{x}^*$ is the best-compromise solution if the DM is indifferent to all trade-offs offered from the current point $\mathbf{x}^*$. In other words, $\mathbf{x}^*$ is the best-compromise solution if

$$W_{kj}(\mathbf{x}^*) = 0 \quad \text{for all } j \neq k. \tag{6}$$

If the DM has not assigned $W_{kj} = 0$ to any design, the analyst uses regression to construct, for each $j \neq k$, the surrogate worth function W_{kj} relating W_{kj} to f_l for all $l \neq k$. Then, the system of equations

$$W_{kj}(f_1, \ldots, f_{k-1}, f_{k+1}, \ldots, f_n) = 0 \quad j \neq k. \tag{7}$$

is solved for the values of f_l, which would correspond to the best-compromised design.

SWT Method Applied to Technology Selection

Three-Bar Truss Example Problem

This is a simple benchmark problem for investigating and teaching design optimization algorithms. Here, the problem combines continuous and discrete variables. The cross-sectional area of the truss elements are continuous variables, and the material selection is a discrete variable with choices of aluminum, titanium or steel. The material properties appear in Fig. 1 with a geometric representation of the truss. Using material selection as a discrete variable represents a technology choice that might be part of a larger system design problem. For instance, if a DM were asked which material would be best to minimize both mass and displacement subject to stress constraints *a priori*, the DM may select aluminum, because this material has the highest stiffness-to-weight (E/σ) of the available choices.

The problem is to minimize both the mass of the truss and the displacement under the design load while satisfying strength constraints and bounds on the radii of the elements. The optimization statement becomes

$$\text{Minimize} \begin{pmatrix} \mathrm{f}_1(\mathrm{x}) = \text{weight} \\ \mathrm{f}_2(\mathrm{x}) = \text{displacement} \end{pmatrix} \tag{8}$$

$$\text{subject to } g_i(\mathbf{x}) = \frac{\sigma_i(\mathbf{x})}{\sigma_{allow}(\mathbf{x})} - 1 \le 0 \quad \text{for } i = 1,\ 3 \tag{9}$$

$$g_{i+3}(\mathbf{x}) = \frac{\sigma_i(\mathbf{x})}{[-\sigma_{allow}(\mathbf{x})]} - 1 \le 0 \quad \text{for } i = 1,\ 3 \tag{10}$$

$$\mathbf{x} = \{A_1, mat_1, A_2, mat_2, A_3, mat_3\} \tag{11}$$

$$A_i \in \mathbb{R} \tag{12}$$

$$0.5\,\mathrm{cm}^2 \le \mathrm{A_i} \le 20.0\,\mathrm{cm}^2 \tag{13}$$

$$\mathrm{mat_i} \in \{\mathrm{Al, Ti, Steel}\}. \tag{14}$$

	Aluminum	Titanium	Steel
E [Pa]	7.20×10^{10}	1.16×10^{11}	2.05×10^{11}
ρ [kg/m^3]	2700	4500	7872
σ_{allow} [Pa]	5.52×10^{7}	1.40×10^{8}	2.85×10^{8}
E/ρ [N-m/kg]	2.67×10^{7}	2.58×10^{7}	2.60×10^{7}
σ/ρ	2.04×10^{4}	3.11×10^{4}	3.62×10^{4}

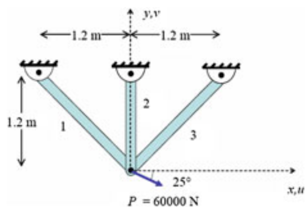

Fig. 1 Physical properties of the metals (*left*). E is Young's modulus, ρ is density, and σ_{allow} is allowable stress. Geometric representation of the *three-bar* truss (*right*)

Procedure of SWT Method

Because this problem has only three discrete options, the ε-constraint method generated Pareto-optimal designs using aluminum, then titanium, and finally steel by using mass as the master objective and constraining displacement to different values of ε. This provides the cross-sectional areas for the truss elements associated with each non-dominated solution and the value of λ_{12}, which is the Lagrange multiplier associated with the ε-constraint. The feasible, non-dominated solutions of the truss using each material appear in Fig. 2. This illustrates where the different "technologies" would have advantages, depending upon the DM's preferences.

Trade-off Matrix and Result

Two scenarios illustrate how a DM would choose the best design from the set of non-dominated solutions; the corresponding best design incorporates the preferred technology (material). The two scenarios are where the DM desires (1) a relatively low mass design and (2) a relatively low displacement design. Within the low-mass scenario, two different assignments of surrogate worth lead to different choices.

The DM is presented with a trade-off matrix containing information about non-dominated designs near the area of interest. Table 1 shows the trade-off matrix containing low mass designs from Fig. 2. The values of λ_{12} are larger in magnitude than f_1 (mass) and f_2 (displacement), so a scaling factor $c = 0.01$ helps interrogate the DM [6]. The DM is asked: "What is your assessment of how much a decrease of 0.0772 kg in mass is worth in relation to an increase of 0.01 cm of displacement, given a truss with a mass of 4.17 kg and a displacement of 0.32 cm?" The DM has thought that he/she would like a low mass design but considered 0.32 cm of deflection too large, so he/she assigned a negative value of W_{12} because he/she does not agree with the trade-off and would prefer to increase mass by 0.0772 kg to reduce deflection by 0.01 cm. For the design in row three, the DM assigns a negative W_{12} of smaller magnitude than for the second row because he/she still liked lower deflection but the mass was starting to increase which was of concern

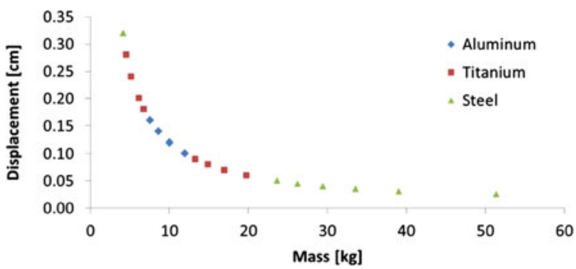

Fig. 2 Non-dominated designs from combining all solutions of the *three-bar* truss

Table 1 Trade-off matrix of (1) low mass (case 1)

Material	ε	Mass (kg)	Displacement (cm)	Area 1 (cm^2)	Area 2 (cm^2)	Area 3 (cm^2)	λ_{12} (kg/cm)	$c\lambda_{12}$ (kg/cm)	W_{12}
Steel	0.320	4.17	0.32	1.950	0.50	0.817	7.72	0.0772	−7
Titanium	0.280	4.55	0.28	4.006	0.50	1.597	9.48	0.0948	−5
Titanium	0.240	5.17	0.24	4.206	0.50	2.205	20.30	0.2030	−3
Titanium	0.200	6.14	0.20	5.050	0.50	2.637	29.23	0.2923	−2
Titanium	0.180	6.79	0.18	5.613	0.50	2.924	36.08	0.3608	3
Aluminum	0.160	7.56	0.16	10.646	0.50	5.494	46.12	0.4612	5
Aluminum	0.140	8.61	0.14	12.169	0.50	6.271	60.23	0.6023	10

to the DM. In the sixth row, the DM assigned a positive worth value W_{12}, because the DM was willing to achieve lower mass than this design at the expense of increasing deflection.

With only two objectives, the relationship between W_{12} and ε (or f_2) is constructed from the DM's responses; here, this is a polynomial fit as shown in Fig. 3. The preferred design corresponding to $W_{12} = 0$ is $f_2 = 0.190$ cm. Considering Table 1, this corresponds to selecting titanium. Solving the ε-constraint problem with $\varepsilon = 0.190$ cm yielded $f_1 = 6.45$ kg, $f_2 = 0.190$ cm, with $A^*_{i=1,3} = (5.32, 0.5, 2.77\ \text{cm}^2)$.

In the second case of desiring low mass designs, this DM favors slightly lower displacement than the DM in the previous case and assigns different W_{12} values. The trade-off matrix appears as Table 2.

From a third-order polynomial fit for W_{12}, the value of $f_2 = 0.173$ cm corresponds to $W_{12} = 0$. This value of f_2 lies between aluminum and titanium designs, requiring two solutions of the optimization problem with $\varepsilon = 0.173$ cm. For titanium, the objectives are 7.05 kg and 0.173 cm with $A = (5.84, 0.5, 7.05\ \text{cm}^2)$; for aluminum, 7.02 kg and 0.173 cm with $A = (10.1, 0.5, 7.02\ \text{cm}^2)$. Here, the aluminum design slightly dominates the titanium design (it has lower mass for the same displacement) and is the preferred design.

The low displacement scenario considers designs nearer the other end of the Pareto frontier; Table 3 shows this trade-off matrix. Here, $c = 0.001$ provided scaling for interacting with the DM. Responding to questions like those above, the DM gives negative W_{12} values when he/she favors increasing mass for decreasing

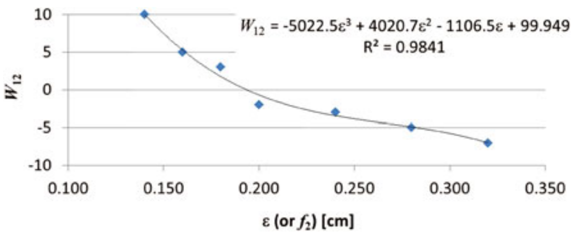

Fig. 3 Relationship between W_{12} and ε or f_2 in (1) low mass (Case 1)

Table 2 Trade-off matrix of (1) low mass (case 2)

Material	ε	Mass (kg)	Displacement (cm)	Area 1 (cm^2)	Area 2 (cm^2)	Area 3 (cm^2)	λ_{12} (kg/cm)	$c\lambda_{12}$ (kg/cm)	W_{12}
Steel	0.320	4.17	0.320	1.950	0.50	0.817	7.72	0.0772	−10
Titanium	0.280	4.55	0.280	4.006	0.50	1.597	9.48	0.0948	−8
Titanium	0.240	5.17	0.240	4.206	0.50	2.205	20.30	0.2030	−5
Titanium	0.200	6.14	0.200	5.050	0.50	2.637	29.23	0.2923	−3
Titanium	0.180	6.79	0.180	5.613	0.50	2.924	36.08	0.3608	−1
Aluminum	0.160	7.56	0.160	10.646	0.50	5.494	46.12	0.4612	2
Aluminum	0.140	8.61	0.140	12.169	0.50	6.271	60.23	0.6023	6

Table 3 Trade-off matrix of (2) low displacement (case 3)

Material	ε	Mass (kg)	Displacement (cm)	Area 1 (cm^2)	Area 2 (cm^2)	Area 3 (cm^2)	λ_{12} (kg/cm)	$c\lambda_{12}$ (kg/cm)	W_{12}
Aluminum	0.120	10.02	0.120	14.200	0.50	7.307	81.98	0.082	−6
Aluminum	0.100	11.98	0.100	17.044	0.50	8.757	118.05	0.118	−4
Titanium	0.090	13.28	0.090	11.242	0.50	5.798	144.29	0.144	−2
Titanium	0.080	14.91	0.080	12.650	0.50	6.516	182.61	0.183	−1
Titanium	0.070	16.99	0.070	14.460	0.50	7.439	238.50	0.239	2
Titanium	0.060	19.78	0.060	16.873	0.50	8.669	324.62	0.325	4
Steel	0.050	23.66	0.050	11.451	0.50	5.904	462.75	0.463	4
Steel	0.045	26.23	0.045	12.725	0.50	6.554	571.28	0.571	7

displacement and positive W_{12} values when favoring a decrease in mass for an increase in displacement. With a second-order polynomial fit, $f_2 = 0.078$ cm sets W_{12} to zero; this lies amongst the titanium designs. Solving the ε-constraint problem yielded 15.5 kg and 0.077 cm, with $A = (13.1, 0.5, 6.77 \text{ cm}^2)$.

Discussion

The SWT method was applied to three cases in which a DM assigned relative worth preferences to select the preferred design from multiple points on the Pareto frontier of an MO-MDNLP problem. In Case 1, when W_{12} was set to zero, $f_2 = 0.190$ cm was obtained for the preferred design. The value of $f_2 = 0.190$ cm lied in the range of titanium between row 4 and 5 in Table 1. Case 2 presented a situation where the value of f_2 corresponding to $W_{12} = 0$ fell between differing materials in the trade-off matrix. In Table 3, $f_2 = 0.174$ cm is between row 5 (titanium, $f_2 = 0.180$ cm) and 6 (aluminum, $f_2 = 0.160$ cm). Now, with the value of ε associated with the best design, the analyst would solve the optimization problem for both materials. In this case, the Aluminum solution dominates the Titanium solution.

The former result indicates that interpolating the "nearest" optimum design point would suffice in selecting material if the value of f_2 could be found within the range of the same material in the trade-off matrix. The latter result tells us that when the value of f_2 falls in between the discrete material choices, the analyst is required to re-run optimization using the ε value of the preferred design and then to compare the solutions using the two different materials.

Case 3 explored the situation where the DM was searching for a low displacement design. If the DM preferred low displacement, initially he/she might have chosen steel because by glancing at the Pareto frontier in Fig. 2 where steel designs with the lowest displacement. However, consulting the DM's preference, the material choice resulted in titanium. The process the DM undergoes using the SWT method may provoke the DM to express the preference he/she holds. Coming up with a different material selection than the initial *a priori* decision implies that the SWT method has possibility in better informing the DM of his/her choice of technology.

There are some limitations to using the SWT method for this problem and for any problem in general. The λ_{12} values correspond to the computed predictions of the designs' performance. Issues not reflected in these predictions are difficult to capture. For example, cost was not an explicit objective in the problem, so the DM's preferred design often used titanium. However, titanium is expensive compared to aluminum or steel. In cases 1 and 3, there may have been less expensive designs that are dominated when only considering mass and displacement as objectives. Adding cost as a third objective could address this; however, many engineering problems have objectives or goals that are difficult to compute in a numerical sense.

The example problem here is quite simple; it illustrates some of the concepts involved in treating technology selection via an MO-MDNLP approach. However, most engineering design problems involve more design variables, more choices of technology, and additional objectives. Additional study of how SWT might support technology selection for a more complicated problem can provide insight into how the method scales with problem size. Further, it is not clear how qualitative or subjective assessments are best incorporated in this approach. Clearly, a DM makes some of these assessments when assigning values of W_{ij}, so an improved way of capturing the rationale behind these or providing guidance in this would help.

Conclusion

In this paper, the SWT method was applied to selected preferred solutions to a MO-MDNLP problem with the intent of investigating how this might assist in selecting technology from discrete alternatives. A version of the three-bar truss problem combining discrete material selection and continuous cross-sectional areas represented a possible technology selection problem. The non-dominated sets of design points were generated for Aluminum, Titanium and Steel, respectively, to represent a material choice problem to the DM.

The SWT method worked effectively in the domain of technology selection by presenting a question to the DM about the available trade-off between objectives. Introducing a value c to scale the trade-off function λ_{12} provided a more understandable question in an engineering context.

The result from investigating the SWT method indicated that a preferred design from the set of non-dominated solutions to an MO-MDNLP problem can be obtained via an *a posteriori* approach that elicits the DM's preference. The material choices obtained here may not have been choices made *a priori*; the choice of aluminum as the highest E/ρ material would not have had the performance of the titanium designs selected in this study. Obtaining designs with material choices differing from a likely initial decision demonstrated that SWT method could be applied to technology selection and could better inform the DM of his/her choice of technology.

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Part VII
Engineering Design and Sociotechnical Systems

The Historical Roots of the Field of Engineering Systems: Results from an In-Class Assignment

Christopher L. Magee, Rebecca K. Saari, G. Thomas Heaps-Nelson, Stephen M. Zoepf and Joseph M. Sussman

Abstract Although the field of Engineering Systems (ES) is young, its intellectual roots originate far back in time. Tracing these roots is the objective of an integrative capstone assignment in the first doctoral subject for incoming ES PhD students at MIT. Teams of two or three students research the intellectual connections between a specific historical root and modern ES method. The assignment has now been offered for 5 years (2008–2012). This chapter describes the faculty and student perspectives on the assignment, including the perceived learning outcomes, and insights gained into the roots of Engineering Systems. Some overall observations include: (1) Interconnections among almost all selected topics are apparent. The historical development of each topic gives rise to overlap and complex interactions between historical roots and modern methods; (2) Students cite Herbert Simon's work as most pivotal to the roots of Engineering Systems. Jay Forrester, John von Neumann, Norbert Weiner, Joseph Schumpeter and others are also identified as having a significant impact; (3) The faculty always learn something about the field from what the students find even when topics are repeated; and, (4) The assignment is a valuable, though imperfect, vehicle for learning about Engineering Systems and for launching budding researchers' efforts in the field.

Keywords Historical roots · Engineering systems · Methodologies · Knowledge relationships · Citation analysis · Engineering pedagogy

C. L. Magee (✉) · R. K. Saari · G. T. Heaps-Nelson · S. M. Zoepf · J. M. Sussman
Engineering Systems Division, Massachusetts Institute of Technology, 77 Massachusetts Ave, Building E40-369, Cambridge, MA 02139, USA
e-mail: cmagee@mit.edu

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Introduction

"Engineering Systems" is the name used at the Massachusetts Institute of Technology (MIT) for the study of complex socio-technical systems. Incoming students in the Engineering Systems doctoral program at MIT are required to complete the Engineering Systems Doctoral Seminar (see [1, 2] for thorough course descriptions). The course has two overarching learning objectives:

1. Increasing students' knowledge of the field;
2. Increasing students' understanding of research in Engineering Systems.

An assignment in this course—dubbed "Historical Roots"—evolved into one of the major tools for accomplishing both learning objectives. Now that the assignment has been offered five times, the faculty decided to share their experiences and student perspectives on the nature and value of this assignment as teaching tool for ES, and its preliminary insights into the historical roots of this new and vibrant field. From these faculty and student perspectives, this chapter explores both the content of and suitable pedagogy for the intellectual foundations of the field, and the relationships among its foundations.

This chapter is structured as follows: the assignment and student submissions are described in section Historical Roots Assignment. Section Methodology describes the sources of the observations provided in this chapter, which are based on the faculty's reflections on the assignment and their review of the submitted materials. Student feedback was also solicited through the use of a web survey. A quantitative summary of the survey data is presented in section Survey Results and integrated results are detailed in section Integrated Observations and Findings. Overall discussion of the results follows in section Discussion.

Historical Roots Assignment

The Historical Roots assignment asks pairs or teams of students to explore the intellectual interconnections between two topics in ES. Each student team selects both a "historical root" *and* a "modern methodology." The assignment further requires[1] that each team explore forward in time from their historical root and backward in time from the modern methodology using careful historical analysis of the literature, citation analysis and other methods to explore the complex web of work which precedes current Engineering Systems practice and research. Students present their analysis in a 5,000 word report and a 25 min in-class presentation.[2] In the faculty's view, the historical development of these interrelated fields is

[1] The full detailed assignment is provided as an appendix to this document.

[2] The presentations were not part of the assignment in 2008 but were from 2009–2012.

Table 1 Root and methodology pairs (on same line) for all 30 papers submitted from 2008–2012. Topics shaded in grey have been selected more than once

Year	Historical root	Methodology
2012	Complexity theory	Modern network analysis
	Game theory	Decision making under uncertainty
	History of technology	Technological dynamics
	General systems theory	System dynamics
	Operations research	Stochastic optimization
	Organizational theory	System architecting
2011	Impact of technology on the economy	Technological dynamics
	Cybernetics and control theory	Strategy
	Sociobiology	Modern network analysis
	Complexity theory	Social networks
	Organizational theory	Real options analysis
2010	Equilibrium economic analysis	Benefit cost analysis for project evaluation
	(Historical) network analysis	Social networks
	Sociobiology	Agent based modeling
	Cybernetics and control theory	System dynamics
	Operations research	Stochastic optimization
	Negotiation	Consensus building
2009	Equilibrium economic analysis	Operations research network analysis
	Impact of technology on the economy	Stakeholder analysis
	(Historical) network analysis	Modern network analysis
	Supervisory control	Decision making under uncertainty
	Scientific management	Real options analysis
	Scientific management	Strategy development
	Game theory	Decision analysis
2008	Decision theory	Decision making under uncertainty
	(Historical) system dynamics	Agent based modeling
	Systems engineering	Multi-attribute tradespace exploration
	(Historical) network analysis	Social networks
	Impact of technology on the economy	Strategy
	Decision theory	Agent based modeling

explored deeply in each submission.[3] Over the past 5 years, students have chosen the pairs of historical roots and modern methodologies shown in Table 1.

Students were free to select any pairing of the topics, including those listed in the assignment, or a topic proposed by the student. Even though a number of roots and a number of methodologies were studied more than once, only twice was the same pairing chosen. Hence, virtually all of the 30 reports submitted represent unique endeavors.

[3] Two example submissions have been posted by the student authors [3, 4] and are worth examination by the interested reader.

Methodology

In advance of the Council of Engineering Systems Universities Network (CESUN) conference in Delft in June, 2012, the authors gleaned their insights and perspectives from the 24 student submissions that had been completed by that time. This chapter's lead author generated the insights described in section Integrated Observations and Findings by reviewing the 24 student submissions and the associated faculty-provided feedback; these represent the faculty perspectives on the assignment. The authors sought the perspectives of all students to complete the course through a web survey described herein. This survey has been offered to all 60 students completing the course from 2008–2012.

Student Web Survey

The authors sought student perspectives on the Historical Roots assignment using a survey designed to gather information in the following categories:

- General attitude toward and retrospective feedback regarding the assignment;
- Recall of insights, ideas, skills and methodologies gleaned from the assignment and their influence on students' subsequent doctoral research activities; and
- Evaluations of the role of the assignment in Engineering Systems cohort and community building.

The survey consisted of 16 questions, including multiple-choice, Likert scale, and open-ended response.[4] It was offered online using Survey Monkey[5] to the 60 students who have completed the Historical Roots assignment in the MIT Engineering Systems doctoral seminar as of December, 2012. Invitations to participate were sent by email in early 2012 and 2013.[6] The survey response rate was 80 % (i.e., 48 responses out of 60), with most respondents completing the survey in 15–30 min.

To complement the multiple-choice responses, 12 of 16 questions allowed for elaboration and open-ended comments, providing a qualitative source to search for common themes in the students' perspectives. One author coded the 225 qualitative responses obtained. The coding categories were developed after reading all responses. They include responses by students about learning the history, development, and interrelation of Engineering Systems fields and scholars. They also include remarks about learning concepts and methods related to ES, and gaining

4 The complete survey instrument is included as an attachment.

5 Available at www.surveymonkey.com.

6 Initial survey was sent out to 2008–2011 students in January, 2012. The same survey was sent again in February, 2013 to participants in the 2012 class.

skills relevant to ES research. The codes are described in an appendix, and the results are presented in section Survey Results.

In collecting and analyzing student perspectives, the authors attempted to mitigate issues such as misunderstanding, respondent fatigue, and bias. In developing the final instrument, the authors consulted four student pre-testers and two MIT survey methodology experts. The final survey instrument was designed to guard against acquiescence bias [5], and social acceptability bias. Steps within the survey included: careful question wording; and the option to gracefully opt-out of individual questions, the whole survey, and the qualitative responses. These biases were further mitigated through measures to preserve respondent anonymity. Specifically, raw responses were available only to the three student co-authors, and were anonymized before they were analyzed; the results were aggregated before they were shared with the professorial co-authors. Certainly, selection, acquiescence, and social acceptability biases may still be present. However, the seemingly frank and sometimes critical nature of the responses provides some measure of confidence.

Another potential bias is a variation in the respondents' ability to recall the pertinent details. Given that the respondents completed this assignment between several months and several years prior to this study, a systematic bias is also possible for students of earlier years (e.g., 2008–2009). To accommodate lack of recall, survey questions included "do not recall" response options and allowed the respondent to skip questions, where appropriate. By way of reminder, the invitation to participate included a list of roots and methodologies chosen by each student pair (see anonymous list in Table 1), but no other efforts were made to aid respondents' recall.

Another potential temporal bias arises from the minor inter-annual differences in the Historical Roots assignment details (see section Historical Roots assignment), though none were deemed important enough to necessitate separate survey instruments for separate years. Instead, results were analyzed by year as well as in aggregate to identify temporal variations (see section Survey Results).

Survey Results

The main survey results are briefly introduced here and later referenced in section Integrated Observations and Findings. The multiple-choice responses are summarized in Table 2, and Figs. 1, 2, 3, 4, 5, 6, 7, 8. They indicate a generally positive attitude toward the assignment and a recollection of useful skills and insights, though these understandably diminish with the time elapsed since completion of the assignment (see Figs. 7, 8).

Responses to specific social and learning aspects of the assignment were generally positive. Figures 1, 2, 3, 4, 5, 6 quantify responses to these individual questions.

In their open-ended responses, students described gaining insights into the roots of Engineering Systems, increasing their knowledge of the field, and increasing

Table 2 Survey responses (*from Questions* 3–6) indicate a positive impact of the historical roots assignment on development of student knowledge and, to a lesser extent, direct contributions to research

	X = Ideas or insights	X = Skills or methodologies
Can you remember any new [X] to which you were exposed through your historical roots assignment? [*If you answered yes, please describe them here*]	81 % replied yes	79 % replied yes
Have you used any [X] from this assignment in your subsequent research? [*If so, which ones?*]	48 % replied yes	35 % replied yes

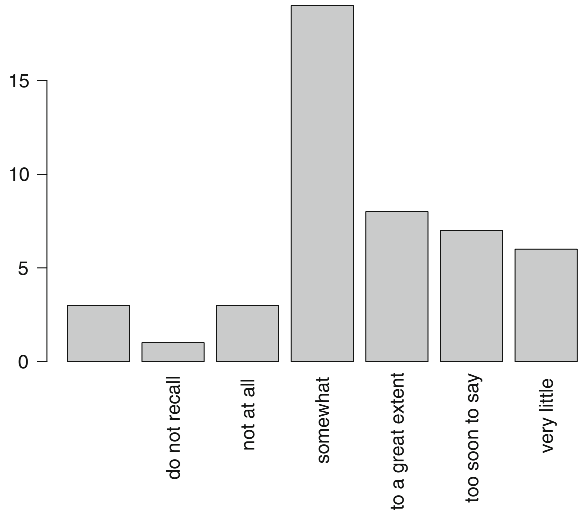


Fig. 1 Students generally were encouraged by the assignment to investigate historical roots more deeply. (Question 8: Did your experience with the ESD 83 historical roots assignment encourage you to explore more deeply the historical roots of your subsequent doctoral research?)

their understanding of research in the field. The major themes found included (number of mentions in parentheses): the interrelation of fields (18); the historical development of Engineering Systems and related fields (34), including the importance of key scholars (13); learning about concepts (38) and methods (33) related to Engineering Systems; and the development of scholarly skills (42) such as literature searches (28) and citation analysis (20). See Fig. 9.

Integrated Observations and Findings

This section summarizes the faculty and student perspectives in two broad categories: (1) development and interrelation of fields underlying Engineering Systems; and, (2) pedagogy, value and limitations of the assignment in developing

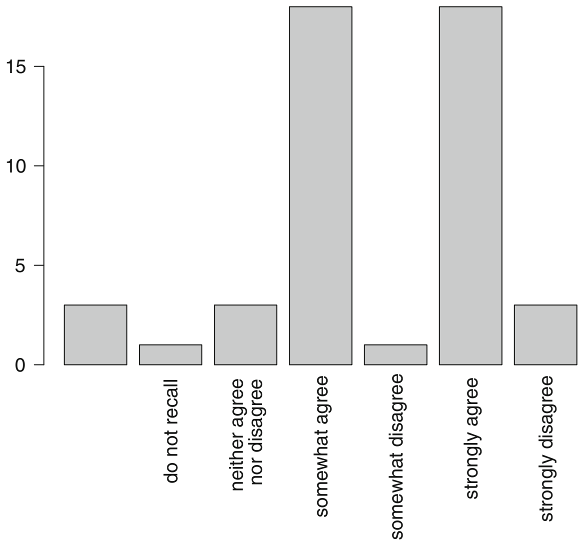


Fig. 2 Students generally reflected positively on the learning aspect of the assignment. (Question 9: Rate your level of agreement with the following statement: From listening to my classmates presentation of their historical roots assignment, I learned a lot about the depth and breadth of Engineering Systems?)

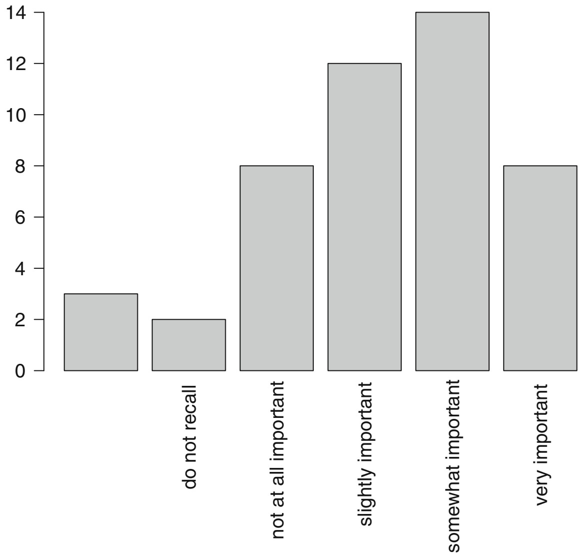


Fig. 3 Students generally felt positive about the community-building aspect of the assignment. (Question 10: How important was the Historical Roots assignment to helping you feel like a part of the emerging Engineering Systems research community?)

future scholars in Engineering Systems. Broadly speaking, the first section introduces some of the specific findings and meta-results from the assignments, and the second provides the student perspectives on their learning.

Fig. 4 Students generally viewed the assignment positively with regard to building their sense of community as a cohort (incoming class). (Question 11: How important was the Historical Roots assignment to helping you feel a sense of community with your cohort of doctoral students?)

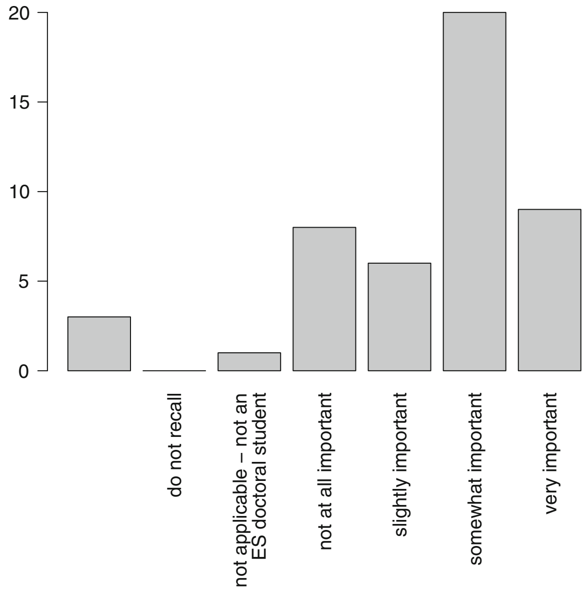
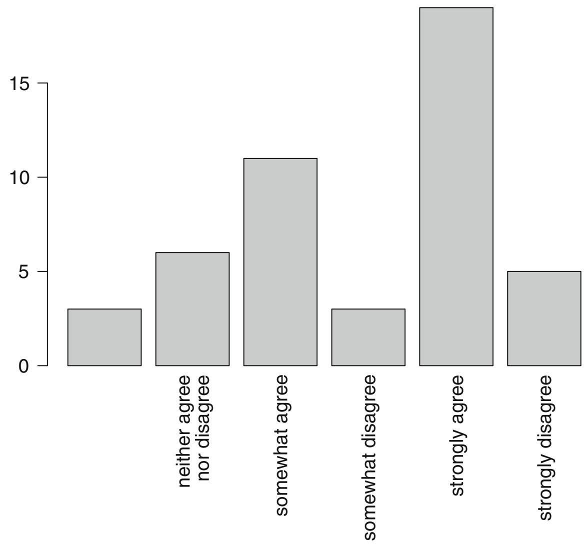


Fig. 5 Students were somewhat polarized by the investment of time in the assignment. (Question 12: Rate your level of agreement with the following statement: Overall, the Historical Roots assignment was worth the time I devoted to it?)



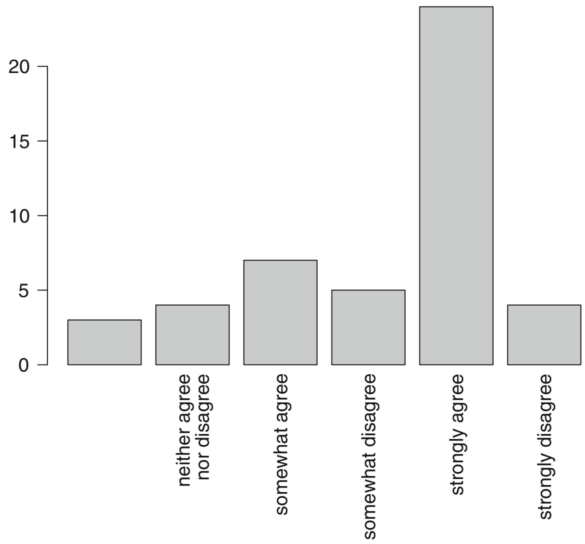


Fig. 6 Students generally responded positively to working with a partner on the assignment. (Question 13: Rate your level of agreement with the following statement: I was glad to work with a partner on the Historical Roots assignment?)

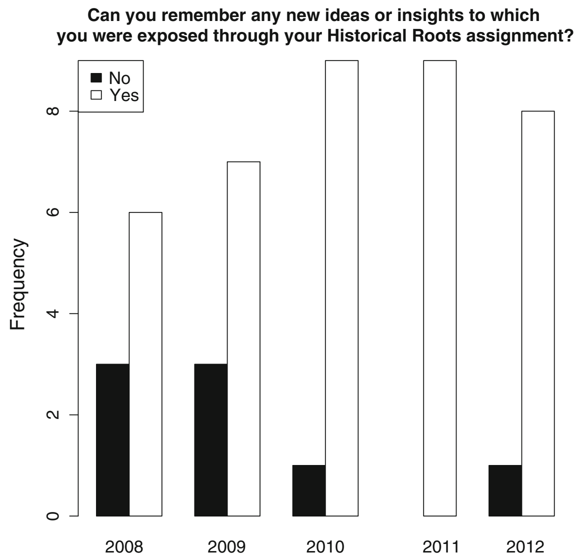


Fig. 7 Nearly monotonic decrease in recollection of new ideas or insights suggests possible recollection bias (Q3). (Question: Can you remember any new ideas or insights to which you were exposed through your Historical Roots assignment?)

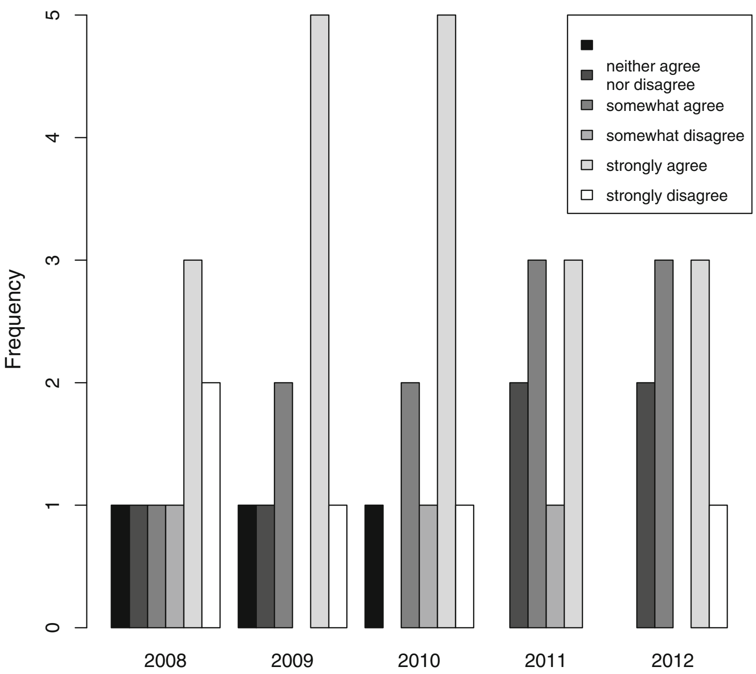


Fig. 8 Responses suggest that more recent classes have a slightly more positive recollection of the historical roots assignment (Q12). Unlabeled responses indicate that no response was given. (Question 12: Rate your level of agreement with the following statement: Overall, the Historical Roots assignment was worth the time I devoted to it?)

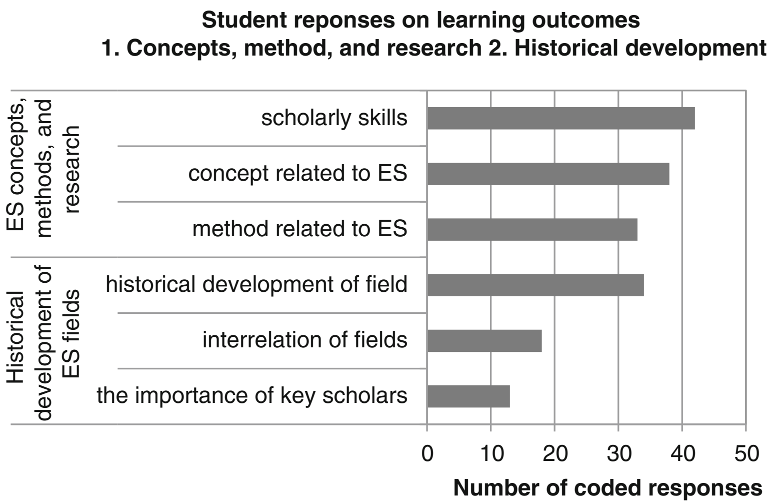


Fig. 9 Students reported learning about the historical development of ES, and about ES concepts, methods, and research (open-ended responses) (The explanation of the codes is provided in Appendix C)

Development and Interrelations of Fields Underlying Engineering Systems

The development and interrelation of fields is a pervasive theme throughout the submitted assignments and is clearly evidenced in many of the open-ended survey comments. The importance of the development and interrelations of the fields underlying Engineering Systems is embodied in several survey responses below[7]:

- "The fact that many of today's challenges were actually being discussed back as early in the 1960s;"
- "Establishing a new discipline (e.g., [Engineering Systems]) requires knowing history and using it in a different way;"
- "Science is a very personality driven process, with major advancements centered around specific individuals."

Relationships Among Fields Underlying Engineering Systems. The submissions' greatest focus is on the relationships among different fields. Some selected examples from the papers that explore these relationships are:

1. A submission containing detailed expositions of the relationships among developers of linear programming, non-linear programming, integer programming, combinatorial optimization, stochastic programming and Monte Carlo methods;
2. A submission demonstrating that the tension between cost-benefit analysis and economic theory that continues even today had its beginnings in the 1930s [6];
3. Submissions demonstrating a strong link of sociobiology to modern network analysis [7] and to agent based modeling [8];
4. A submission identifying Homans [9] as the first to use matrix realignment in identifying social groups in Social Network Analysis;
5. Numerous submissions demonstrating that particular roots have direct impact on numerous modern methods—for one example, OR can be shown to have influenced stochastic optimization, strategy development, dynamic programming, and network theory among other methods of relevance to Engineering Systems.

The assignments frequently produce novel observations, including the discovery of "deep roots" of a field, surprising inter-relationships, and apparently deliberate ignoring of closely related work, among others.

"Deep roots" are those that originate in centuries past. One example is a submission tracing modern social network analysis back to a stochastic model of social networks developed in 1875 by Francis Galton. A second deep root was illustrated in a submission chronicling the evolution of cost–benefit analysis in

[7] Note that typographical errors in student responses have been corrected when presented here. When they have been edited (either for anonymity or clarity), this is indicated by square brackets.

18th century France and its use in the early 19th century by Thomas Jefferson's Secretary of the Treasury, Albert Gallatin.

Surprising inter-relationships were those that created unexpected linkages between fields, often through convoluted pathways, individual scholars or unique works. A submission demonstrating a strong linkage between cybernetics and business strategy by emphasizing, among others, the work of Maruyama [10] and Boyd [11] is an example. A second surprising inter-relationship is identified in a submission demonstrating a strong connection between scientific management [12] and strategy development [13, 14] via the conduits of OR, organizational theory and industrial psychology. In addition to these direct and indirect links, the papers often demonstrate substantial conceptual linkages in novel ways; for example: between a "Engineering Systems framing paper" by Moses [15] and the work of Schumpeter [16–18]; and, another submission demonstrating the links from negotiation to game theory, decision-making and social psychology [19]. Another interesting if not surprising example is the influence of cybernetics on social sciences, evidenced by convincing quotations from scholars like Phillips [20] and Simon [21, 22].

The concept of "apparently deliberate ignoring" refers to a lack of citation or collaboration where it would be expected. One submission showed the total absence of references between four leaders of system dynamics and five leaders of cybernetics despite their evolution in close proximity. A quote from the open-ended survey results reflects on this unexpected finding, "I was exposed to the complicated relationship (or lack thereof) between Norbert Weiner and Jay Forrester. Despite largely the same subject material, their lack of collaboration is unusual."

In addition to those noted in individual submissions, some interrelations between fields became clear only during the session dedicated to student presentations. Reading and listening to each assignment gave both students and professors a wider appreciation of the breadth of Engineering Systems and the complex interlinking of its underlying fields. This element of student learning is evidenced by their responses to survey Question #9 (see Fig. 1), in which 86 % indicated that they learned a lot from listening to their classmates' presentations.

The Importance of Historical Context in the Development of Fields

Several students noted the importance of historical context in shaping the development of concepts and fields. For example, in their class presentation, one group noted how Euler's publication in Latin may have slowed the diffusion of his foundational contributions to graph theory. Another student noted, "how different concepts are shaped and forged depending on the historical context (e.g., the birth of Operations Research as a consequence of WWII)."

Apart from "apparently deliberate ignoring," the papers also describe how concepts can be lost in time, or discovered separately by distinct groups of scholars. Many submissions delineate differences in approaches from different

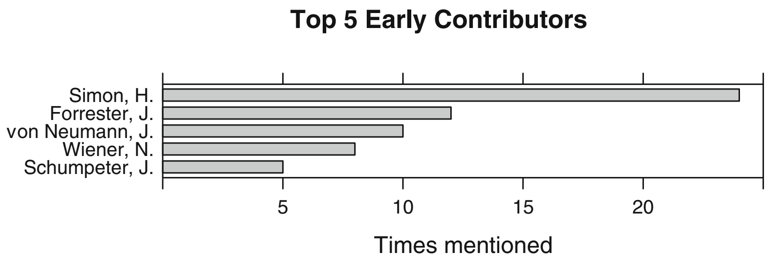


Fig. 10 Seminal engineering systems contributors most cited by survey respondents

disciplines and frequently find evidence of lost or delayed conceptual connections. (A specific example arises between de Solla Price's original work in power laws (see [23]) and independent "rediscovery" later by researchers from outside of the social networks field.) This shows that careful cross-disciplinary literature search is not always practiced as widely as would be desirable.

The Importance of Key Individuals to the Development of Engineering Systems

An important common theme among the assignments was the prominent role of certain scholars. As one respondent put it, "Every methodology and root analyzed had not only common themes, but common actors in their past." Collectively, the assignments point to substantial intellectual legacies in multiple fields by the likes of Jay Forrester and John Von Neumann. The authors were surprised by the evidence—in the papers and from the survey—of the singular influence of Herbert Simon among these historical roots.

In response to the survey (Question 7), students named a maximum of three important early contributors to Engineering Systems as a field. Figure 10 depicts the top five contributors mentioned: Herbert Simon, Jay Forrester, John Von Neumann, Norbert Wiener, and Joseph Schumpeter. Others mentioned include (those with multiple mentions are noted in parentheses): R. Ackoff (3), P. Anderson, R. Bellman, G. Dantzig, I. de la Sola Pool, L. Euler (2), J. Holland (2), H. Kahn, D. Kahneman (2), J. Little, M. Maier (2), B. Mandelbroit, J. March, A. Marshall, D. Meadows, S. Milgram, P. Morse (2), L. Mumford, K. Popper (2), H. Raiffa (3), E. Rechtin (2), P. Romer, L.J. Savage, C. Shannon, C.P. Snow (2), R. Solow, F. Taylor, A. Tversky, and L. von Bertalanffy (3). The breadth of fields represented by this group of scholars attests to the broad foundations of Engineering Systems.

Pedagogy: Value and Limitation of the Assignment

From the findings described above, the assignment appears to provide, from the faculty's perspective, a valuable vehicle for meeting the two overarching objectives of the course: increasing knowledge of Engineering Systems; and increasing understanding of research in this field. This section employs the survey results to illuminate the student perspective on the relevance of the assignment to the two learning objectives, its potential limitations, and its reported value.

With respect to the course objectives, that of learning about the field was clearly met. The majority of the qualitative survey responses pertained in some way to learning about Engineering Systems. Specifically, the assignment taught them about Engineering Systems as a field, its boundaries, and its breadth. As one student put it, "I really appreciated the time we devoted to learning more about the history of [Engineering Systems] since I believe it added color and depth to my understanding of the field." Fifty-five open-ended responses describe specific insights about concepts and methods related to their chosen fields or to Engineering Systems more generally. One survey respondent said in this regard, "It was great. I learned a lot about my root and methodology and […] I also learned about various other areas of thought from reading my classmates papers and listening to their presentations."

Students also grew as Engineering Systems scholars, and developed specific research skills. Again, many of these pertained to specific Engineering Systems methods, but fundamental skills in literature search and citation analysis proved to be an important learning outcome. That the students developed these skills is clear from their submissions and was also cited by 71 % survey respondents. Some students gained broader insights into academic research, e.g., "By encouraging us to look at the linkages among different strains in research, I gained new insights to the notion of research as a career and an industry. […] the main takeaway was learning about the processes by which we have arrived at a new field, and the innovations necessary to be able to think critically about the massive sociotechnical systems with which we are concerned." Others, however, were pleased to learn specifically about their own area of research, e.g., "The assignment provided a great grounding in ES, an opportunity to dig into the literature of one of my areas of research […]."

Not all students were so fortunate as to learn material that applied directly to their dissertation research. Some students noted this as a limitation of the assignment. At this early stage in their doctoral program, it can prove challenging for each student to choose a relevant root or method. Table 2 in section Survey Results gives quantitative evidence relative to this issue. While approximately 80 % of the respondents remembered new insights, ideas, skills or methodologies they learned from the assignment, only 30–50 % used them in subsequent research. Two quotes from the open-ended survey input highlight this discrepancy:

- "Not applicable to my research, but history and context for the methods one uses generally is a good thing."

- "The skills gained in performing literature searches and citation analyses were useful. The exercise of research, writing and presentation were good practice. Not "strongly agree" because the content of the paper was quite tangential to my research."

Related to these responses were indications in six open-ended comments about the (possibly excessive) time commitment needed to complete the assignment. Perhaps conversely, two other students critiqued the level of depth of study afforded by the assignment's format. The remaining critiques cited the limitations of citation analysis and suggested improvements to the assignment wording (e.g., the level of guidance). There were several strong objections to the use of assigned partners, but the majority of students were pleased to work in pairs (>70 %).

Despite these limitations, the majority of students found the assignment to be worthwhile overall (>70 %), as shown by their responses to Question 12 (see Fig. 8). In the words of the students:

- "Most valuable assignment I have completed in the doctoral program thus far. It was very time-consuming, but helped to frame what [Engineering Systems] actually is and from where it has emerged."
- "I really think this was an excellent assignment. It was a great way to explore the key methodologies in engineering systems and their roots. I really learned a lot."

Figure 11 summarizes the author and student perspectives of the learning benefits realized by students through their completion of the Historical Roots assignment.

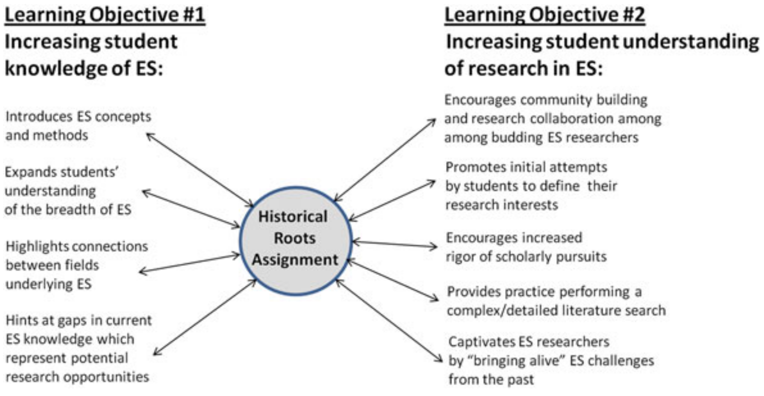


Fig. 11 Summary of key pedagogical benefits conferred by the historical roots assignment

Discussion

Re-examining the student submissions to the Historical Roots assignment and surveying the students who completed the assignment produced a broadly consistent set of observations. Specifically, Engineering Systems roots and methodologies are intertwined in a complex fashion and arise from a wide variety of disciplines and fields. Nonetheless, several key individuals have published work which has profoundly shaped the field. In particular, the work of Herbert Simon is most notable. Having had an outsized impact on this field is consistent with Simon's tendency to cross-over strongly between technical disciplines, such as computer science and artificial intelligence, and social sciences, such as economics and social psychology, not to mention his impact on organizational theory and engineering design. Other highly cited contributors to the roots of engineering systems including von Neumann, Wiener, Forrester and Schumpeter also exhibited particularly wide-ranging intellectual pursuits and interests.

The interdisciplinary nature of Engineering Systems imparts the advantage of insight derived from disciplines in the natural sciences, engineering, social sciences and business. Consequently, however, it is difficult to isolate the impacts of these disciplines on the overall field. The origins of Engineering Systems are deep and varied, with each root bringing the intellectual imprints of its source discipline. As one might expect, it is often difficult to accurately untangle and definitively establish a clear relationship between a particular root and a modern methodology. This is not a critical problem except to budding scholars attempting to learn enough about this field to become practicing and viable researchers. One key challenge for the development of Engineering Systems as a vibrant discipline may revolve around the need to educate researchers just starting out in the field. The evidence reviewed in this chapter and summarized in Fig. 11, indicates that the "Historical Roots" assignment discussed herein can serve as a highly useful—but imperfect—tool for meeting this crucial challenge.

Acknowledgments The authors would like to acknowledge several colleagues who provided significant insight, particularly with respect to the survey instrument; both Lisa D'Ambrosio and Roberto Perez-Franco offered much appreciated advice in this area. We would also like to acknowledge our four student survey pre-testers, particularly Judy Maro for her comprehensive review of the instrument and an earlier draft of this chapter. Finally, we would like to acknowledge the 60 MIT Engineering Systems Division students from ESD.83's 2008–2012 classes for their diligent and innovative efforts on the assignment and for their participation in the assignment survey.

Appendix A: Historical Roots Assignment as Given Fall, 2011

The field of contemporary engineering system derives from many historical roots. Some selected roots of engineering systems are as follows:

Some Selected Historical Roots of ES

Author	Field or concept	Starting date (approximate)
L. Euler	Network analysis	1776
A. Marshall	Equilibrium economic analysis	1890s
F. Taylor	Scientific management	1890s
J. Von Neumann	Game theory	1928
J. Schumpeter	Impact of technology on the economy	1930
L. Bertalanffy	General systems theory	1930s
K. Lewin	Social psychology	1930s
H. Simon	Organizational theory	Early 1940s
C. Shannon	Communication theory	1940s
P. Morse	Operations research	1940s
N. Weiner	Cybernetics and control theory	1950
S. Ramo	Systems engineering	1950s
V. Hubka	The science of engineering design	1960s
R. Richta	Technological evolution	1960s
H. Simon	Complexity theory	1962
E.O. Wilson	Sociobiology	1975

From these roots (and others as well), the field of contemporary engineering systems has emerged.

One way (but far from the only way) to characterize the field of contemporary engineering systems is by considering the various methodologies that support the field now. Examples of what we might consider as methodologies for contemporary engineering systems along with key authors are as follows:

Some Methodologies for Contemporary ES

ES methodology	Suggested authors
Real options analysis	R. de Neufville
Stakeholder analysis	R. Freeman
Strategy development	H. Mintzburg, M. Porter
Grounded theory	B. Glaser, A. Strauss
Decision making under uncertainty	R. Keeney, H. Raiffa
System architecting	E. Rechtin, M. Maier
Social networks	S. Wasserman, K. Faust
Modern network analysis	A. Barabasi, D. Watts, M. Newman
Dynamic programming	D. P. Bertsekas

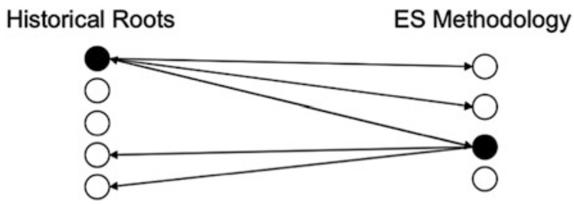
(continued)

(continued)

ES methodology	Suggested authors
Stochastic optimization	J. Schneider, S. Kirkpatrick, J.C. Spall
OR network analysis	R. Ahuja, T. Magnanti and J. Orlin
Technological dynamics	J. Utterback, C. Magee, J. Trancik

We note that similar terms appear in both the list of historical roots and methodologies of contemporary engineering system, reflecting the evolution of these concepts. In many cases, the approaches changed over time so today's methodology is quite different from a similarly termed root.

This relationship between historical roots and current engineering systems methodologies can be approached in one of two possible ways and is illustrated in the figure below.



The first approach is to choose one of the possible historical roots noted above (or perhaps an additional one you would like to suggest) and trace it forward to indicate its impact on the field of contemporary engineering systems as characterized by the methodologies, also noted above. So you want to identify scholarly work that built upon the root, tracing it through to today's foundation methodologies. Some of the roots may impact several of the contemporary methodologies.

There is an alternative way to think about the relationship between past intellectual developments and the field of contemporary engineering systems. This involves "backcasting" from where we are today to the roots. In this construction, one chooses one of the methodologies of *contemporary engineering systems* and works backwards in time to ascertain from whence it came. Again, a methodology as used today may derive from several of the roots. We have defined each methodology as currently used by noting the work of key authors on that methodology. Again, you could suggest additional current methods or authors.

For this assignment, we ask you to work in pairs, which we have specified, to create diversity in interests. Each pair will select one historical root and one contemporary Engineering Systems methodology as currently practiced. We request that you post your selections to the ESD.83 Wiki (https://wikis.mit.edu/confluence/display/esdDOT83fa11/Historial+Roots+Assignment+Selection). We suggest (but don't require) that you choose a root and methodology that you presume are related such that the root will be one you believe a priori affects your current methodology. The instructing staff will approve your root/method pair, and we will let you know this via email. *Remember you are invited to propose other historical roots or current methodologies.*

It will be interesting to contrast what we learn from the two approaches—e.g., if a root-based analysis shows impact on a methodology, did the methodology-based analysis trace back to that root?

This assignment should involve careful historical research of the literature and result in a single jointly submitted paper that describes **both** the flow from historical root to current methodologies, and the flow from current methodology to historical roots. The paper should be about 5,000 words, not including tables and figures you may use to illustrate the interconnections in the literature. (Remember, visual thinking can be powerful.) It is envisioned that the references should be extensive (30–40 or more might be typical).

Some approaches you should include in your paper:

- Contributors *not* listed in the historical roots table and contemporaneous scholarly responses to the work of the author we cite
- Citation analysis to estimate the influence of various works as paths between roots and methodologies are developed
- Influences on practice and research in various domains/contexts that are clear today

Some useful resources

In many cases, Wikipedia may provide an excellent starting point (www.wikipedia.org). From there you may be able to identify the major works which you may then build from in more rigorous and in-depth library research. The MIT Libraries has online access to the Web of Science, a citation database that may be a good place to start your citation analysis as well as discover important works. (http://libraries.mit.edu/guides/cheatsheets/wos/)

Appendix B: Survey Distributed to Historical Roots Participants

Historical Roots

Introduction

The purpose ofhb is survey is t gather your t oughts and opinions about t e Historical Roots assignment you completed as part of t e doctoral seminar course ESD.83 (Doctoral Seminar in Engineering Systems) which you took at MIT. The survey results will be incorporated into one or more academic/conference papers which describe the assignment and analyze its strengths and weaknesses. There have only been a total 47 ES doctoral students at MIT who have completed the Historical Roots assignment, so every survey response counts!

The survey should take you approximately 15-30 minutes to complete.

Please answer the following questions regarding that assignment to the best of your ability.

Historical Roots Survey Page 1 of 3

***1. What were your main reasons for selecting your Historical Root? Please select all that apply.**

- [ ] I do not recall
- [ ] Prior knowledge in that area
- [ ] Curiosity about a new field
- [ ] Expected usefulness for intended doctoral research
- [ ] Personal affiliation with area practitioners/theorists
- [ ] My partner proposed this root
- [ ] Other (please specify)

***2. What were your main reasons for selecting your Modern Methodology? Please select all that apply.**

- [ ] I do not recall
- [ ] Prior knowledge in that area
- [ ] Curiosity about a new field
- [ ] Expected usefulness for intended doctoral research
- [ ] Personal affiliation with area practitioners/theorists
- [ ] My partner proposed this methodology
- [ ] Other (please specify)

Historical Roots

*3. Can you remember any new ideas or insights to which you were exposed through your Historical Roots assignment?

- ◯ Yes
- ◯ No

If you answered Yes, please describe them here.

*4. Have you used any ideas or insights you gained from this assignment in your subsequent research?

- ◯ Yes
- ◯ No

If so, which ones?

*5. Can you remember any new skills or methodologies to which you were exposed through your Historical Roots assignment?

- ◯ Yes
- ◯ No

If you answered Yes, please describe them here.

*6. Have you used any skills or methodologies you learned from this assignment in your subsequent research?

- ◯ Yes
- ◯ No

If so, which ones?

Historical Roots Survey Page 2 of 3

7. In your view, who are the most important early thinkers (i.e., with main intellectual contributions occurring prior to 1980) in the field of Engineering Systems? (up to a maximum of 3)

Contributor 1

Contributor 2

Contributor 3

Historical Roots

*8. Did your experience with the ESD.83 Historical Roots assignment encourage you to explore more deeply the historical roots of your subsequent doctoral research?

- ◯ do not recall
- ◯ too soon to say
- ◯ not at all
- ◯ very little
- ◯ somewhat
- ◯ to a great extent

Please elaborate here if you desire

*9. Rate your level of agreement with the following statement: "From listening to my classmates presentations of their Historical Roots assignment, I learned a lot about the breadth and depth of engineering systems."

- ◯ do not recall
- ◯ strongly agree
- ◯ somewhat agree
- ◯ neither agree nor disagree
- ◯ somewhat disagree
- ◯ strongly disagree

Please elaborate here if you desire

*10. How important was the Historical Roots assignment to helping you feel like a part of the emerging Engineering Systems research community?

- ◯ do not recall
- ◯ not at all important
- ◯ slightly important
- ◯ somewhat important
- ◯ very important

*11. How important was the Historical Roots assignment to helping you feel a sense of community with your year's cohort of doctoral students?

- ◯ do not recall
- ◯ not applicable – not an ES doctoral student
- ◯ not at all important
- ◯ slightly important
- ◯ somewhat important
- ◯ very important

Historical Roots Survey Page 3 of 3

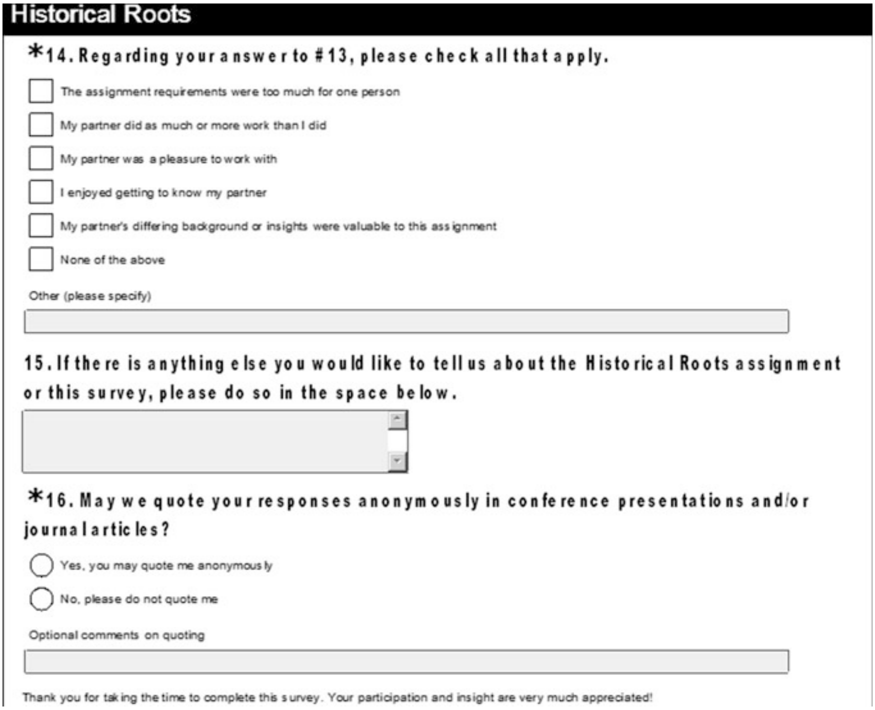
*12. Rate your level of agreement with the following statement: "Overall, the Historical Roots Assignment was the worth the time I devoted to it."

- ◯ do not recall
- ◯ strongly agree
- ◯ somewhat agree
- ◯ neither agree nor disagree
- ◯ somewhat disagree
- ◯ strongly disagree

Please elaborate, if you wish

*13. Rate your level of agreement with the following statement: "I was glad to work with a partner on the Historical Roots assignment."

- ◯ do not recall
- ◯ strongly agree
- ◯ somewhat agree
- ◯ neither agree nor disagree
- ◯ somewhat disagree
- ◯ strongly disagree



Historical Roots

*14. Regarding your answer to #13, please check all that apply.

- [ ] The assignment requirements were too much for one person
- [ ] My partner did as much or more work than I did
- [ ] My partner was a pleasure to work with
- [ ] I enjoyed getting to know my partner
- [ ] My partner's differing background or insights were valuable to this assignment
- [ ] None of the above

Other (please specify)

15. If there is anything else you would like to tell us about the Historical Roots assignment or this survey, please do so in the space below.

*16. May we quote your responses anonymously in conference presentations and/or journal articles?

- ◯ Yes, you may quote me anonymously
- ◯ No, please do not quote me

Optional comments on quoting

Thank you for taking the time to complete this survey. Your participation and insight are very much appreciated!

Appendix C: Explanation of Codes

Code	Meaning of code
Interrelation of fields	Remarks that mention a link between topics or fields, or remarks in general about the interrelation of fields
Importance of key scholars	Remarks that cite learning about the importance of specific individual scholars, or of learning in general how certain scholars had particular influence
Historical development of field	Remarks that cite learning about the history of engineering systems, the history of an ES topic, or the development of the field, or the history of an ES concept or idea
Concept related to ES	Remarks that cite learning a specific new ES-related concept, (e.g., theories, definitions) or says they learned about ES concepts in general
Method related to ES	Remarks that cite learning about a specific new ES-related method, or, said they learned about methods in general
Scholarly skills	Remarks that mention scholarly skills, which primarily included citation analysis, literature search, scholar search, forward/back casting between scholars or fields, and research communication (e.g., clear writing and presentation of research)

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Complexity Induced Vulnerability Assessment: How Resilient are Our Academic Programs?

Behnido Y. Calida, Adrian V. Gheorghe, Resit Unal, Dan V. Vamanu and Corneliu V. Radu

Abstract Academic departments in the field of critical societal infrastructures need to assess and upgrade their existing programs and course offerings for several important reasons such as: (1) to regularly assess a curricula's structure, (2) to maintain competitiveness, (3) to assess the resiliency of a given academic program, and (4) to ensure its relevance to the fast changing environment and context among others. This work builds on previous work to apply the previously developed resiliency assessment methodology to compare and ascertain some similarities and divergences in two Engineering Management programs, albeit in the same discipline but offered in different countries. A graph theory-based complexity perspective was used as a tool to make a comparative assessment of the course offerings between the two programs. Specifically, we can regard a Graduate program offering as a multi-component (many body) system consisting of its internal connectivity (i.e. combination of course offering as member interactions) defining structural complexity and as a source of vulnerability, hence resiliency. Authors propose an alternate methodology that combines the state-of-the-art in clustering text analysis as well as complexity-induced vulnerability quantitative methodologies recently used in performance quantification of complex systems.

Keywords Complexity-induced vulnerability · Academic program governance · Decision support system · Engineering management · Graduate program assessment

B. Y. Calida (✉) · A. V. Gheorghe · R. Unal
Department of Engineering Management and Systems Engineering, Old Dominion University, Kaufman Hall, Rm. 241, Norfolk, VA 23529, USA
e-mail: bcalida@odu.edu

D. V. Vamanu
Horia Hulubei' National Institute of Physics and Nuclear Engineering, 30 Reactorului Street 077125 Bucharest, Magurele, Romania

C. V. Radu
Economic Engineering Department, University Politehnica of Bucharest, Bucharest, Romania

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Introduction

Academic departments need to analyze, assess and qualify their existing program and course offering for several important reasons such as (1) to regularly assess a curricula's structure, (2) to maintain competitiveness, and (3) to ensure its resiliency and relevance to the fast changing environment and context, among others. At the heart of these programs as promoted by every educational enterprise is a curriculum. It has been noted that the topic of curriculum development is still not a central topic in research literature for higher education although related educational institutions have expanded and become more complex [1]. Several intricate societal factors interplay continually shaping individual academic departments [2] and even the entire US education system [3, 4] as a whole to create responsive and effective educational programs. At the level of individual academic departments, as represented in Fig. 1, which is the focus of this study, findings and assessments resulting from these types of exercises are helpful in many ways. For instance, department chairs or graduate program directors need data in order to make informed decisions.

A situation arises when academic departments see the need to incorporate changes in the curricula or course program offerings. In [5], a methodology was

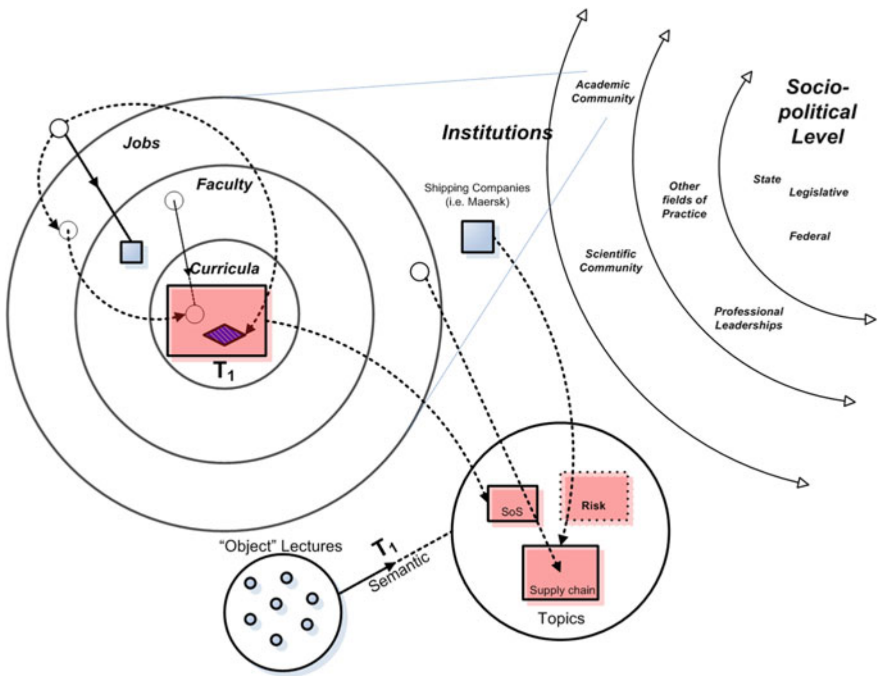

Fig. 1 Framing problem context in curricula assessment and development for higher educational institutions

demonstrated that will help quantify and visualize where some updating needs to be addressed in an academic department's curriculum offering. This is particularly meaningful when working in an area or discipline such as engineering management; this is as dynamic and wide-scoped domain. Interdisciplinary knowledge on management, governance, systems engineering, investment sciences, advanced modeling and simulation, inter alia, are of high relevance and practical applicability. In the context of the present work, resiliency is a system characteristic highlighting the capability of a given system/system of systems (e.g. a graduate curricula) to include, adapt, modernize in order to incorporate new knowledge, abilities, and skills, to comply with rapid developments in science, technology and practical endeavor.

The objective of this follow-on work is to compare two existing Engineering Management curricula using the methodology mentioned above. This methodology adopted a comprehensive systemic approach to analyze, assess, and quantify performance of the two identified graduate academic programs. This exercise will allow an university administrator to design or to assess *the resiliency* of a graduate program in times of dynamic societal and technological changes. The two cases in focus are about engineering management and systems engineering programs being offered at Old Dominion University and the University Polytechnica of Bucharest (Universitatea Politehnica din Bucuresti).

Engineering: Societal Programs Dealing with Complex Interdependent Systems

Engineering Management Programs

A quick glance of recent literature from the field of engineering management (EM) would easily include a wide-range of topics that cover hard engineering-related problems to the soft social aspects of management [6]. Still a fast-evolving discipline, scholars and practitioners find it difficult to pinpoint a core area that is unique to the field [7, 8]. Rather, many core areas give EM its multidisciplinary nature. Nonetheless, the challenge of identifying EM's core area or areas, its associated concepts and future direction are the continuing impetus for the discipline to constantly evolve and grow. Thus, EM practitioners and scholars must search for novel ways to characterize, visualize and interpret the many emergent issues in the field, in view of dealing with contemporary complex issues of infrastructures (e.g. stakeholders interactions, smart technologies).

According to Kotnour and Farr [9], the five main knowledge roles in EM can be broken down as *research*, *education*, *training*, *technical assistance*, and *service*. Obviously, research tracks areas that are growing in relevance to the EM practice, which goes hand in hand with education component, the first two have particularly strong implications in the dissemination, training and educational component of the discipline [10]. That is, one cannot interpret the variety of topics within EM to mean that *anything can be related to EM.* Rather, identifying main themes and topics within the discipline is crucial to the search for relevance and timeliness. Academic efforts should embody aspects of technical complexity e.g. infranomics, to be able to claim leadership and relevance.

Complexity-Derived Resiliency Metrics in Multi-Attribute Decision Environment

Over the years, several different approaches evolved in modeling and structuring complex situations that will ensure a favorable decision outcome. Howard [11], it characterizes the space in terms of its (1) associated complexity, (2) degree of uncertainty, and (3) time factor elements. There is a rich tradition of techniques and tools that can be utilized specifically from the multi-criteria decision analysis (MCDA) area which can fit across a decision problem space. Several of these developments followed efforts to better approach problems under conditions of risk and uncertainty. Detailed reading about these new methodologies, improvements, their theoretical progress and their corresponding applications are discussed and reported in numerous conferences proceedings or edited books [12–14].

In contrast, parallel threads of decision analysis techniques, especially for conditions with high degrees of complexity, are still not widely utilized. In this paper, we introduce one tool using the concept of complexity and an approach where it can be applied to an evolving decision context. Utilizing the rigor of complexity-derived constructs from the principle of maximum entropy and graph theory, [15] introduced the concept of *complexity-induced vulnerability*, as a substitute resiliency metric. In the context of this work, resiliency is defined as the system's structural ability to survive external disturbances, within a non-linear dynamic and even wicked operational/behavioral environment. It is one of several tools developed as part of the Quantitative Vulnerability Assessment (QVA) application toolkit originally developed for critical infrastructure protection and management. To begin applying the suggested approach, the problem system needs to be described using graph theory notations and subjected to a '*breadth-first*' algorithm.

An excerpt from the application software documentation describes the over-all methodological approach below:

"A 'breadth-first' search consists in identifying all knots in a graph that can be reached by way of continuity, that is, by walking the edges, starting from an initial, given knot, known as 'the source' of the search… The relevance of 'breadth-first' sets of knots for the QVA issue is as intuitive as its links to system's complexity:

- The deeper the breadth-first sets go into the overall system (graph) structure, the ampler the potential influence on the system, of a single defect, at any given knot;

- On the other hand, the more complex, that is—less modular, a system is, the larger the number of source-knots that would associate extended 'breadth-first' trees into the system.

…(T)o make the QVA assessment as general as feasible, it is proposed that two quantities be defined, to feature a system as a result of 'breadth-first' investigations:

(a) The *Average System Penetrability*—obtained by computing the penetration numbers of all knots in the system's graph, and then taking their average; and
(b) The *Maximum System Penetrability*—obtained by sorting the penetration numbers in process above."

Centering Resonance Analysis

Centering resonance analysis (CRA) seemed the most appropriate method for text analysis because it is used to identify the most crucial words and link these words into a network; which is also helpful in organizing these structures of words in a holistic manner by looking at the influences of these words due to their locations within the structure [16]. Overall, CRA involves three steps namely selection, linking and indexing. First, the selection step categorizes texts by recognizing connective patterns between words that are crucial to the centering process. Compiling the words and their connections across all utterances in a text yields a CRA network representing the text. In a second linking step, it converts the word sequences into networks of relationships between words. The author or speaker of a text being analyzed with CRA intentionally groups the words into noun phrases and strings these phrases together (using verbs, pronouns, determiners and so forth) to form *an utterance*. Accumulating links over a set of utterances comprising a text (or paper, collection of papers, transcribed speaking turn or set of turns) yields a symmetric, valued, undirected network whose nodes represent the center-related words. Finally, the third indexing process analyzes the network of word associations to determine the relative influence of each word (or node).

The noun-phrases will be the basis for computing an internal influence and over-all resonance measure. Using word and word-pairs, (pp. 177–179) describes this operational sequence of steps to represent influence and resonance mathematically. Using individual words as the unit of analysis, influence and resonance is given as follows:

The influence I of a word i in text T is given by:

$$I_i^T = \frac{\sum_{j<k} g_{jk}(i) \Big/ g_{jk}}{[(N-1)(N-2)/2]} \tag{1}$$

where g_{jk} refers to the quantity of shortest paths connecting the jth and kth words, $g_{jk}(i)$ is the quantity of those paths containing the word i, and N is the number of words in the network. Once influence I is measured throughout the analyzed data text, the over-all resonance or a combined resonance in the presence of another CRA network can be determined next. This can be directly calculated easily using the influence scores of words belonging to two different data text sets. Let the individual words belonging to text A be represented by $\left[w_1^A, w_2^A, \ldots w_{N(A)}^A\right]$ with accordingly influence scores given by $\left[I_1^A, I_2^A, \ldots I_{N(A)}^A\right]$. N(A) is the quantity of unique words found in text A. In the same manner, suppose that we have a secondary data text B having a similar representation form given by $\left[w_1^B, w_2^B, \ldots w_{N(A)}^B\right]$ with again the influence scores given by $\left[I_1^B, I_2^B, \ldots I_{N(B)}^B\right]$ where N(A) $\neq$ N(B) in general. Let us also assign an indicator variable α_{ij}^{AB} as equal to 1 if w_i^A and w_i^B are the same words and 0 otherwise. The word resonance (p. 178), WR_{AB} between text A and B can be calculated using:

$$WR_{AB} = \sum\nolimits_{i=1}^{N(A)} \sum\nolimits_{j=1}^{N(B)} I_i^A \cdot I_j^B \cdot \alpha_{ij}^{AB} \tag{2}$$

To standardize [7] similar to how covariance between two random variables is used to establish a measure of correlation, [7] can also be handled similarly to show:

$$WR'_{AB} = WR_{AB} \Big/ \sqrt{\sum\nolimits_{i=1}^{N(A)} \sum\nolimits_{j=1}^{N(B)} I_i^A \cdot I_j^B \cdot \alpha_{ij}^{AB}} \tag{3}$$

where WR'_{AB} is the appropriate standardized measure of resonance. The full mathematical representation for using word-pairs as the unit of analysis for computing resonance is shown in detail in [14] (pp. 176–178).

A Methodology for Resiliency Assessment of Academic Graduate Programs

An Overview

The general schema is shown in Fig. 2. This simplified systems analysis diagram represent the over-all approach towards 'resilience' measurement of academic programs, which helps to further analysis and facilitate inquiry. It involves three steps, namely: (1) determining contextual conditions ($\sim$the story), (2) data processing, and (3) analysis, The specific methodology employed for data processing and analysis utilizes a two-stage approach using cluster analysis as input to a novel

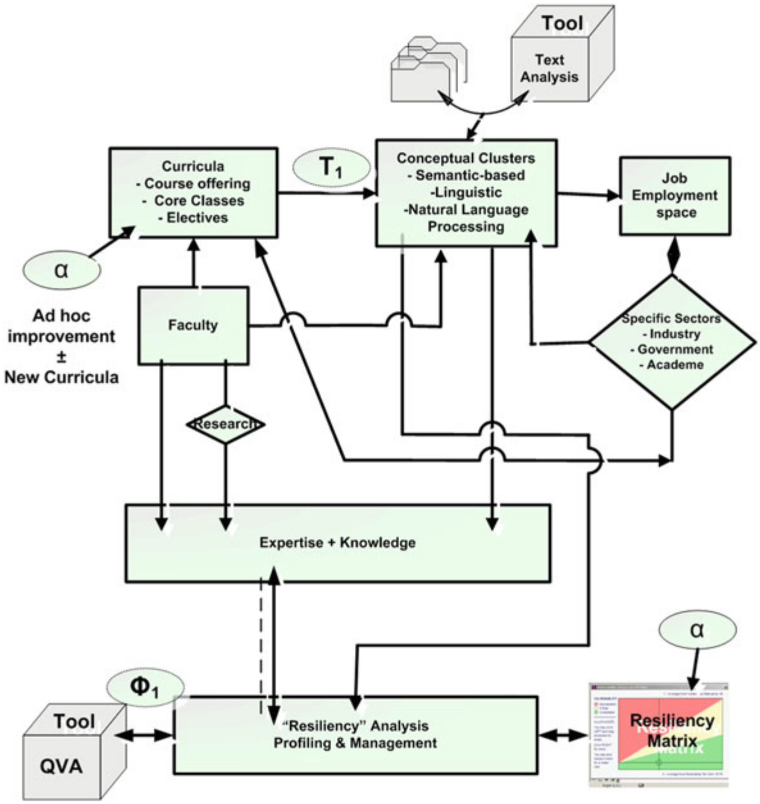

Fig. 2 General schema arriving to a conceptual 'resilience' measure

complexity-induced vulnerability DSS application. Text data was extracted from Old Dominion University's (ODU) 2008–2009 Graduate Program Catalog, specifically the Department of Engineering's Engineering Management and System Engineering (EMSE) graduate-level course offerings. Using individual courses as the unit of analysis, each data file per course were subjected to cluster analysis. The textual network clustering establishes the conceptual linkage association between courses. This is an important input to the second-stage which in terms of the tools specific notation, individual courses can be regarded as 'knots' with the provision of the 'knot neighbors' or cluster links identified in the prior stage. Output analysis results from the second-stage allow an insightful characterization of the over-all system (in terms of *average system vulnerability* and *total system penetrability*) and/or individual components of the system (in terms of quantitative vulnerability or penetrability from a given *knot—cluster item*).

Data Preconditioning and Cluster Analysis Process

Resonance itself, while a latent property of a single CRA network structure, is only realized in the presence of an external signal (i.e., another network). Hence, word resonance is a more general measure of the mutual relevance of two texts. The more frequently two texts (communicators) use the same words, especially in influential positions, the more the word resonance and the more prominent those words in structuring the text's coherence. We carried out the CRA using the Crawdad Text Analysis System software, which eliminated many of the problems often associated with traditional content analysis (e.g., individual bias) that may affect reliability.

To make it implementable and produce a resonance textual network structure, each Graduate Catalog course description is extracted and saved as individual ASCII-text files (*.txt) and saved inside a single directory folder. The assigned single directory folder will be the main folder where the clustering analysis software can automatically perform its unique clustering algorithm. Each of these text files undergoes preliminary text parsing to extract significant noun-phrases, to extract influence and resonance measures accordingly.

Complexity-Induced Resiliency Comparative Assessment: The Two Cases

In this study, we performed the analysis of curricula from two independently developed engineering management programs. One is from the Engineering Management program at Old Dominion University. The other one are the related programs offered in University Poltechnica of Bucharest (Universitatea Politehnica din Bucuresti). Specifically, Table 1 is a quick profile of the different programs that were assessed using the developed resiliency assessment methodology.

Table 1 Quick profile of two engineering management departments

Old Dominion University	Universitatea Politehnica din Bucuresti
EMSE graduate program currently has 5 degrees offerings namely:	Master's level programs with two focus areas:
1. Master of Engineering Management (MEM)	1. MANAGEMENT şi INGINERIE ECONOMICĂ
2. Master of Science in Engineering Management (MSEM)	2. MANAGEMENTUL şi INGINERIA AFACERILOR
3. Master of Science in System Engineering (MSSE)	
4. PHD	
5. D. Eng in EMSE	

Briefly, the EMSE Graduate program currently has five degrees e.g. Master of Engineering Management, Master of Systems Engineering, Master of Science in Systems Engineering, Doctor of Philosophy, and Doctor of Engineering, with focus on different core areas/methods: empirical, analytic, social research, professional development, amongst others. The department offers over 50 different courses, distributed between 15 faculty members. More information about the program and the different faculty can be found at http://eng.odu.edu/enma/. Meanwhile, the Universitatea Politehnica din Bucuresti offers two similar programs, specifically the graduate level programs in Business Management Engineering (Ingineria Afacerilor) and in Economics Engineering (Inginerie Economica). As with its US counterpart, these programs also offer a similar set of focus areas. Detailed information about their program offerings can be accessed at http://www.upb.ro/en/.

We now use the specific terminologies known as graphs, knots and links. A ***graph*** is a multi-component system consisting of the following:

- The members, or constituents, or parts, of the system are the graph's ***knots*** (e.g. clusters from the semantic analysis);
- The interactions of the clusters/classes are represented by directed knot ***links***; and
- The graph is customized to a system by attaching to knots a set of ***features***, appropriately quantified and normalized on a resiliency-relevant scale.

The knots are the irreducible components or 'atoms', of a system, and the subjects of the analysis. The type of knots identified depends on the nature of the targeted system. These may represent employees, departments, subsidiaries, *or collections of these*. Together knots show a sufficient degree of coherence to play a coordinated part in the overall system's internal interaction game.

Using the above terms, the graduate program offerings can be regarded as a multi-component (many body) system, with its internal connectivity (member interactions). From the inherent definition of complexity arising from these interactions, knots or a collection of knots may be to some extent act as a source of vulnerability. We can describe the interaction or interconnection between knots such as exchange of information, energy, and/or substance—defines the system structure, by way of its exchange boundaries. Links enter the model by *Connection Lists* attached to each and every knot in the system's graph. Normally, exchanges between knots proceed under an authority rule, or otherwise said—in hierarchic fashions. That is why links are *directed* (i.e. knot A may have knot B on its connection list, while knot B may not necessarily have knot A on its connection list).

What relevant features can we represent as proxies to be able to arrive to a scaled quantification for complexity induced resiliency? Tentatively, we assigned features we picked up from the graduate program description. All the EMSE courses in Graduate Program Catalog can be considered either as a *core course*, an *elective* or a *program degree requirement* depending on the specific graduate program level, i.e. Master's or PhD. These assigned features were meant to characterize the knots. To introduce some level of assessment, we describe quantitative vulnerability through *values*, and *weights*. 'V*alues*' are attached to system's 'knots'. A feature 'value' is a decimal number in the range 1 through 9, assumed to be in direct proportion to the degree of *vulnerability relevance* that the feature may attain for different knots. 'W*eights*', on the other hand, compare features in terms of their *relative* vulnerability relevance and are assigned according to the individual or group decision maker's subjective preference.

Here are some operational assumptions that need to be highlighted. The expression higher connectivity is taken as interchangeable with higher vulnerability. Specifically, a higher internal connectivity in a system is a desirable quality only to the extent that the cumulated vulnerability relevance of the connected knots is tolerable. The higher the vulnerability relevance of the knots involved in the exchange path of any knot of origin, including the relevance of the knot of origin itself, the higher the vulnerability induced in the overall system by the respective knot of origin. Hence conversely, the higher the cumulated vulnerability relevance of the system's knots, the higher the system vulnerability itself.

Having necessarily transformed the system using the above notations, it is easy to introduce the associated metrics namely system penetrability and vulnerability relevance. System' ***penetrability***—a quality that may have as a metrics the (average) number of knots that can be accessed starting from a (any) given knot in the system; and The connectivity's ***vulnerability relevance***, depending on the penetrability defined yet also on the vulnerability relevance grades assigned to knot features. This is can be displayed as separate dashboard style visualizations outputs of the DSS and will be shown together with the results in the next section.

Quantitative Resiliency Assessment for Two Academic Graduate Programs

Conceptual Linkages Overview

For brevity, the methodology is demonstrated only on the ODU EMSE programs though the same methodology was also done on its counterpart programs. For the ODU EMSE programs, the clustering analysis solution shows five distinct 'conceptual' clustering effects between the different courses. Average size per cluster is around 9.80 with a minimum cluster size of 5 and a maximum cluster size of 19.

In Table 2, the five distinct clusters are as follows: (1) Operations Research (O.R.) and related techniques, (2) Systems and Project Management Theory and Application, (3) EM Degree and Program Requirements, (4) EM Core and Related Courses, and lastly, (5) EM Special Topics and Dissertation Research.

A similar analysis was conducted for the two Engineering Management degree programs offered at University Polytechnica of Bucharest. For the Business

Table 2 Clustering analysis of EMSE graduate courses

Cluster #	Cluster name/KNOT ID (course ID)	Cluster size
37	*O.R. and related techniques*	5
	ENMA 603_Operations Research	
	ENMA 607_Stochastic Decision Methods	
	ENMA 613_Logistics and Supply Chain Management	
	ENMA 703_803_Optimization Methods	
	ENMA 710 810 Modeling and Analysis of Systems	
39	*System and project management theory and application*	11
	ENMA 604_Project Management	
	ENMA 614_Quality Systems Design	
	ENMA 640_Integrated Systems Engineering I	
	ENMA 704_804_Design of Project Knowledge System s	
	ENMA 711_811_Methodologies for Advanced Engineering Projects	
	ENMA 714_814_Cirsis Project Management	
	ENMA 715_815_Systems Analysis	
	ENMA 717_817_Cost Engineering	
	ENMA 721_821_Research Methods in Engineering Management	
	ENMA 743_843_Reliability and Maintainability	
	ENMA 763_863_Robust Engineering Design	
42	*EM degree and program requirements*	7
	ENMA 605_Program Capstone	
	ENMA 641_Requirements Management,Verification and Validation	
	ENMA 667_Cooperative Education	
	ENMA 668_Internship	
	ENMA 669_Practicum	
	ENMA 688_Preparation Seminar for Systems Engineering Certification	
	ENMA 999_Engineering Management 999	
43	*EM core and related courses*	19
	ENMA 600_Cost Estimating and Financial Analysis	
	ENMA 601_Analysis of Organizational Systems	
	ENMA 602_Systems Engineering Management	
	ENMA 606_Engineering Law	
	ENMA 616_The Entrepreneurial Engineering Manager	
	ENMA 660_Systems Architecture and Modeling	
	ENMA 700_800_Economic Analysis of Capital Projects	
	ENMA 702_802_Methods for Rational Decision Making	
	ENMA 705_805_Financial Engineering	
	ENMA 712_812_Multi-Criteria Decision Analysis and Decision Support Systems	
	ENMA 716_816_Complex Adaptive Situations Environment	
	ENMA 723_823_Enterprise and Complex System Dynamics	
	ENMA 724_24_Risk Analysis	
	ENMA 725_825_Team Performance and Decision Making in Engineering	
	ENMA 750_850_System of Systems Engineering	
	ENMA 751_851_Complexity, Engineering and Management	
	ENMA 771_871_Risk and Vulnerability Management of Complex Interdependent Systems	
	ENMA 780_880_Leadership for Engineering Managers	
	ENMA 888_Ph.D. Seminar	

(continued)

Table 2 (continued)

Cluster #	Cluster name/KNOT ID (course ID)	Cluster size
44	*EM special topics and dissertation research*	7
	ENMA 695_896_Topics in Engineering Management	
	ENMA 697_Independent Study in Engineering Managem ent	
	ENMA 699_Thesis	
	ENMA 727_827_Engineering Management and Technology	
	ENMA 797_897_Independent Study in Engineering Management	
	ENMA 898_Research in Engineering Management	
	ENMA 899_Dissertation Research	

Management Engineering (Ingineria Afacerilor) program, the clustering analysis solution shows six distinct 'conceptual' clustering effects between the different course offerings. Average size per cluster is around 3.33 with a minimum cluster size of 2 and a maximum cluster size of 7. A stark difference was observed in the six distinct clusters as follows: (1) Managerial Psychology, (2) Financial Accounting, (3) International and European Economics, (4) Statistical Economics and Techniques, (5) Ecological Economics and lastly, (6) Operational Supply chain Management. In the same fashion, for the Economics Engineering (Inginerie Economica) program, the clustering analysis solution yielded four distinct clusters namely: (1) Operational Supply Chain Management, (2) Intellectual Property Management, (3) Ecological Economics, and (4) Miscellaneous Topics (to include Negotiation tactics, strategic management, multimedia marketing, etc.). For this group of courses, Average size per cluster is around 3.75 with a minimum cluster size of 2 and a maximum cluster size of 7.

The clustering results allow us to establish a conceptual association between the different courses. This conceptual association between courses makes it easier to define links and knot neighbors and will be an input to the next stage of the analysis. With these as preceding stage inputs (see Table 2), there are different possible output analysis that can be performed at the succeeding stages. We can consider an overview picture such as Over-all system penetrability or an individual analysis such as system penetrability from a knot. Both typical sample outputs are elaborated in the following sections.

Over-all System Penetrability

The overall system penetrability analysis generates a report of penetrability percentage for every source knot. As earlier described, penetrability is taken as a measure of how deep a specific source knot can easily reach other distinct knot neighbors. Average knot penetrability percentage and its associated average knot vulnerability relevance can then be simultaneously plotted on a vulnerability status

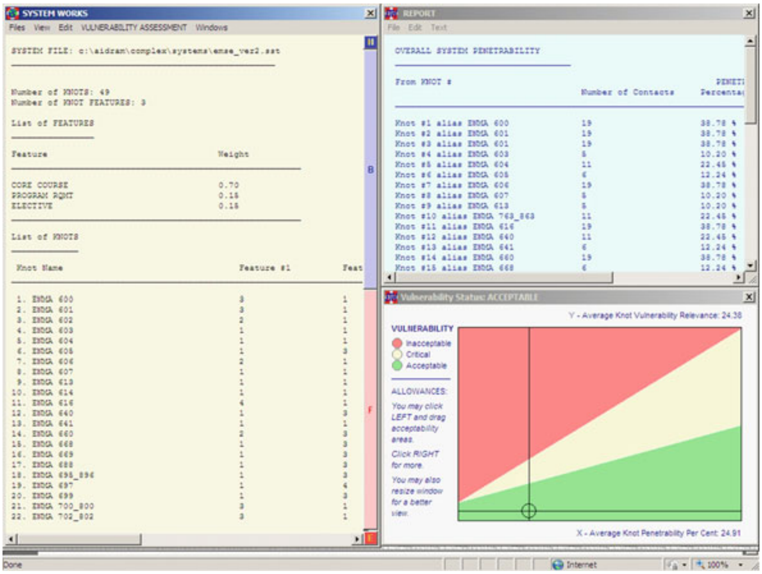

Fig. 3 Overall system penetrability and vulnerability status dashboard for ODU EMSE

dashboard and a quick assessment of vulnerability status. Vulnerability status can fall in either one of three regions namely: (1) inacceptable, (2) critical, and (3) acceptable. Based on Fig. 3, and given the weights assigned to the three features (i.e. core course, program requirement, and elective), EMSE overall resiliency assessment is in the acceptable region despite having some knots have a high number of direct knot neighbor contacts.

A similar analysis conducted on the two other counterpart programs also showed their over-all vulnerability in the acceptable region.

System Penetrability from a Knot

The next set of analysis as shown in Fig. 4 is a demonstration of the breadth-first algorithm in action. The department chair may be interested in finding out how a specific knot contributes to the over-all system penetrability and which vulnerability status region a specific knot falls. For example, consider Knot ID #11 that has an 19-order knot neighborhood is calculated to have a vulnerability relevance index (VRI) equal to 3.40. Also, the tool will provide the user several potential penetration path (PPP) scenarios and their associated VRI numbers. In another example as shown in Fig. 5, individual knot level penetrability and their cumulated results can also be generated.

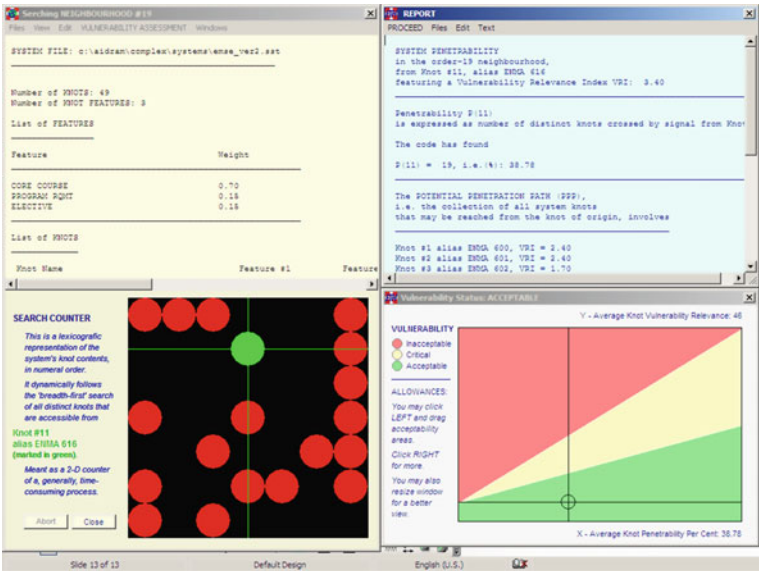

Fig. 4 System penetrability from a given knot resulting from a 'breadth-first' search algorithm

```
SYSTEM PENETRABILITY
in the order-19 neighbourhood,
from Knot #12, alias ENMA 640
featuring a Vulnerability Relevance Index VRI:  1.30
________________________________________________

Penetrability P(12)
is expressed as number of distinct knots crossed by signal from Knot #12

The code has found

P(12) -  11, i.e.(%): 22.45
________________________________________________

The POTENTIAL PENETRATION PATH (PPP),
i.e. the collection of all system knots
that may be reached from the knot of origin, involves
_____________________________________________________

Knot #5 alias ENMA 604, VRI - 1.30
Knot #10 alias ENMA 614, VRI - 1.00
Knot #24 alias ENMA 704_804, VRI - 1.30
Knot #27 alias ENMA 711_811, VRI - 1.15
Knot #29 alias ENMA 714_814, VRI - 1.30
Knot #30 alias ENMA 715_815, VRI - 1.15
Knot #32 alias ENMA 717_817, VRI - 1.30
Knot #33 alias ENMA 721_821, VRI - 1.30
Knot #38 alias ENMA 743_843, VRI - 1.15
Knot #41 alias ENMA 763_863, VRI - 1.30
Knot #12 alias ENMA 640, VRI - 1.30
________________________________________________

The knot and its PPP
shows a CUMULATED VULNERABILITY RELEVANCE: 14.85
representing 3.37 % of the maximum possible, of 441
```

Fig. 5 Knot level system penetrability reporting

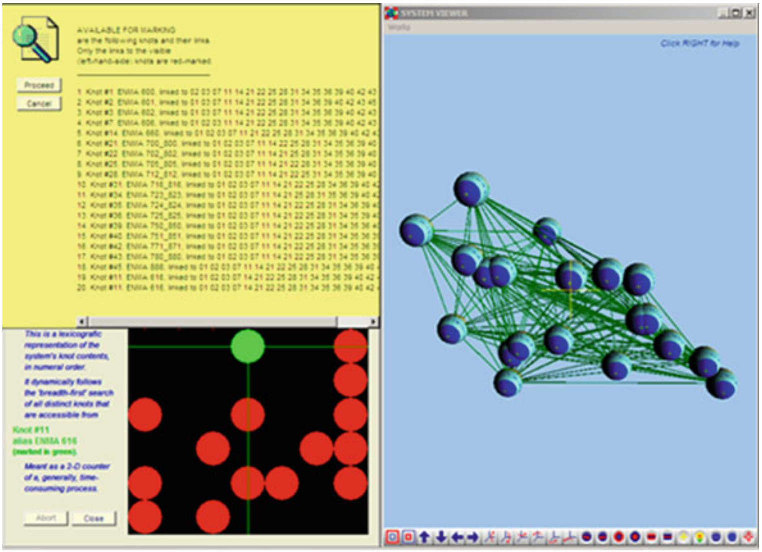

Fig. 6 A 3D-visualization glimpse of complexity: the complexity from a given knot perspective (**a**) and a closer view of knot tagging view is also possible showing all the relevant knot-level information

Complexity Implications and Scenario Multi-Assessment

More detailed reports and analysis can be investigated. Analysis can be performed by using 3D visualization and individual knot tagging capabilities allowing for a more thorough study of individual knot and their associated penetrability configurations. This is shown in Fig. 6, where upon a closer look at individual knot shows additional visual information. This visual information is called tagging where it contains all the pertinent information an user can easily recognize when performing the analysis.

Conclusion and Recommendations

This project demonstrates another possible application of the complexity-derived concept of 'vulnerability', specifically in a typical EM graduate program assessment situation. Notations from graph theory-based and complexity perspectives were utilized as a tool to compare two department's course offering of Old Dominion University College of Engineering's Engineering Management and Systems Department and the University Politehnica of Bucharest. Academic departments in the emerging field of infranomics need to assess and upgrade their existing programs and course offerings for several important reasons such as: (1) to regularly assess a curricula's structure, (2) to maintain competitiveness, (3) to assess the resiliency of a given academic program, and (4) to ensure its relevance to the fast changing environment and context among others. This work builds on previous work to apply the previously developed resiliency assessment methodology to compare and ascertain some similarities and divergences in two Engineering Management programs, albeit in the same discipline but offered in different countries.

Engineering (EMSE) department or specifically its Graduate program as a multi-component (many body) system consisting of its internal connectivity (i.e. combination of course offering as member interactions) defining structural complexity and as a source of vulnerability. In conclusion, this exercise demonstrates an alternate methodology which combines the state-of-the-art in (1) clustering text analysis as well as (2) complexity-induced vulnerability quantitative methodologies recently used in resiliency quantification of complex systems. As demonstrated here, higher education policy educators/administrators can benefit from this analytic approach as it will enable them to implement a learning approach to tackle the following difficult questions: (1) How to design a new curricula based on industrial needs or societal conditions as a whole?, (2) What are possible ways to improve current curricula or programs?, and (3) How resilient is our academic program?

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Managing the Risks of a Large-Scale Infrastructure Project: The Case of Spoorzone Delft

Hugo Priemus

Abstract Risk management in large-scale infrastructure projects is attracting the attention of academics and practitioners alike. After a brief summary of the theoretical background, this chapter describes how the risk analysis and risk management shapes up in a current large-scale infrastructure project in the Netherlands. The project in question is Spoorzone Delft, which involves the construction of a railway tunnel, the demolition of a railway viaduct, and the realisation of some 1,500 housing units, 20,000 m^2 of office space, covered parking lots, bicycle sheds, new civic offices and a ticket hall in a railway station. ProRail and Ontwikkelingsbedrijf Spoorzone Delft B.V. drew up a risk management plan to identify potential risks and to present strategies for controlling or reducing them. It emerged that risks were determined and quantified largely based on subjective estimates. The risk inventories exhibit strong dynamics from quarter to quarter. The findings indicate that it would be sensible to concentrate more closely on the insurability of risks and to differentiate between risks at system level and component level. The academic theory advises a stronger orientation towards flexibility and the identification of options.

Keywords Risk management · Railway station area · The Netherlands · Delft

H. Priemus (✉)
OTB Research Institute of the Built Environment, TU Delft/Delft University of Technology, P.O. Box 5015, 2600 GA Delft, The Netherlands
e-mail: h.priemus@tudelft.nl

H. Priemus
Emeritus Professor, System Innovation and Spatial Development, TU Delft/Delft University of Technology, Jaffalaan 9, 2628 BX Delft, The Netherlands

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Introduction and Theoretical Background

In recent decades, both academic journals and professional publications have homed in on the risks associated with large-scale infrastructure projects [12, 13], [17], primarily with a view to the avoidance of overrun budgets. This very theme has been discussed several times by Flyvbjerg (e.g. [6–8]), who makes a case for 'reference-class-forecasting', a strategy in which the primary steering instrument is not the project budget but references to similar previously implemented projects against which the project in question can be compared.

A second strategy involves the systematic application of 'checks and balances'. Often, projects are hampered by principal-agent problems, whereby the empowered authority (central or local government) is largely dependent on the knowledge of the parties who are directly involved. Checks and balances can be strengthened by professional, independent supervision, the four-eye principle and the insertion of go/no go moments, when benefits can be reaped from market forces [20]. In such cases, an integrity policy is certainly advisable [22].

This brings us to a third strategy: the utilisation of market forces and the reinforcement of competition. A level playing field is stimulated in the construction industry by, amongst others, European tender procedures, which place constraints on the formation of monopolistic power blocks. Until recently, the construction sector in the Netherlands was riddled with cartels and, even now, deals between construction firms, real-estate players and suppliers, and sub-contractors may still be hampering fair competition.

Finally, some authors make a case for keeping the options open: promote flexibility to avoid entrapment [2] and 'groupthink' [10, 13]. The determination of alternatives and keeping the options open for as long as possible can prove important in this regard. Value can be created by deploying the options in the course of time. Accordingly, the 'real-options framework' has been developed academically along the same logical lines as the model that has been [1] developed for the financial markets. The translation from financial options to 'real options' is analysed by [5, 21]. The latter strategy is at odds with the strategy propagated by the Elverding Commission [3], namely: early determination of a preferred variant after a broad orientation phase involving many different players.

The main questions addressed in this chapter are: How does the risk management of a large-scale infrastructure project take shape in practice in the Netherlands and how can it be improved?

It should be noted beforehand that there is no reliable database for recently executed projects, so the actual application of 'reference class forecasting' is not yet possible.

The methodology is simple. It involves one case study: risk management in the Spoorzone Delft Project. This project was chosen because it represents a good combination of infrastructure and real-estate development. The main focus is risk management in the execution phase. The case is placed in a broad theoretical framework in which many problems that commonly arise in strategies for large-scale infrastructure projects are explained. We look for the theoretical framework that best explains current risk management for Spoorzone Delft.

The aim of this study is twofold: to point the way towards a more effective and efficient risk management for large-scale infrastructure projects and to find theoretical explanations for the problems that arise in practice. The subject of this chapter is the railway tunnel project in Delft: a large-scale combined infrastructure (a rail tunnel to replace a rail viaduct) and real-estate project (new civic offices, homes, offices and parking facilities). The combination of functions and the embedment in a dynamic environment make this a very complex area-development project.

This chapter starts with a brief history and description of Spoorzone Delft and the structure of the project organisation. This is followed by a discussion on concrete aspects of the risk analysis and the risk management. It concludes with some evaluative comments and recommendations.

For the record, it should be noted that the author has been a member of the Supervisory Board of Ontwikkelingsbedrijf Spoorzone Delft BV from 2009–2012. Though certainly not the *auctor intellectualis* of the risk management method, the author agrees that this chapter could be interpreted as an example of a 'butcher who approves his own beef.' It would indeed be difficult to contest allegations of mixed roles. However, the aim of this chapter is not to evaluate the methods that were applied but rather to present these methods. This will take place as clearly and as objectively as possible so that every observer can draw his own conclusions on the basis of the information. If such conclusions lead to practical improvements in the way risks are managed in large-scale infrastructure projects in the Netherlands, then the purpose of this chapter would be realized.

Brief History of the Spoorzone Delft Project

In 1988, the Dutch Railways set out its vision for the future in a publication entitled *Rail 21* [15], in which one of the main spearheads was quadruple tracks on the entire Amsterdam-Dordrecht line. The double-track rail viaduct that cut straight across Delft was identified as a bottleneck and a search began for creative solutions to what was a very noisy stretch of railway. The preliminary sketches showed a quadruple-track railway tunnel, which would not only get rid of this bottleneck in the transport system of the Randstad but would open up opportunities for enriching the city of Delft with a top-notch urban development comprising homes, offices, central amenities and parking facilities [18]. In 1990 the Municipal Executive of Delft incorporated the railway tunnel in its programme [16].

A public–private partnership was set up with Ballast-Nedam and NS Vastgoed (partners in the Spoorzone Delft Development Combination/*Ontwikkelingscombinatie Spoorzone Delft/OCSD*) to work out the plans, the costing and the exploitation prospects. The Spanish architects' firm Busquets drew up an ambitious plan for the layout of the railway terrain. The contest for the contract for the civic offices had attracted a lot of publicity and was awarded to Mecanoo

Architects. The station upon which the civic offices would be built was designed by Benthem Crouwel Architects.

In October 2006 Ontwikkelingsbedrijf Spoorzone Delft (OBS/Spoorzone Delft Development Company) was set up with the Municipality of Delft as the sole shareholder.

In July 2008 the Ministry of Transport, Public Works and Water Management revised the budgets and reallocated them between the Municipality of Delft and the Dutch Government: the Government assumed the risk for the construction of the tunnel.

The Spoorzone Delft Project

The area covered by the Spoorzone Delft Project is shown in Fig. 1.

The tunnel would be funded by the Ministry of Infrastructure and the Environment (formerly, Transport, Public Works and Water Management) and realised by ProRail. The municipal authority would contribute to the costs. ProRail was awarded the contract for the shell of the tunnel (not for the railway infrastructure) and CrommeLijn contractors' consortium (CCL) was awarded the contract for the underground station (rail section of the Transport Hub). ProRail also commissioned CCL to make the entire area ready for the construction work and the new layout of the public space (IOR): the OBS acted as the principal for the construction of the Spoorsingel parking garage (PSS).

The OBS would be responsible for the urban redevelopment and the realisation of the urban part of the Transport Hub and the civic offices. At the request of ProRail the OBS also took charge of the realisation of the ticket hall.

Rail Tunnel

The rail tunnel scope included the underground station, complete with bicycle shed, and the preparations for the construction of housing on the surface. The rail tunnel would be built as a concrete shell with a capacity for four tracks, but only

Fig. 1 Area covered by Spoorzone Delft

two tracks would be laid for the time being. ProRail would be responsible for realising this part of the project. Since then, the timetable has been adapted: the work will take 13 months longer than originally planned. The milestones in the contract planning (excluding risk profile) have been revised on the basis of the planning scenarios developed in the collective planning studio (OBS/ProRail/CCL/partnership team).

Town Hall and Ticket Hall

The town hall (29,000 m^2) and the aboveground ticket hall (4,500 m^2) would be integrated in one building located on and beside the tunnel to the north of the Station Square. The ticket hall and the public hall would be located on the ground floor of this building—on and beside the tunnel respectively.

The ticket hall would form the main entrance to the underground station and the space where NS would develop commercial space. The municipality would set up the public desks, the information centre and the working area in the public hall. The premises above the two halls would be used by the municipal staff/third parties and include a restaurant and a meeting centre. A bicycle shed for the staff, the boiler rooms etc. and the dispatch centre would be built in the basement of the civic offices.

Plan Busquets/Public Space

The sub-project for the layout of the public space (*Inrichting Openbare Ruimte/IOR*) revolved around the realisation of Plan Busquets. It was split into two parts:

- The part in the CCL contract. ProRail awarded the contract for this part of the layout of the public space to CCL in July 2008.
- The rest of the project—for which the contract is still to be awarded.

CCL has recruited Grontmij to work out the design for the public space.

Real-Estate Development

The area development encompasses the construction of around 1,500 homes, 20,000 m^2 of office space and covered parking facilities. A public park on the tunnel will be a crucial quality element in this new part of the city.

At present, market downturns appear to have stymied the chances of realising the desired proceeds from the land. There is also a growing awareness that the developments in the area need to be tackled in a different way from the one that was contractually agreed.

Various real-estate scenarios were discussed with OCSD and the consequences were mapped out. The urban planning structure, the programme, the phasing and the finances were comprehensively studied in these scenarios. A decision has since been taken to pursue a more flexible, process-based strategy with no predefined results. This is a major departure from the original plans.

Parking

OBS has been tasked with solving the following parking issues in the Spoorzone:

– Compensation for parking places that will cease to exist (residents' and visitors' parking);
– Parking places as a result of new-builds (residents' and visitors' parking for homes and offices);
– Parking places for the civic offices (users and visitors);
– P + R places.

Initially, the car park for the civic offices and the station was to be built under the civic offices. This plan was abandoned in the tendering phase because it was financially non-viable. New locations are being sought adjacent to the Spoorzone.

Management of Conditions

Risks stem not only from the project itself but also from the prevailing conditions. The quarterly OBS report pays attention to the following determinants: archaeology, permits, land acquisition and other land transactions, soil transport and—most importantly—groundwater abstraction. Safety and communication are also important themes. These themes are explored further below.

Business Case

The business case is systematically updated twice a year (the end of June and December) whereby all information known at that moment is taken into account. The updated business case at the end of 2010 (version: January 2011), with an end value of zero in January 2031, addressed, amongst others, the effects of the adapted realisation timetable, the new analysis of the economic value of the parking facilities, and initial cohesion with the financial administration. A new analysis was drawn up for the public space comprising elements that depend on the real-estate development and other, more detached elements. The planning and phasing in the business case were updated on the basis of this analysis.

Planning

The second half of 2010 was spent mainly on drawing up an uncertainty analysis for the tunnel planning and the effects on the parts of the projects within the scope of OBS. The most important element was the construction of the new civic offices and the integrated new ticket hall. A 4D (3D+Time) simulation was made of the construction of the civic offices and connected to the draft timetable. ProRail, CCL and the partnership team made a start on a phasing book (2D+Time) for the station area.

Risk Management Plan

On 14 December 2010, the basis for the risk policy of Ontwikkelingsbedrijf Spoorzone Delft was recorded in a Risk Management Plan authored by Robert Huisman [8]. Joris Hoogerwerf drew up a similar plan for [17]. It was clear that, for many years, there had been no risk management plan for the development planning. The risk management for Spoorzone Delft is described in an analysis by [14], commissioned by Delft Municipal Council.

The risk management plan "should explicitly set out all risks and opportunities that could influence the outcome of the project so that they can be adequately addressed or utilised via prompt and efficient action." [9, p. 3].

Huisman [8] suggests: "The primary aim of risk management is to support the project management. The continuous and pro-active identification and quantification of uncertainties that influence the outcome of the project and the implementation of management measures and subsequent reports are of prime importance. The aim of risk management is, at all events, to stabilise the project risk or reduce it to an acceptable level and to get an optimal result. A direct link must be laid with the Business Case and the management of unforeseen items" (p. 5).

An additional, incidental aim of risk management in the OBS part of the Spoorzone Delft project is to support the tendering procedure across the entire spectrum, all the way from issuing invitations to offers, negotiations, selection and planning permission.

The risk management process for Spoorzone Delft consists of ten steps [9, p. 6, 18, p. 7]:

1. "Organise the project management
2. Compile an inventory of/identify uncertainties and opportunities
3. Determine and confirm cause and phase of action
4. Allocate and categorise uncertainties and opportunities
5. Name risk/opportunity owners (internal allocation)
6. Quantification (estimate risk/opportunity)
7. Management (fix management tactics)

8. Monitor, evaluate and update risk/opportunity and management tactics
9. Analysis (in relation to available resources) and
10. Report."

Steps 2 through 8 are on-going; the last two take place at the end of each report period.

Every step in the process is supported by a risk dossier. Every risk/opportunity that is identified is recorded in one of the risk dossiers.

Risks/opportunities can be identified by any employee of the OBS Project Organisation. The risk manager is responsible for recording any new risks/opportunities in a risk dossier. The risk manager ensures that the inventory procedures are properly structured. Interviews are held once every 6 weeks and plenary sessions are organised at least once a year for this purpose. Theme sessions and top-down analysis can also be organised.

Every risk is allocated to a risk owner in the OBS project organisation. The risk owner is operationally responsible for managing a risk/opportunity. He decides how the risk is to be managed and coordinates the actions. The chance of action, the planning implications and the (direct) financial consequences are estimated for every risk/opportunity. The guiding principle for Spoorzone Delft is that all deviations from the scope (and quality) be redressed; the project aims are not adjusted.

Risk management comprises the following elements [9, 18]:

- determination of the management strategy;
- balancing management tactics with decision-making;
- allocation to an action owner;
- quantification of adjustments and registration of development;
- closing a risk.

In the case of bigger risks a management strategy is first determined by the Management Team. The chosen strategy is then converted into concrete actions. In the case of smaller risks the risk owner can start right away on an inventory of management tactics. The management strategy is recorded in the respective risk dossier [9].

The risk-management proposal for overlapping and overarching risks must be approved by all relevant, participating parties and have a strong support base [8] Each action is assigned to an action owner, who is operationally responsible for implementing it and monitoring the results. Every project worker can be an action owner. Every risk should be reviewed at least once a quarter to ascertain whether the quantification needs to be adjusted. The development of the management tactics and the risk/opportunity as a whole must be recorded in full in the respective risk dossier [8]. If the risk/opportunity has expired (because the project has moved on or because the risk has been contained or eliminated, it is accorded the status of 'closed/expired'. If a risk/opportunity has materialised (and corrective measures are taken), it is accorded the status of 'materialised'. The plan economist is then contacted to decide whether the 'unforeseen' item in the Business Case should be adjusted [8].

The financial risk profile shows the current effects of the uncertainty on the extra costs in the budgets for the different sub-projects, viz: public space layout (*Inrichting Openbare Ruimte/IOR*), car parks and bicycle sheds, real-estate development, and civic offices. Towards the end of each quarter a financial profile is drawn up for all the risks. This profile is based solely on the information in the risk dossiers. Any changes that have occurred since the previous quarter are explained [8, 17].

Uncertainty analyses are performed to define the feasibility of the milestones. Because of the interconnections between the activities of the different parties, the planner performs the uncertainty analysis for the milestones in the current 'overall' planning. The financial consequences of overrunning (cost-related) milestones are calculated and recorded as one or more separate risks in the risk dossier. The planning economist and the controller agree on the consequences of the risks and the planning economist records them in the Business Case.

To ensure that nothing is missed and to enhance reliability quarterly 'challenge' meetings are held with the budget holders from the Project Management Department [8, p. 9]. The risk manager is responsible for the risk management process and a well-structured inventory. Risk analysis and risk management are a permanent item on the agenda for the discussions between the risk manager and the Director and the Supervisory Board.

Amongst other things, this may include change processing in the risk dossier, trend analyses, the facilitation of risk sessions and management support. The risk manager also checks that the risk dossier is filled in consistently.

The risk owner is operationally responsible for managing his risk. He decides on the risk management strategy (possibly in consultation with the risk manager and/or the core MT) and coordinates the actions [8, p. 10].

Once a quarter the OBS director reports on the ten greatest risks, divided over the three categories: OBS business case, civic offices, and other risks to the municipality. The risk inventory, which is constantly updated, is much longer and consists of multiple risks which, in monetary terms, are smaller than the top 10 in each category. The OBS risk inventory is sent once a quarter to the Supervisory Board and Delft Municipal Council. The Municipal Council is informed later of any confidential or market-sensitive risks. The risk report by ProRail is for internal use only. Neither the Supervisory Board of OBS nor Delft Municipal Council are informed of the risks of the ProRail scope.

Concluding Remarks

This final section establishes a link with the questions posed at the start of this chapter:

> How does the risk management of a large-scale infrastructure project take shape in practice in the Netherlands The Netherlands and how can it be improved?

The risk management strategies described in this paper are commonplace in large-scale projects in the Netherlands. Risks (i.e., probability × consequence) are identified at fixed intervals. Probability and consequence must be estimated subjectively to some extent. We can see some strong dynamics at work when we compare the quarterly risk inventories. New risks materialise with some regularity. Meantime, other risks disappear, either because they have been addressed or because they have not emerged within the set period.

It is key to understand the interconnection between the risks and to determine the cost implications of changes in the timetable and throughput times. A change in risk A may cause a change in risk B. Delays can lead to new risks or to changes in already identified risks. Therefore, it is important that the OBS organisation continue to report the risks once a quarter to the OBS Supervisory Board and Delft Municipal Council. In this context, it is all the more remarkable that ProRail, which also identifies and quantifies the risks once a quarter, does not share its findings with either party. ProRail should report periodically to the Municipal Council in the same way as OBS.

It might prove worthwhile to perform risk management at two levels: system level and component level with the main emphasis on the relationship between the two. Reviews of the area development and adjustments to the agreements with OCSD are typical risks at system level. The chances of unexpected windfalls are underexposed. Potential windfalls merit as much attention as potential setbacks.

In practice a key role is played by the interaction between the risk manager and the other players. The risk manager is dependent on document analysis, and particularly on what is referred to in the OBS organisation as 'challenge' meetings. The initiative can come from the risk manager or another project worker or the director. As soon as a risk is identified, action is undertaken to control it so that no new risks can arise.

Separate attention should be paid to the question of which risks are insured or insurable. The national government does not normally insure externally against risks. To cover municipal risks more insight is required into the ins and outs of insured risks.

Miller and Floricel [11, p. 120]: "The real-options approach recognizes that decisions that determine project cash flows are made sequentially over many episodes. The key insight of this approach is that uncertainty or volatility can actually increase the value of a project, as long as flexibility is preserved and resources are not irreversibly committed." This general perspective is not yet operational in Dutch project management. The spirit of the real-options approach is, however, being followed in the current redefinition of area and real estate development in Spoorzone Delft. Recently, a process-based approach and greater flexibility have been accorded a more important place in the real-estate brief, which had to be fundamentally reformulated in the aftermath of the credit crunch and the debt crisis.

The strategy for the Spoorzone project in Delft was not introduced until the execution phase had begun. It is advisable to apply a robust method of risk analysis and risk management at an early stage, preferably when the project is being developed and concretised.

As mentioned earlier, ‘reference class forecasting’ recommended by Flyvbjerg is unfortunately unworkable at present because there are not enough data on completed projects.

The above comments on the risk management of Spoorzone Delft can be put to use in the broader risk management context of large-scale infrastructure projects in general. It is important that risk management be concretised not only in the execution phase of the project, but also in the planning phase, when it is vitally important to identify and work out alternatives. When market-sensitive information needs to be protected, limits can be set regarding the public disclosure of the risk inventories. Otherwise, the risk policy should be disclosed in full to the empowered authorities (Municipal Executive and Council; States Deputed/States Provincial; Cabinet/House of Representatives).

A study of recent project histories would prove an interesting exercise in a more general sense. How were risks perceived beforehand and how did they pan out later? Where did surprises still spring up—despite a prospective risk analysis? How can these surprises be explained and how can they be prevented in the future? The study of project histories requires reliable documentation of the decision-making and can deliver useful information for future infrastructure projects. In the long term ‘reference class forecasting’ [6, 10] is a useful method not only in relation to costs and overrun budgets but also planning times, throughput times, risk factors and risk analysis.

The literature that highlights the value of checks and balances, competition, and the four-eyes principle has practical relevance for managing the risks in large-scale infrastructure projects in the Netherlands. Go/no-go moments are seldom defined in advance; this needs to change. It is far more difficult to keep alternatives open for the railway than for the real-estate development. The flexibility in the railway tunnel stems, amongst other things, from the possibility of realising a quadruple track—if desired—at a later stage: enough scope has been allowed for this. The real-estate development, on the other hand, was fixed in a fairly early stage. Unfavourable developments on the market (homes, offices) and the inevitable cuts in public spending (civic offices) forced the OBS to make the plans more flexible and process-based. It would have been better to adopt this approach from the start. So far, the experience gained from Delft Spoorzone has certainly borne out the academic arguments and theoretical frameworks that emphasise the need for flexibility and a process-based approach.

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The Actor-Option Framework: A General Framework for Modelling Socio-Technical Systems in Transition

Gönenç Yücel

Abstract A very fundamental need in transition studies is a general modelling framework that allows representing the state of different systems, as well as the change processes related to reinforcing or counteracting their transitions. Such a framework is needed in order to be able to benchmark different transition cases and to integrate case-specific insights for developing general understanding. This chapter briefly presents a general modelling framework, Actor-Option Framework (AOF), for modelling transitional change processes of socio-technical systems. The framework provides a toolbox with conceptual components and a structure about the way these components can be combined for representing a particular system of concern. AOF is based on an extensive set of empirical cases on technological change and socio-technical transitions. The general applicability and appropriateness for developing quantitative and qualitative models of change is assessed through a set of modelling exercises.

Keywords Socio-technical transitions · Modelling · Simulation

Introduction

A very fundamental need in transition studies is a general modeling framework that allows representing the state of different systems, as well as the change processes related to (reinforcing or counteracting) their transitions. Such a framework is needed in order to be able to benchmark different transition cases, and to integrate case-specific insights for developing a general understanding. The existing conceptual models in the transition studies literature (e.g. Multi-level

G. Yücel (✉)
Department of Industrial Engineering, Boğaziçi University, 34342 Bebek, Istanbul, Turkey
e-mail: gonenc.yucel@boun.edu.tr

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perspective [1], pillar theory [2]) are either under-developed, or too abstract to constitute such foundations for modeling. This chapter presents a general modeling framework that can be used to develop qualitative, as well as quantitative models of socio-technical systems in transition; i.e. actor-option framework (AOF).

Actor-Option Framework

In this section, a brief introduction to AOF is provided. A more detailed description of the framework, as well as its grounding is provided by Yücel [3]. Briefly, AOF is an outcome of an inductive study based extensive set of case studies from the literature [4–26].

The basic components of the framework, which will be introduced in the following sections, are based mainly on these cases and relevant literature.

Briefly, according to AOF, a transitional change is conceptualized as a conjoint consequence of the changes related to the options, actors, and the way actors and options interact. In the following two sub-sections, the building blocks of the framework are discussed. The third section focuses on the dynamic nature of the actors and the options, and discusses mechanisms of change, i.e. the third basic component of the framework.

Options

An *option* is defined as an alternative choice that can be utilized for fulfilling a societal need. Depending on the need, an option can just be a physical artifact or a technology. However, in most of the cases, an option is more than that; it also incorporates the way that artifact/technology is used. For commuting needs, using private cars, car-pooling, and car-sharing are three alternative options. Although the artifact, i.e. the automobile, is identical, the ways this artifact is being used differentiate these three as distinct options. The properties that differentiate the options are not just related to the techno-physical aspects, but also go beyond that and are related to the contextual embedding of these options. Two broad classes of properties are identified;

Embodied Properties

These are the properties mainly related to the techno-physical nature of the options, and as the name clearly indicates they are embodied in the option. In other words, these are properties that can be observed even when the option is studied in isolation from its socio-technical context

Disembodied Properties

These properties are related to the context in which the option functions. For example, consider public trains as an option for personal mobility needs. The important properties are not confined to the technical properties of these trains; other aspects such as the frequency and reliability of the service, or the crowding level are also important.

The changes in option properties, as well as in the role of an option in the socio-technical system (e.g. its dominance) are important developments considering transitional change processes. However, options do not possess a dynamic nature by themselves, but all option-related developments are the consequences of related social actors' behaviours, such as commuters shifting to a new mode of commuting, or manufacturers allocating resources for a new technology. Therefore, social actors and their behaviours are central in understanding the transition dynamics. The following section discusses the way these actors are conceptualized according to AOF.

Actors

Contrary to what the term implies, an actor in AOF does not necessarily correspond to an individual person in the socio-technical system, but it is a social unit of analysis, which can be attributed goals, preferences, resources, and actions (e.g. an organization, a firm, etc.). One of the key characteristics of transitional change processes is their multi-actor nature. These interacting actors are not identical, but they possess very different properties, such as their preferences, objectives and resources. In other words, transitional changes in socio-technical systems are driven by a set of actors, which are heterogeneous in multiple dimensions. Two broad dimensions of heterogeneity are especially important for analyzing transitional change; heterogeneity with respect to decision drivers, and heterogeneity with respect to decision consequences.

Heterogeneity in Decision Drivers

First of all, an actor's decisions are driven by what is known to the actor. Therefore, a clear source of heterogeneity is the information possessed by the actors in the system. Secondly, the actors can diverge in the decisions they make due to the differences in the factors that determine the way this information is evaluated during the course of a decision making process. Generally, outcomes of a certain action, or attributes of a certain alternative are judged against a neutral reference outcome (or simply a reference). Such a reference may be a state to which an actor has adapted, a set of social norms, or a level of aspiration (ibid.). Similar concepts are referred to as aspiration levels, *reference points*, or target levels in the decision-making literature [27–29]. In our conceptualization, these references define what is acceptable/desirable for the actor.

These standards, norms and habits of the actors' (i.e. *references* in AOF) can act as an important source of heterogeneity in actor decisions. Thirdly, an action can be related to an existing account linked to similar actions taken in the past (e.g. sunk-costs due to previous investment decisions). In that respect, the *commitments* of an actor (e.g. financial or effort-wise) in the past can be as important as the options' properties in influencing the decisions. Naturally, different levels of commitments to certain courses of action will differentiate the decisions of the actors even when they are exposed to identical information. Lastly, the assessment of the possibilities (e.g. options) before making a decision is not a simple uni-dimensional assessment; actors face a multi-dimensional assessment problem. In this context, it is the *preference structure* of the actor, which represents the relative importance of the different issues, such as environmental friendliness, loss of former investments or operating costs, for the actor. Difference in preference structures is another source of heterogeneity in actor decisions. In summary, an *actor* is characterized in terms of four main aspects in AOF; *information*, *references*, *commitments* and *preferences*.

Heterogeneity in Decision Impact

An actor's decisions' impact is primarily dependent on the role the actor occupies in a socio-technical system. When we consider the fulfilment of a societal need as a sort of social interaction, we identify, by deduction, four main categories of actors involved in this process. The first category consists of actors who have such a need, and use available options; i.e. *practitioners/users.* The second group is related to the provision of the means (including maintenance infrastructure as well as the options themselves) of fulfilling the societal need; i.e. *providers*. However, neither the utilization, nor the provision of the alternative options takes place in an unstructured manner. The actors who are related to altering regulations and rules constitute the third category of actors; i.e. *regulators*. Lastly, there are actors who can influence the way other actors behave with the opinions they hold about the need itself and the available options (e.g. NGOs; i.e. *opinion groups.*

Besides an actor's role, the possible extent of impact of the actor within the given context is another factor that differentiates the influence of the actors' decisions on the way system functions. Among other things, the extent of the impact is mostly related to the *resources* controlled by the actor.

Mechanisms

Two key concepts, i.e. *actor* and *option*, are discussed in the previous sections. Along a transitional change process, neither the actors, nor the options stay as they are, and they both change over time. Moreover, the dynamics of the actors and the options are not independent from each other; i.e. a change in the behaviour of the actors trigger a change related to the options, and vice versa. his subsection introduces a set of general *mechanisms* that represent the major processes related the ways the *actors* and the *options* change over time. The first group of mechanisms is related to the dynamics of the *options*. The second group of *mechanisms* is related to the information possessed by the actors. The last group of mechanisms is about deeper changes in the actors with regard to the way they make their decisions; *mechanisms* that alter the behavioural identity of the *actors*.

Mechanisms Related to Option Properties

This group contains four major mechanisms in AOF, which are elaborated below.

Experience-Driven Change

Cumulative experience of the actors with an option leads to the option's development according to this mechanism. Such a development can be caused by both provisional and practical experience. When it is the experience of the providers that drives the development, this mechanism is equivalent to a widely known phenomenon; learning-by-doing [30–35].

In the case of the practitioners, it is the cumulative utilization of the option that yields to the option development. Rosenberg discusses this process using the term 'learning-by using' [33].

Scale-Driven Change

The scale of utilization (e.g. number of users), or provision (e.g. volume of production) of an option can have an impact on the option attributes in some cases. This general mechanism has both provider- and practitioner-driven manifestations, and the change induced by the scale may be negative, as well as positive. Provision side instances of the scale-driven change are direct consequences of the provision scale, and are simply about more/less efficient exploitation of the provision opportunities. The impact need not always be positive in the scale-driven change. Especially, in the provision systems that consist of multiple sub-systems with heterogeneous capabilities, as the provision scale increases less efficient subsystems need to be exploited. This in turn leads to an overall performance decrease in the provision system. Practise side instances include crowding effect (i.e. deterioration of the properties of an option as a consequence of increasing load on the system) and network externalities (i.e. the more users on the system the more benefit a user can get from the option).

Resource-Driven Change

The system actors also influence the properties of the options by utilizing the resources they possess. These resources are not only financial, but they also include, for example, physical capital, manpower, and time (R&D, managerial, etc.). In general, such changes are induced by purposeful resource allocations of the actors who aim to alter the option properties. In line with such an aim, these resources may be directed to three different aspects related to the option; the option itself, the means/methods of provision, and the capacity of the provision system.

Exogenous Change

The property changing mechanisms discussed so far are all endogenous to the socio-technical system being analyzed; the changes are triggered by the actions of the actors in the system. However, changes in the option properties may be rooted in the developments that take place beyond the boundaries of the socio-technical system being analyzed; i.e. developments that are autonomous from the dynamics of the system. For example, some properties of electrical cars, such as driving range, develop almost independent of the dynamics of the Dutch mobility system.

Mechanisms Related to Actors' Perceptions

The processes via which actors' perceived information change over time play an important role in the actors' behaviour change. This set includes three mechanisms related to perception[1] change.

[1] In the sense the words perception and learning are used, it is the information that changes via these learning processes, not the values or norms used by the actors to attribute meaning to this information. The latter aspect, which can be considered as subjective evaluation of the gathered information, is closely related to the actor's behavioural identity, and the mechanisms related to this identity will be discussed later in this chapter.

Individual Learning

The individual learning mechanism refers to the improvement of the information precision via direct observation, or experience of the actor. The actors can learn about the situation of the system, and/or options (i.e. their availability and properties. In the experience-based individual learning, a provider's, or a practitioner's direct experience with an option (e.g. a practitioner using a alternative fuel vehicle, a provider investing in new generation wind turbine) enables the actor to learn about the actual properties of the option.

Social Learning

This learning mechanism is about the diffusion of information among the actors; it is the information possessed by other actors that acts as the source of new information for an actor. Information flows via social interaction (e.g. word-of-mouth, or information contagion).

Learning from External Sources

Although personal experience and social communication are important means of learning, they are not the only ones. The actors are also exposed to information from numerous other indirect sources; marketing campaigns, bulletins, newspapers, and scientific reports. These all serve as information sources, and are also very important in shaping what is known by the actors. The special importance of this mechanism comes from the fact that this is the mechanism via which novel information gets introduced into a particular socio-technical system.

Mechanisms Related to Actors' Behavioral Identity

Actor decisions are determined as a consequence of the subjective assessment of each actor based on the actor's preferences, beliefs, norms and priorities; i.e. an actor's behavioral identity, as the term is used in this text. The mechanisms that are discussed below are related to changes in this identity.

Reference Formation/Change

An important concept related to option assessment is a reference point used for the assessment; a reference point against which properties of an option are evaluated. The assessment references can be considered as a sort of 'demand requirements' of the actors with respect to their societal need. Reference formation/change can take place due to various factors. A reference can be dictated from outside to an actor, as in the case of laws and regulations. References of an actor can also change as a consequence of the actor's interaction with the options. An actor's experience with a certain option to fulfill a need conditions/shapes the expectations of the actor regarding the way that need has to be fulfilled. These references, which are formed and reshaped by individual experiences of the actors, get stronger and deeply rooted as experience accumulates. Social influence can also be an important driver of reference formation and change. Apart from what is dictated to, and experienced by the actor, the practices (and references used) in the social sphere of the actor set an example about the way things might/should be done.

Commitment Formation

A commitment to a certain course of action (e.g. investing in a certain technology, using a certain computer operating system) can develop as a consequence of decisions in the past, and of tangible and intangible assets acquired as a result of these decisions. However, not all decisions contribute to commitment formation at the same level, if they do at all. In the broadest sense, a commitment-forming decision yields to consequences that are relevant for the subsequent decisions of the actor (e.g. making it easier to repeat the same course of action). The accumulations of the consequences of the actor decisions (e.g. allocation of physical or economical resources, or effort spent on an option) are important sources of commitment in the socio-technical systems. These accumulations can be considered as assets acquired by the actor in relation to an option, and these assets can be tangible (e.g. funds spent on R&D, or buildings and machinery owned), as well as intangible (e.g. expertise, know-how, and acquaintance) in nature.

Preference Structure Change

The preference structure of an actor indicates the important issues for the actor in assessing the available options, as well as the relative importance (e.g. weights) of these issues. In other words, this structure specifies which issues the actor cares about, and also how much the actor cares about these issues in the context of fulfilling the relevant societal need. The most prominent mechanism of preference change is the problem-induced one. Such a change is a consequence of the awareness about a problem, which can be directly related to the way socio-technical system functions, or to the consequences of the mode of functioning. The problem that induces change need not be local to the system of concern, but also a problem with a wider scope can induce preference structure changes. A landscape problem can also trigger a change in the preference structures of the actors.

Although it is the most frequently discussed case in the context of socio-technical transitions, a preference structure change need not always be induced by a problem, be it a regime or landscape problem. For example, cultural, economic, or institutional landscape developments can also play an influential role on the priorities of the actors. Although such an external influence on the preference structures can be important in transitional change process, it does not qualify as a mechanism in the way it is stated above; the conditions which trigger it, and the chain of events/processes that links the trigger to a preference change are not well specified based on the inductive analysis of the case studies.

Modelling with the Actor-Option Framework

The main constituents of AOF are introduced in the previous sections. Although AOF provides a toolbox of concepts that can be used to develop a model, the modeling process requires a structure in combining these concepts. In order to help with the modeling process a set of guiding questions are proposed. They are organized as a sequence of fundamental questions that need to be answered throughout the model development process. The questions are expected to help in specifying the boundaries of the system to be modelled, as well as the way internal structure of the system may be represented. Although following the sequence of the questions is not vital, this may prove useful in keeping the development process well structured.

(a) What is the societal function/need of concern subject to transition study?
(b) Which aspects of the societal function characterize the transitional change? What are the directions of change that are of interest?
(c) What are alternative means of fulfilling the societal function (i.e. options)?
(d) Who are the major social actors in the system (i.e. actors) and what are their roles?
(e) How to formalize actors' decision-making (e.g. rational, boundedly-rational, intentional, etc.)?
(f) How are the options characterized in the model? What are their key attributes?
(g) Which mechanisms are 'active' for which options and actors in the analysis context?

Both the applicability of the approach as well as its relevance in studying transition in dynamics has been assessed through a set of modeling exercises. Two of the studied cases are historical transitions; a transition in the British naval transportation system [36, 37], and a more recent transition in the Dutch waste management system [38, 39]. The third case focuses on current state of the Dutch electricity system, and its plausible change dynamics [40]. Primary reason for choosing diverse socio-technical contexts is related to exploring the extent to which the framework is a (contextually) general one. As a result, of these modelling exercises, it is seen that the basic concepts of the framework (i.e. *actors* and *options*) can successfully be applied to these different contexts without difficulty. Additionally, we see that the mechanisms introduced in the framework are applicable in these different contexts: the key processes taking place in the studied socio-technical systems can all be classified as specific instances of these general mechanisms, and they are represented using these general mechanisms in the developed models.

An advantage of using historical transition cases is the presence of detailed *ex-post* analyses about important developments during the transition. This allowed us to evaluate the sufficiency of the actor-option framework in covering social and techno-physical developments that played an important role in those transitions. In this evaluation, we observed that all those key developments could be formalized as instances of the *mechanisms* of the framework. In other words, the ex-post analysis of processes that drove these historical transitions can be re-constructed using AOF in a formalized manner, without leaving out major processes or developments.

Discussion and Conclusions

This chapter briefly presented a general modelling framework, i.e. AOF, for modelling transitional change processes of socio-technical systems. The framework provides a toolbox with conceptual components and a structure about the way these components can be combined for representing a particular system of concern. AOF is based on an extensive set of empirical cases on technological change and socio-technical transitions. Its general applicability and appropriateness for developing quantitative as well as qualitative models of change is assessed through a set of modelling exercises. As a result, it is concluded that AOF is rich enough to be used in different contexts, and it is very useful in structuring the modelling process.

Looking at AOF with a critical perspective, the way mechanisms are depicted can be considered as not being specific enough, since the framework leaves the task of formal specification and quantification to the analyst. Depending on the perspective, this can be seen both as a shortcoming, and as a merit. Since it leaves an important gap between conceptualization and implementation, it can be seen as not providing enough guidance. However, the objective of this study is not to deliver ready-to-explore simulation models. It aims to provide a general perspective and system depiction that can be used for a wide range of systems, and by a wide range of analysts with differing backgrounds. The non-specific depiction of the mechanisms is chosen to assure such a broad coverage.

Authors evaluate the proposed set of mechanisms as rich enough in its current form to be used for analysing transitional change in socio-technical systems. However, the set may be improved in the future by addition of new mechanisms, and refinement/revision of the existing ones. The defining characteristics of the analytical perspective are rooted in the actor/option-based depiction of the system. While preserving these characteristics, the analytical perspective can be improved via refining the mechanism set in the light of new evidence and findings. When we reflect on the current set of mechanisms, the most promising direction of improvement is the social mechanisms. Especially, an elaboration on the mechanism of preference change can be a very valuable addition to the current state of the proposed mechanism set.

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Erratum to: Infranomics

Adrian V. Gheorghe, Marcelo Masera and Polinpapilinho F. Katina

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The affiliation of Marcelo Masera which should be: "Institute for Energy and Transport, Joint Research Centre, Petten, The Netherlands"

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A. V. Gheorghe (✉) · P. F. Katina
Engineering Management and Systems Engineering, Old Dominion University, Norfolk, VA, USA
e-mail: adriangheorghe9145@gmail.com

P. F. Katina
e-mail: pkatina@odu.edu

M. Masera
Institute for Energy and Transport, Joint Research Centre, Petten, The Netherlands
e-mail: marcelo.masera@jrc.ec.europa.eu

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Epilogue

Adrian V. Gheorghe, Polinpapilinho F. Katina

Infranomics Synthesis and Future Challenges

This book provides a rough entry into the interdisciplinary field of *Infranomics*. It is proposed as a thesis enabling better decision making in an increasing ambiguous, complex, emergent, interdependent, and uncertain world where we attempt to anticipate modern society trends and pertains to react appropriately. However, as with any emerging discipline, much research is needed at the applications and conceptual level.

The applications level may require development and testing of methods, tools, and techniques to enable analysis and decision-making in ambiguous, complex, emergent, interdependent, and uncertain conditions while the conceptual level may require taping into driving philosophies, theories, and methodologies that form the basis for *Infranomics*.

Striking the right balance between applications and conceptual foundation (theory) requires rigorous research. It is from this perspective that the editors hope that this book provides a springboard for robust discussions on applications, theory, and transformation of current thinking to better deal with modern society's problematic issues using *Infranomics*.

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