Fátima Dargam · Jorge E. Hernández
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LNBIP 184

Decision Support Systems III – Impact of Decision Support Systems for Global Environments

Euro Working Group Workshops, EWG-DSS 2013
Thessaloniki, Greece, May 29–31, 2013
and Rome, Italy, July 1–4, 2013
Revised Selected and Extended Papers

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Preface

These proceedings of the third edition of EWG-DSS contain extended and revised versions of a set of selected papers submitted and presented at the EWG-DSS research events held in Thessaloniki and Rome in May and July 2013, respectively. These events include the EWG-DSS annual workshop and the EWG-DSS DSS stream organization in the 2013 EURO-INFORMS OR international conference. Both were supported and sponsored by the EURO Working Group on Decision Support Systems (EWG-DSS) and the Association of European Operational Research Societies (EURO), in cooperation with: the Business Administration Department of the University of Macedonia in Greece; SimTech Simulation Technology, Austria; University of Toulouse and the Institut de Research en Informatique de Toulouse (IRIT) in France; the University of Liverpool Management School (ULMS) in the UK; UNINOVA Computational Intelligence Research Group (CA3) in Portugal; School of Management, University of Plymouth in the UK; Instituto de Lógica Filosofia e Teoria da Ciência (ILTC) in Brazil; the University of Namur in Belgium; and the University of Belgrade in Serbia.

The major objective of the EWG-DSS 2013 Workshop in Thessaloniki and of the EURO-INFORMS DSS Stream at the 26th European Conference on Operational Research in Rome was to bring together academics, researchers, practitioners, and enterprises interested in modelling, implementing, and deploying decision support systems for enhancing the decision-making process in different types of environments, considering conceptual as well as applied approaches with emphasis on the impact of DSS in global environments and on exploring new directions for decisions in the Internet age. The scientific areas of interest for selected contributions from these two outstanding events were: decision making using social networks and Web resources; spatial–temporal Web-based decision making; technical, legal, and social aspects of Web-based decision making; group support systems/distributed/collaborative decision making; methods, languages, and tools to support decision making; Web 2.0 systems for decision support and globalization context spatial–temporal decision support systems; knowledge management and decision support systems; knowledge and resource discovery and decision making; business intelligence and data warehousing; and negotiation support systems. This rich variety of themes in the contributions allowed us to present in this edition a high-quality selection of approaches and applied solutions for the implementation of decision-making processes for various global environments. In this context, the selected papers are representative of the current and relevant research activities in the area of OR and decision support systems.

Both 2013 EWG-DSS events, in Thessaloniki and Rome, considered 45 papers presentations, respectively. From the total of 45 papers, 15 papers were selected for publication in this edition on the basis of their content, structure, and presentation qualities. This yields a full-paper acceptance ratio of about 33 %, which enforces the EWG-DSS tradition in preserving a high-quality forum for the EWG-DSS editions. The selection and publication phase of these proceedings considered a triple-blind paper evaluation method: Each selected paper was reviewed by at least three internationally renowned experts, partially from the EWG-DSS Program Committee of the 2013 research events and partially from external international experts in the field of Decision Support Systems. The editors of this volume are very grateful for the high-level evaluation support from this edition's reviewers.

The EWG-DSS 2013 Thessaloniki Workshop program was enhanced by six keynote lectures, delivered by distinguished invited speakers who are renowned experts in their fields. Their lectures were very interesting and there was a high level of information exchange for further fruitful cooperation among all participants. The Thessaloniki Workshop keynote lectures included:

- Alexis Tsoukias, the University Paris Dauphine, France, with the talk: "What Is a Decision Problem?"
- Francesca Toni, Department of Computing, Imperial College London, UK, with the talk: "Computational Argumentation for Decision Support on the Web"
- Petraq Papajorgji, Canadian Institute of Technology, Tirana, Albania, with the talk: "Model-Driven Architecture in Designing and Developing Complex Agricultural and Environmental Information Systems"
- Robert Kenward, Vice-Chair of IUCN Sustainable Use and Livelihoods Specialist Group, with the talk: "Concepts, Case Studies and Design for Environmental Decision Support: The TESS Project"
- Max Henrion, Chief Executive Officer, Lumina Decision Systems, Inc., with the talk: "Decision Analytics: From Big Data to Clear Decisions with Analytica"
- Giuseppe Lugano and Mafalda Quintas, COST Office Science Officers, Trans-Domain Proposals, with the talk: "COST TDP Pilot: Introducing a Pilot Evaluation Procedure for Trans-Disciplinary Proposals"

This EWG-DSS Springer LNBIP edition includes the following contributions: "A Decision Support Framework for Crisis Management", authored by Daouda Kamissoko, Pascale Zaraté, and Francois Peres; "Spatio-Temporal Decision Support System for Natural Crisis Management with TweetComP1", authored by Stuart E. Middleton, Andrea Zielinski, Öcal Necmioğlu, Martin Hammitzsch; "Near Real-Time Decision Support for Disaster Management: Hurricane Sandy," authored by Tina Comes; "A Web-Based Decision Support System for the Capacitated Facility Location Problem", authored by Jason Papathanasiou, Nikolaos Ploskas, and Nikolaos Samaras; "A Web-Based Decision Support Platform for Multidimensional Modeling of Complex Engineering Systems", authored by Mariam Nouh, Ahmad Alabdulkareem, Waleed Gowharji, Anas Alfaris, and Abel Sanchez; "Purchase Decision Processes in the Internet Age", authored by Sahar Karimi, K. Nadia Papamichail, and Christopher P. Holland; "Dynamic Process Building to Support Business Process Exception Management with the BEM Framework", authored by Isabelle Linden, Myriam Derbali, Gabriel Schwanen, Jean-Marie Jacquet, Ravi Ramdoyal, and Christophe Ponsard; "An Agent Architecture for Concurrent Bilateral Negotiations", authored by Bedour Alrayes and Kostas Stathis; "Integrating Environmental Policies into Business Strategy: A Framework for Decision Support", authored by Maria de Fátima Teles and Jorge Freire de Sousa; "A Web-Based Decision Support System for Supply Chain

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We would like to take this opportunity to express our gratitude to all those who contributed to the EWG-DSS research events in 2013, including authors, reviewers, Program Committees and institutional sponsorships. Finally, we hope you will find all the addressed contents of this EWG-DSS LNBIP edition useful and interesting for your own research activities.

July 2014

Fátima Dargam
Jorge E. Hernández
Pascale Zaraté
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Jason Papathanasiou

EURO Working Group on Decision Support Systems

The EWG-DSS is a Working Group on Decision Support Systems within EURO, the Association of the European Operational Research Societies.
The main purpose of the EWG-DSS is to establish a platform for encouraging state-of-the-art high-quality research and collaboration work within the DSS community. Other aims of the EWG-DSS are to:

- Encourage the exchange of information among practitioners, end users, and researchers in the area of decision systems.
- Actively contribute to enlarge the networking among the DSS communities available and facilitate activities that are essential for developing international cooperation research and projects.
- Facilitate professional academic and industrial opportunities for its members.
- Support the development of innovative models, methods, and tools in the field of decision support and related areas.
- Actively promote the interest in decision systems in the scientific community by organizing dedicated workshops, seminars, mini-conferences, and conference streams in major conferences, as well as editing special and contributed issues in relevant scientific journals.

The EWG-DSS was founded during a memorable EURO Summer Institute on DSS that took place at Madeira, Portugal, in May 1989. This Summer Institute was organized by two well-known academics of the OR community: Jean-Pierre Brans and José Paixão. It had the participation of 24 (at that time) young researchers of 16 different nationalities. Most of them still continue to pursue their goals today, working actively in their research areas.

The number of EWG-DSS members has substantially grown along the years with members coming from all parts of the globe. Several research co-operations among the group members are leading to important contributions to the DSS field and to joint journal publications.

Since its creation, the EWG-DSS has held annual meetings in various European countries, and has taken active part in the EURO Conferences on decision-making related subjects.

Since 2007, the EWG-DSS has been managed by a coordination board. One of the aims of this coordination board is to better promote joint work among the group members and to encourage more participation of the whole group in DSS-related projects and events. Currently, the EWG-DSS coordination board is composed of: Pascale Zaraté (France); Fátima Dargam (Austria); Rita Ribeiro (Portugal); Jorge Hernández (UK); Boris Delibašić (Serbia); Shaofeng Liu (UK); Isabelle Linden (Belgium); and Jason Papathanasiou (Greece).

For more details about EWG-DSS organized events and publications, please check the homepage at: http://ewgdss.wordpress.com/.

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Contents

A Decision Support Framework for Crisis Management

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Abstract. This paper deals with the development of a Decision Support System (DSS) for infrastructure network vulnerability analysis in the natural disaster context. The developed DSS named VESTA supports dynamic modelling and interdependence modelling. The issues in this particular decision context are identified. Characteristics to be respected and the software architecture are also presented. The strengths of the DSS and its functionalities are highlighted. It calculates parameters by a simulation based on a vulnerability model. This paper discusses the implementation granularities of and the use of such a DSS.

Keywords: Decision Support System · UML · Database · Disaster · Infrastructure · Network · Vulnerability

1 Introduction

Natural disasters have always been societies' destabilization sources since the beginning of the human societies. In the past, they were attributed to divine wrath sign. Much later their manifestations were explained scientifically. Actual knowledge allows the disaster description through models more or less established. Although the causes of such events are most often known, it turns out to be very difficult to prevent natural disasters. At most it is possible to think about protection systems.

Disaster affects many stakes including infrastructure networks. Through interdependence, a failure of one component might lead to those of the others by cascading failures. This situation can quickly lead to a complex crisis.

One of the challenges in the crisis management is the responsiveness of decision makers. The use of a Decision Support System seems to be primordial to meet the challenge. Indeed, every second counts and decisions must be taken quickly. Consequently, the use of simulation systems in such context seems essential.

The objective of this paper is to present a Decision Support System for infrastructure network disruption in the context of natural disaster. First of all the issues of the DSS are presented. Features to overcome these issues are then shortlisted. Following on, the used architecture is described before presentation of the resulting software.

2 Issues

Decision making is one of the human being's main cognitive activities. In fact, man is a being who doubts. Through the doubt mechanism, it is in constant reflection in every

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decision process. This situation is further emphasised when there are several possible options. In general decision making, [1] pointed out some elements which make the decision process difficult:

- Uncertainty of the problem;
- Several different objectives;
- Different conclusions that may derive from different perspectives.

In the particular area of infrastructure failure many other difficulties indices could be added to the above enumerated:

- Decision maker's emotional state instability;
- Consequence extent;
- Interdependence between networks;
- Interdependence between feared events;
- The need of justification;
- Multiples actors.

For illustrative purpose, the 2010 volcanic eruption in Iceland affected about 20 countries because of the interdependences in air transportation networks. Because of this number of decision maker implied in the decision process, actions synchronisation is harder and time consuming. This kind of situation is source of stress and anxiety for decision makers which judgment could be affected. The stress erasing from this situation leads to the instability of decision maker emotional state. In addition, the justification of every action is very different from a normal situation.

It follows that a normal decision context is different from a crisis one. Currently everyday routine decisions are less complex, their consequence scope is limited, and the decision makers' emotional state is quite stable. On the contrary, in a crisis situation, decisions are more complex, the consequence scope is high, decision justification needs are different, and the decision makers are emotionally instable.

Whatever the consequences, a decision has to be justified and in the case of natural disasters, maybe more than any other context, it is crucial to explain what is intended to be done. Natural disaster decision context varies greatly according to the decision-makers emotional states, the consequences extent, the need of justification, and the decision subject complexity. Thus, in natural disaster situations, the need of support seems to be obvious for decision making.

The previous example highlights the need of justification of every decision. In fact this is not specificity of infrastructure failure but in disaster situation in general. Stakes represented by the travellers has to be informed about why theirs flights was cancelled, diverted, delayed etc. Using computer software (Decision Support Systems) is therefore valuable.

In the following sections, we will describe the architecture of a DSS to overcome these issues and take efficient and effective actions according to crisis management phases. The aim of an effective action is to fulfil objectives in the assigned time, while that of an efficient action is to fulfil objectives with the assigned means.

We have identified some phases in natural disaster crisis management. They consist of:

- Investigation: To identify the feared events and the stakes: This is the phase of ignorance which aims to identify risks;
- Awareness of the situation: In this phase, the risk is known, stakes are awarded of the situation which means the beginning of cognitive processes to integrate the risk culture;
- Simulation: Aims to evaluate different scenarios through models more or less elaborated;
- Warning: This is the phase where we assist to the appearance of the hazard's signs;
- Event: Occurrence of the hazard;
- Replication: The event is over but the risk of recurrence is high. Replicas are seen especially when it comes to earthquakes;
- Post-event: The crisis is over, but it remains to rebuild and repair damages;
- Stability: This is the last phase. Choices are evaluated and feedback formalized.

The next section presents definitions of DSSs and some of their features.

3 Definitions and Features

A Decision Support System is a computer-based system for decision support [2]. It is defined as an integration of computer hardware and software that is designed to complement the cognitive processes of humans in their decision making [3]. In this paper, the designed system can be used in many phases. It is called VESTA.

DSS features as those of classical software depend on the use. They were described by Sprague and Carlson through the ROMC approach [4]: Representations, Operations, Memory Aids, Control Mechanisms. With regard to decision support systems in a disaster management, they have to be flexible, adaptive, responsive, interactive [2], progressive and controllable [3]. In addition to these features, we have also identified other parameters like: response time, geographical distribution, ease of use, portability, ergonomic and efficiency.

Next section introduces the architecture that incorporates these features.

4 Architecture

As recommended by Sprague [5], the architecture adopted is composed of three parts namely: a Human Computer Interface, a Data Base, and a Model Base. William A. Wallace in [3] added to these parts a data analysis capability. In our approach, this module is managed by the Data Base Management System. In some situations like those related to territorial management, a spatial DSS can have prominent spatial components [6].

Data Base is devoted to data analysis capability performed by a Data Base Management System (DBMS). The Model Base is related to a normative model implemented in a Model Based Management System (MDBS). The Human Computer Interface is related to a Dialogue Management System.

Next section presents these components.

4.1 Human Computer Interface

A Human Computer Interface (HCI) represents all windows accessible to users. The nine windows of the application have been prototyped with Balsamiq [7]. At the encoding time, the GUI was drawn by WindowsBuilder - an Eclipse IDE plug-in [8]. The dialogue management system related to the Human Computer Interface is implemented through Java Classes.

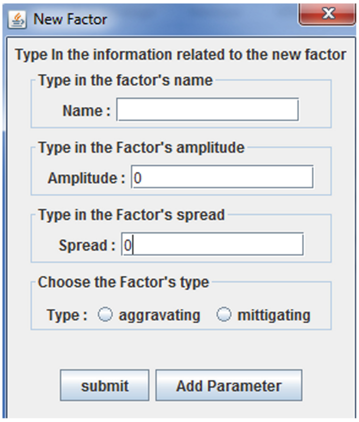

Fig. 1. Human Computer Interface of VESTA

A feared event like a flood can be aggravated or mitigated by some natural or artificial factors (like a dam for instance). As an illustration, Fig. 1. presents this particular HCI.

4.2 Database

Decisions emerge from the performed data processing. Data are located in a database. The Unified Modelling Language (UML) is used for the data description. We used a methodology inspired from that presented in [9]. This approach included actors identification, building the static context diagram, relationships between use cases, use cases for human actors, sequence diagrams, activity diagrams and class diagrams.

Figure 2 presents part of the class diagrams in UML. At its occurrence, a feared event (Hazard) affects circulating flows in the network and stake. The real data base implements 30 classes and 12 relations.

4.3 Model Base

The model base is managed by a Model Base Management System (MBMS). The functional and dynamic modelling of MBMS are performed through the object approach.

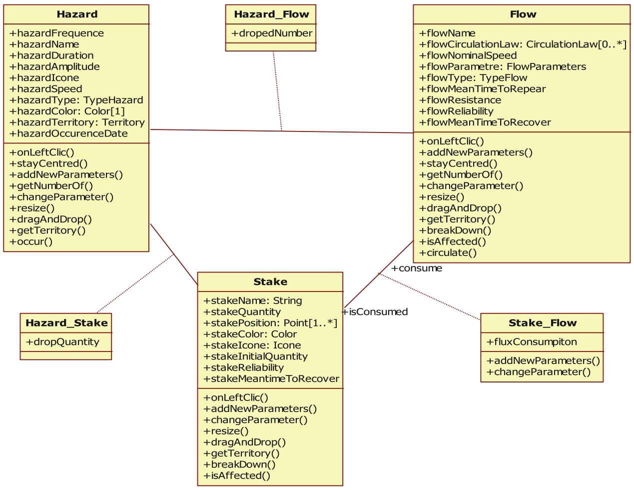

Fig. 2. Class diagram with StarUML [10]

Several kinds of actors are identified: International, National, Regional, Infrastructure Manager, Local Operator, Emergency, Citizen and the Analyst. For each of them several use cases are defined. We have defined 14 scenarios. The example in Fig. 3 shows that a local actor can determine among others critical components, effective actions, feared events etc.

Use cases in Fig. 3 are based on the vulnerability model [11] presented in the next section.

Vulnerability Model

Vulnerability is "a stake's inability to resist the hazard's occurrence and to recover effectively its nominal functioning for a given period of time" [12]. Vulnerability depends on the hazard and the system state. It is given by:

$$V = P(Hazard) \times \left(1 - \prod_{n=1}^{N} (1 - \vartheta_n)\right) \tag{1}$$

N is the number of component. ϑ_n is the intrinsic vulnerability of a single component n. It is given by:

$$\vartheta_n = (1 - R_b)(1 - R_s) \tag{2}$$

R_b is defined as the robustness and R_s the resilience. The reader may refer to [11] for more information.

The originality of the DSS is also in the implementation of this model.

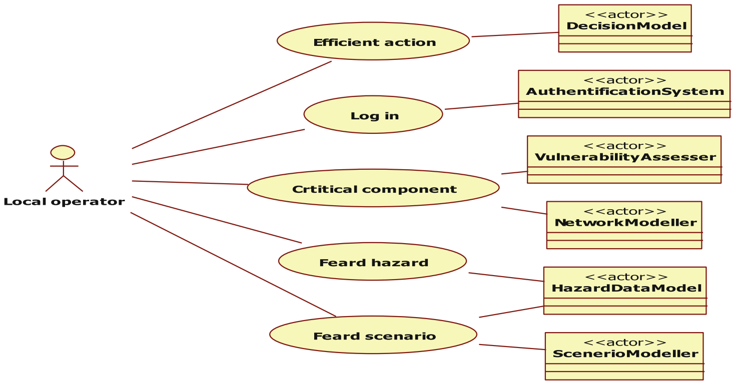

Fig. 3. Use case for local operator

Model Implementation

Because of its portability Java was retained as development language to implement the model in the previous section. In addition, Java is free and can run on different computer environments without any change.

The system is fully implemented by using swing as an API for graphics and JUNG to represent the network [13].

5 The Decision Support System: VESTA

Many terms are related to Decision Support System in the literature: artificial intelligence, data mining, on-line analytical processing, knowledge management [14], Group Support System (GSS), Executive Information System (EIS). In general, a Decision Support System is a computer-based system for decision support [2]. There are many definitions in the literature. We divided these points of views into three groups:

- Definitions focusing on the characteristic [2, 15];
- Definitions on the objective [3, 14];
- Definitions on the architecture [5, 16].

A recapitulative is given by [14, 17]. The developed DSS complements shortcoming of the existing. Its functioning is presented in the following section.

5.1 Functioning

In the literature there are several Decision Support System for disasters management. Their applications are related to many disciplines: pollution control, water resource management, flood, forecasting, prevention of epidemic etc. [14]. A recapitulative is given by [14, 17]. None of these systems take into account the vulnerability calculation in a generic way. The Decision Support System for Interdependent Network Vulnerability Analysis realized in this study contains an ergonomic graphical user interface which allows the user to choose different possibilities depending on his/her rights. The functioning is composed of five phases: Characterization, Modelling, Simulation, Decision, and Evaluation.

The first step of this approach is to describe the decision context in the characterization phase. After this description, networks and interdependences modelling would be performed in the modelling phase. The simulation will allow best actions determination. Determined actions are evaluated in the Evaluation step.

VESTA is able to calculate the vulnerability of a geographical region or a network. The region must first of all be modelled by the analyst. Next parameters as feared events and stakes have to be estimated and the system can assess the vulnerability of the defined target. Its strengths are presented in the next section.

5.2 Strengths

Dynamic Network Drawing

The strength of VESTA resides in the dynamic network drawing. The software enables the user to import a map as a picture or to select an area from a real map (using Google maps for example). Then, specify the boundaries of the geographic area to work within. If the user does not find a map, the software offers the possibility to draw the territory and represent it by its boundaries on the zone. Territories are resizable (zoom, extension…).

During the simulation, the user can draw the network by a drag and drop function. He/She can add and remove component dynamically. Figure 4 shows an example of network drawing.

Vulnerability-Based Simulation

VESTA simulates network functioning and determines the vulnerability according to the model presented in [11]. This model takes account of interdependence among networks, flow circulation, the impact of a feared event such as an earthquake, the component failure due to its unreliability etc. VESTA could determine other parameters which are described in the next section.

5.3 Results Representation

The system has been used in two cases study. The first is a generic one. The reader is invited to see [11] for more information. The second is real situation. The analysis is performed for Lourdes, in the "Hautes-Pyrénées" (France). Indeed, the

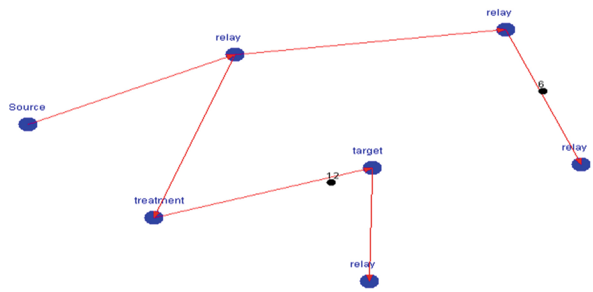

Fig. 4. Network drawing

Hautes-Pyrénées lies in the highest seismic area in the French metropolitan country. Lourdes is a pilgrimage city since 1858. As an illustration the city hosted during the 150th anniversary of the Virgin apparition nearby 70,000 pilgrims per day. This may amplify the dramatic character of the consequences in case of the occurrence of a seism. Among the different topics of concern, the city wishes to analyse the vulnerability of the sewage network. The simulation was performed with our DSS and we proposed some actions. The details of the analysis and the methodology are available in [18].

For a single element (single network, territory, network component, stake, flow, factor, feared event), the application calculates the vulnerability and shows the result in the form of Pareto chart. This chart provides information on the importance of the considered element to the global vulnerability. The system could also calculate the part of vulnerability induced by interdependence. For now, it is a prototype and must be improved.

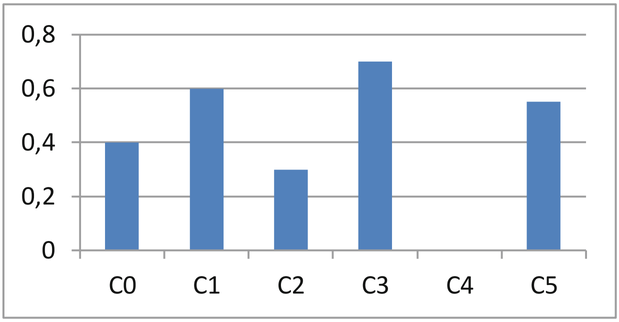

Fig. 5. Parameter calculation

Figure 5 represents the vulnerabilities of six components. It shows that the component C4 is the least vulnerable with respect to the feared event. Conversely C3 is the most vulnerable. Let us remark that the user could also select more or less components and choose to display resilience instead of vulnerability for example.

5.4 Functionalities

The approach used in the DSS is to minimize the effects of interdependences and detect the vulnerable elements. The main developed functionalities are presented in the following.

- Evolution of the parameter: The user can follow the evolution of one or more parameters during the simulation time (vulnerability, robustness, resilience etc.).
- Feared event or scenario: One of the aims of vulnerability analysis is to determine the consequences of feared events and scenarios. The DSS is able to provide the decision maker with some information about one parameter of a selected component in the case of different possible scenarios.

- Effect of interdependence: Interdependence when activated could change the behaviour of the system. The user can select a parameter of a component and see the effect of one or more interdependences on it.

But the following functions are still under implementation: Estimation of the Time to break down of a single component, the minimum value on one parameter (reliability, Mean Time To Repair…), Determination of the worst feared event occurrence point.

6 Conclusion

The objective of this paper was to present a vulnerability model-based Decision Support System. Every component of the architecture has been described. The obtained DSS allows an estimation of infrastructure network vulnerability taking interdependences into account. The main contributions are in the following:

- Characterisation of a natural disaster decision context;
- Identification of DSS features in this context;
- Description of the DSS functionalities;
- Proposition of a DSS for natural disaster management.

Thus it is possible to deduce among others vulnerable areas, critical components and the most threatened stakes.

Our model takes into account interdependences only between systems of the same type. So we did not investigate the interdependences between feared events and infrastructure networks. But in our simulation, we implemented a model (out of the scope of this paper) to assess the impact of feared events on infrastructures. In the future our perspective is to deploy this application on the internet and on mobile devices (smartphone, tablet).

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Spatio-Temporal Decision Support System for Natural Crisis Management with TweetComP1

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Abstract. This paper discusses the design of a social media crisis mapping platform for decision making in natural disasters where tweets are analysed to achieve situational awareness during earthquake and tsunami events. A qualitative end user evaluation is undertaken on our first prototype system to get feedback from practitioners working in the field of hazard detection and early warning. Participating in our evaluation is the Kandilli Observatory and Earthquake Research Institute (KOERI) and the Portuguese Institute for the Sea and Atmosphere (IPMA). We conclude that social media crisis mapping is seen as a valuable data source by control room engineers, with update rates of 10–60 s and false positive rates of 10–20 % (general public incident reports) needed. Filtering crisis maps and statistical reports by social media platform and user type is desirable as different report sources have different credibility and response times.

Keywords: Decision support · Web 2.0 · Twitter · Social media · Crisis mapping · Geoparsing · Multilinguality · Early event detection

1 Introduction

In recent years vast amounts of Web 2.0 content has become available, such as Twitter messages, YouTube videos, blogs and RSS feeds. Such ‘unconventional’ social media sensors allow rapid in situ crowd-sourced measurement by people actually experiencing a crisis event (e.g. via mobile devices). Social media can provide incident reports on tsunami wave arrival and inundation at coastal areas. This provides Tsunami simulation units and decision makers with observations on the wave’s propagation and impact. In highly populated areas such as the Mediterranean region there can be a huge

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number of potential coastal areas at risk [11], so receiving timely incident reports could be of great benefit to a Tsunami warning centre.

However, social media streams also bear risks: such data has variable quality and a high noise to signal ratio. Ultimately decision makers need a situation assessment picture they can trust, is updated in real-time and offers the possibility to manually check and verify incident reports on demand. It is particularly important to find the right balance between responsive alerting and avoidance of time-wasting false positives.

We have observed during our own monitoring of recent crisis events (e.g. New York hurricane Sandy 2012, Oklahoma tornado 2013, Philippines Tsunami 2012) keyword filtered Twitter Streaming API throughput of up to 20,000 tweets per hour [17]. Given the rapid adoption rate of social media around the world this throughput is only expected to get larger. On average about 1 % of the tweets we observed during crisis periods contained a geotag, making the processing of tweet content important if we want access all available location information. Social media crisis mapping is the provision of situation assessments from real-time social media feeds. Key research challenges include intelligently handling the large volume of social media reports available, keeping false positive rates low and accurately geo-parsing map information from microblog content. Further to this is the challenge of convincing Tsunami warning control room engineers of the value social media reports offer to a situation picture for inclusion and use in the control room itself.

Our approach of combining content-based geo-parsing of social media streams, at both the region and street-level, multi-lingual event classification and real-time crisis mapping is novel. Our end-user evaluation of an integrated tsunami early warning system prototype combining social media and traditional sensor-based data sources is also a valuable contribution to practitioners in this field. Our goal is to quantify the tsunami early warning control room end-user performance targets for acceptance of social media crisis mapping into the decision support workflow, and analyse how close this technology is to meeting these targets.

2 Decision Support for Tsunami Event Natural Crises

The heart of an Early Warning System is an Operation Centre, where the seismic and/or tsunami monitoring networks are connected via reliable and robust communication channels utilizing a Decision Support System based on event source parameters, such as magnitude, location and depth. This information constitutes the essential part of the early warning process, and any errors introduced at this stage may lead to false alarms, especially considering that it would also affect the assessment of the impacted areas. In fact, an Early Warning Centre should adopt all possible methodologies to minimize the false alarm rate, since any false alarm would undermine the credibility of the Early Warning Centre, and therefore would jeopardize the community's earthquake preparedness. On the other hand, a false alarm in the case of earthquake may only correspond to the ill-determined magnitude, since a seismic network consisting of tens or hundreds of stations could not lead to a false alarm for a non-existing event.

For a real event the combination of unconventional human sensors through the use of web 2.0 system would provide a verification mechanism beyond conventional methodologies. The mapping of social media activity presented to the operators could assist the information obtained from instrumental recordings.

In the case of an earthquake, near real-time shake maps providing ground motion and shaking intensity maps, are of crucial importance for Civil Protection and Disaster and Emergency Management Authorities to assess the criticality of the event in order to better assist post-event response and recovery actions. Social-media activities, displayed jointly with the shake maps, could provide a near-real time correlation of the two datasets of different nature, which could provide the extent of the damage associated to the events.

In the case of the tsunamis, parameters such as arrival times and tsunami wave-heights obtained from pre-calculated or near real-time tsunami simulations are the key elements. Nevertheless, in the case of tsunamis, the scale of the instrumental observations is much more lower than the earthquake case, especially in a region where DART-like offshore buoys are not operated. In such an environment, Early Warning Centre's main conventional support is tide-gauge measurements at the coastal locations, from which the Centre could initiate an "early-warning" only applicable for a further distant location. In such a situation, the human sensors could play a very important role in terms of identifying the affected areas, such as through the interactive visualization of Twitter streams. This assumption, however, may not be valid in the areas affected strongly by extreme catastrophic events, where the communications lines could be destroyed or the human sensors would be ineffective in localities of major destruction. On the other hand, such inactivity could also be considered as the evidence of major destruction if some activity could be monitored in the surrounding regions favourably located. Such information would be of "supplementary" status, and its primary use would be by the Civil Protection and Disaster and Emergency Management Authorities.

The TRIDEC project [5, 6] is building a prototype tsunami early warning system for the North-Eastern Atlantic and Mediterranean (NEAM) region. Our aim is to provide decision support for National Tsunami Warning Centre (NTWC) deployments integrating 'conventional' real time sensor data (e.g. seismometer networks, tide gauges, GPS stations, GPS buoys, ocean bottom units including pressure gauges) and social media human sensor data (e.g. crisis maps, news feeds). Additionally access to support information such as bathymetric and topographic data sets, pre-computed tsunami simulations and/or on-demand simulation computations is provided to help make predictions on Tsunami wave propagation and the estimated impact times at coastal regions. Operators on duty need to quickly assess the relevance and tsunamigenic properties of earthquake events and, if necessary, make use of information logistics and dissemination facilities to send customized, user-tailored warnings to responsible authorities and the general public under immediate risk.

A 'conventional' command and control user interface [2] is shown in Fig. 1. Our crisis maps, alongside publically available social media and traditional media reports such as news reports and mobile video footage, can provide additional rapid incident reports from people experiencing both earthquakes and Tsunami wave inundation. Our hypothesis is that the combination of situation assessment from 'conventional'

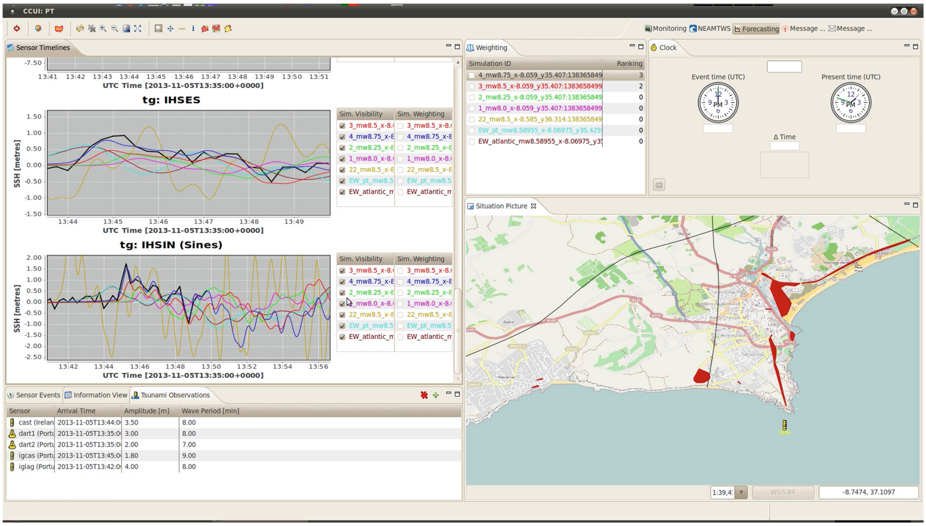

Fig. 1. TRIDEC command and control user interface (CCUI) with sensor-data (left) and social media crisis map (right) showing flooded areas (red lines and polygons) (Color figure online)

hardware-based sensor systems and 'unconventional' social media systems will improve the overall situation picture quality and timeliness within the control room.

Decision support is provided via the command and control user interface, for situation assessment and manual decision making, and a BPMN2 workflow engine for faster automated decision making. Control room personnel can define a decision matrix with rules to handle specific events in a simple Excel spreadsheet, which is imported and converted to Drools Expert rules for automated execution. Workflows and rules exist for the Tsunami relevance, assessment, verification and warning phases. We use rules triggered on earthquake alerts to start recording tweets and generating relevant crisis map display layers for the command and control user interface.

3 Related Work

In the last decade there has been growing interest in the exploitation of social media for crisis management. The most prominent framework for earthquake and tsunami detection, Toretter [7, 8], is based on a probabilistic state sequence model which aims to locate the centres of earthquakes by means of Kalman and particle filters. Their experiments confirm that Toretter often can send notifications for detected earthquakes quicker than traditional seismic-based sensors. The Tweet Earthquake Dispatch (TED) system managed by U.S. Geological Survey (USGS) [14] uses a short-term-average over long-term-average algorithm, which compares the frequencies of raw incoming tweets over a fixed time window against the background noise to detect seismic events. Furthermore [10] propose to filter tweets with respect to whether they might contribute to enhance situational awareness during an earthquake event using linguistic features. The systems are operated in earthquake endangered zones, i.e. Japan and the United States.

Humanitarian organizations and networks of volunteer's have setup live web-based manual crisis mapping sites [4] for recent natural disasters such as the Haiti 2010 earthquake, New York's 2012 hurricane Sandy and Oklahoma's 2013 tornado. These organizations manually filter crowd-sourced information from news reports, social media and civil protection agency alerts, and collate it into live web-based crisis maps for the general public to see. The challenge [4] for these organizations is to automate the real-time data fusion of large volumes of multi-source heterogeneous information for scalability, whilst still maintaining trust and credibility in this data.

In the context of decision support or early warning, a strong focus needs to be placed on usability and integration aspects [9]. Most central to this is the possibility to browse and visualize social media data in real-time. For instance, the Emergency Situation Awareness (ESA) system has been set up in collaboration with the Australian Crisis Coordination Centre to fulfil these aims. ESA can cope with different emergency cases, for which social media activity (Twitter, images, video) is displayed on a map and presented to the operators [13]. Twitcident [1] is a framework for filtering, searching and analysing information for different kinds of real-world incident and social media types. It is connected to an emergency broadcasting service for adaptive filtering of Twitter information and uses enhanced semantic analysis tools and faceted search facilities. SensePlace2 [3] is another framework which is able to extract deeper semantics from Social Media streams. Moreover, it uses elaborate visualization techniques to present an overview to the user [3]. In a user-study, the user-interface was designed such as to provide optimal support.

4 TweetComP1 Architecture: A Framework for Human Sensor Network Analysis and Crisis Mapping

The TRIDEC social media framework [16], see Fig. 2, is called TweetComP1. For scalable communication we use an event bus, deploying a message oriented middleware backbone. The TRIDEC database layer is a shared workspace for processing services. A decision support framework driven by expert-authored decision tables orchestrates the processing sub-systems. Various video demonstrations of the TRIDEC prototype in action can be found at [18].

Real-Time Acquisition of Social Media: An adaptive twitter crawler [12], which is capable of following trending keywords and adapting the filter keywords used in requests to the Twitter Streaming API. For basic crawling we have a list of earthquake and flood related keywords in multiple languages (e.g., deprem, terremoto). All tweet data and metadata is logged to a MySQL database.

Geoparsing and Geospatial Clustering: Offline processing involves the download and geocoding of map data for coastal regions at possible risk of Tsunami. Map information sources include OpenStreetMap, Google Places API and gazetteers such as Geonames and GEOnet Names (GNS). The location names, addresses and OpenGIS geometry are loaded into a MySQL database and geocoded using the Goggle Geocoder API to extract address components such as short versions of street names. Map sources provide street and building level locations whilst gazetteers provide region level locations.

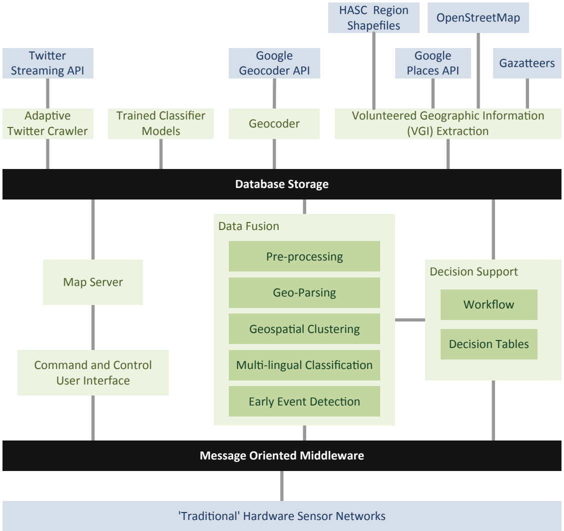

Fig. 2. Information viewpoint for the TweetComP1 architecture

For online processing Tweets are geo-parsed [17] and locations matched to the offline database of coastal geographic information. Tweets are first tokenized into n-gram tokens and then named entity matching performed. A baseline historical dataset, during which no crisis occurred, is used to statistically calculate threshold levels for map reporting; this helps reduce false positives for locations with common names such as ‘Hollywood’ that are tweeted often. Hierarchical clustering is used to overlay polygons onto groups of nearby streets. Figure 3 shows an example of a crisis map display showing tweeted street level flood reports.

Fig. 3. Street level crisis map of flood inundation for a Tsunami scenario in Portugal

Multilingual Classification: It is often difficult to separate real valuable information from background noise in social media data. To handle the increasing load of noisy and off-topic information, enhanced filtering techniques are needed. Our approach is based on supervised learning [15] and works for a variety of languages. A configurable threshold level is used to filter out tweets below an acceptable relevance score.

Figures 4 and 5 shows our tweet analytics interface during an Earthquake in Turkey. In live-mode, the display is continuously refreshed. In historic mode, predefined scenarios for specific events can be selected and replayed in normal or acceleration mode. The twitter activity can be shown for any user-selected time range or can be configured for a certain geographic region.

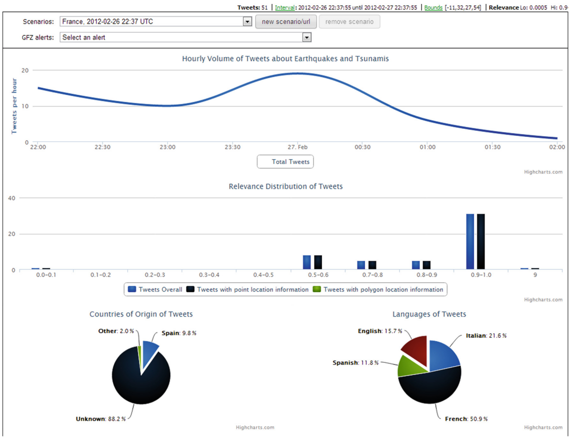

Fig. 4. Visual analytics interface including timeline statistics for a Tsunami scenario in Turkey

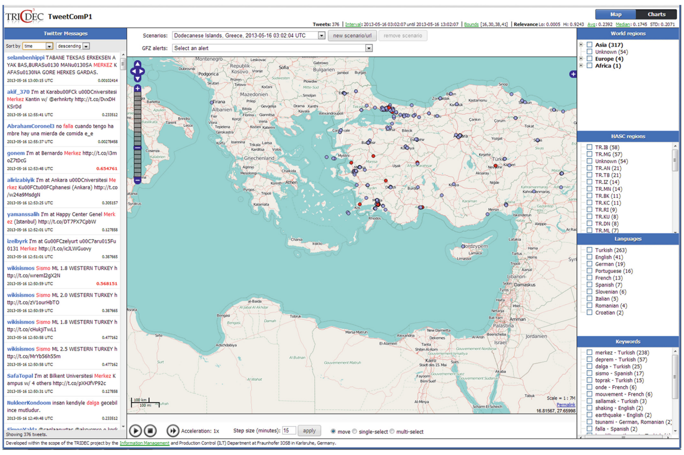

Fig. 5. Region level crisis map of earthquake reports for a Tsunami scenario in Turkey

Additionally, a visual presentation of three graphs is displayed: a timeline graph with the hourly volume of tweets, a bar graph that clusters tweets by their relevancy score, and a pie graph that shows the share of languages and geographic destination of the tweets.

Early Event Detection: With the increasing number of Twitter users all over the world it becomes possible to automatically detect novel earthquake/tsunami events from a twitter stream in a timely manner. We aggregate tweets for a certain spatial region and time-span, e.g. an interval of one minute. Geo-location information is extracted from metadata (i.e. geotag) and the unstructured twitter text (i.e. region names) and mapped to Hierarchical Administrative Subdivision Code (HASC) regions.

Emergency Alerting: Warning alerts are triggered according to specified thresholds, for example if the relevant tweets per time period in a region is exceed. The alert message format is based on the Common Alerting Protocol (CAP) standard of the Organization for the Advancement of Structured Information Standards (OASIS).

Crisis Map Visualization: We can use either the MapServer or Geoserver mapping applications, driven from OpenGIS geometry data in a MySQL database. At the region level we plot tweet geotag point data, HASC regions and centroid points for mentions of local region names such as cities or suburbs. At the street level we plot roads and building outlines for any above threshold report frequencies within a rolling 3–6 h sample window updated every 30 s. The design of the interactive visualization of Twitter streams is inspired by SensePlace2 [3], aiming to present an aggregated high-level overview of the situation to the operator on duty in real-time.

5 User Evaluation of the TweetComP1

Our evaluation methodology involves each organization’s operation room staff watching a demonstration of our prototype during a Tsunami simulation off the coast of Portugal. Feedback from end-users is elicited via semi-structured questionnaires and the data used to define performance targets for end-user acceptance of social media crisis mapping in the decision support workflow. We then compare these performance targets with published [15, 17] benchmark results for our prototype.

We asked Tsunami control room engineers from the Kandilli Observatory and Earthquake Research Institute (KOERI) and the Portuguese Institute for the Sea and Atmosphere (IPMA) to participate in our study. The semi-structured questionnaires asked users to specify acceptable update and false positive rates for crisis maps, rank incident types/social media user types in order of importance, provide preferences for crisis mapping display artefacts and rank possible information in order of importance for the decision support process in the control room.

5.1 Acceptance Criteria

Our experts considered Twitter a credible information source overall, scoring it 4/5. The most trusted types of Twitter users were government units/municipality, news agencies and humanitarian/volunteer agencies. Lowest in the ranking were the general public. The most trusted information source was tweets from agencies such as U.S. Geological Survey (USGS) and European-Mediterranean Seismological Centre (EMSC).

The type of tweeted incident considered most useful for a crisis map were major earthquake shaking/damage, infrastructure damage reports and flood inundation reports. Opinions varied for the importance of individual cries for help and Tsunami wave sightings as these may not be indicative of specific Tsunami damage. Minor earthquake shaking reports were least useful.

The minimum crisis map update delay was 10 s during a crisis, and 60 s for normal activity. A false positive rate of 10–20 % was specified for tweet users with a low credibility (i.e. general public) and a 'minimum possible' false positive rate for tweets originating from more trusted sources.

5.2 Performance of the TweetComP1 Prototype with Regards Acceptance Criteria

The current TweetComP1 system processes streams of tweets in real-time and provides map updates every 30 s on modest hardware (i.e. 2.5 GHz CPU, 8 GB RAM). A 10 s update rate is achievable but some optimization of the data processing is needed from twitter crawler to final crisis map.

Our false positive rate [15, 17] for large events such as major earthquakes and Tsunami is within the range 10–13 % for the major languages like English and Spanish. There is still room for improvement for other languages with more limited training material. We need to work on lowering the false negative rate for smaller events, such as minor earthquakes and floods, since the quality of any Twitter crisis map depends on having enough people tweeting about the event in the first place.

It should be noted that general public tweeters are the least trusted but they can produce incident reports sometimes within seconds of the event itself. Multiple tweeters can raise the credibility of an incident report. We need to look at ways to allow filtering of our map layers based on the user type and data source. For example viewing less trustworthy general public reports in the very early stage of a crisis and moving to more reliable reports from official organizations as the crisis develops.

6 Conclusion

We present in this paper the TRIDEC high-level architecture for crisis mapping of 'unconventional' social media sensors. We are able to process real-time Twitter microblog streams and extract region, street and building level location information relating to earthquake events, Tsunami wave arrival and inundation reports. We performed a qualitative evaluation of our TweetComP1 system using Tsunami control room engineers from two organisations, showing that social media crisis maps are credible as a data source for use within a control room. For control room use an update rate of 10–60 s and false positive rate of 10–20 % (general public incident reports) is needed. These targets are within the reach of our prototype system and we are looking now at future plans to move this work into the exploitation phase.

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Near Real-Time Decision Support for Disaster Management: Hurricane Sandy

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Abstract. Assessing vulnerability is fundamental for efficient risk management and emergency response. Integrating analyses from preparedness and risk reduction to inform the response phase requires that structural information about demographics or industry is combined with specific local information that highlights hotspots or emerging risks in near real-time. Owing to its availability on social media or other platforms, this local information is today often collected and processed remotely with the aim to inform responders and the public via reports, maps and apps published online. This paper addresses and discusses the challenges of remote near-real time vulnerability assessments by using an indicator model, which enables the combination of heterogeneous types of information while keeping track of the associated uncertainty. This approach is illustrated by the near real-time assessments for Hurricane Sandy that hit the East Coast of the United States in 2012.

Keywords: Near-real time risk assessment · Natural hazard · Vulnerability · Decision support · Composite indicator · Disaster and crisis management · Information update · Hurricane sandy

1 Introduction

The analysis of vulnerability against natural disasters and man-made threats has attracted increasing attention. More frequent and severe natural hazards such as floods, earthquakes or storms increasingly threaten the safety and well being of the population and sustainable growth [1]. Malicious attacks and terrorist threat are a particular concern because they can be expected to be targeted at the most vulnerable or critical elements of a society, such as the critical infrastructures electricity supply, drinking water or communication. Additionally, some major trends have increased the stakes at risk: tendencies of urbanization and concentration, or migration to coastal regions have lead to a higher exposure in some hotspots. At the same time a globalisation, and the growing interconnectedness worldwide have lead to a higher risk of cascading effects. While in the past it has been possible to limit the impact of a hazard event to a specific region or economic sector, today the impact of any event will propagate through interlaced infrastructures and supply networks [2]. Therefore, societies have to implement adequate risk management and emergency management strategies to prepare for and respond to these challenges.

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1.1 Decision Support in Risk and Emergency Management

Risk management and analysis encompasses the study of the main components, which determine risk: the hazard and the vulnerability of the affected systems. While the hazard describes a prototypical event in terms of its nature magnitude, frequency (e.g., an earthquake in a given region and with a given magnitude and its likelihood of occurrence), the vulnerability characterises the susceptibility of a system to damages (e.g., regions, industries, communities). Since hazards and extreme events are of an increasingly unpredictable nature, adaption strategies need to focus not only on forecasting the most likely or plausible events, but increasingly aim at reducing vulnerability or improving resilience [1]. Therefore, research on vulnerability has evolved as a key area of risk management. In the context of disaster management, the term vulnerability usually refers to the "*conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility* […] *to the impact of hazards*" [3]. It is commonly accepted that vulnerability depends on the three components: the exposure to the hazard, the fragility of the affected system and its resilience [4].

Information is the most valuable resource to manage risks and crises. Along with the rise of modern information and communication technologies (ICTs) more and more heterogeneous data than ever before is available. Today, information is for the most part distributed and shared virtually, and accessible via electronic devices, which enables rapid exchange of large amounts of information among humans. The opportunities of these new forms of communications are yet to be fully exploited by emergency responders and public authorities. It is important to distinguish the use of information at the design phase of risk management from the strategic or operational decision-making during the response phase. In this paper, we will highlight the differences between both realms of decision-making.

1.2 The Use Case: Hurricane Sandy

In October 2012, *Hurricane Sandy* made its way from the Caribbean Sea into the Atlantic Ocean and finally entered the United States near Atlantic City (NJ). A coastline of more than 1,000 km length was hit with severe consequence for society and economy. As Sandy approached the US, the Centre of Disaster Management and Risk Reduction Technology (CEDIM) assessed the potential consequences. The results presented below were part of this work, and first impact assessments were available about one week after the incident.

The work described in this paper focuses on the problem of measuring socio-economic vulnerability in near real-time settings. Any vulnerability or risk assessment can only be meaningful in context: aspects need to be integrated such as the characteristics of the region (e.g., population density, infrastructure system, level of preparedness) as well as the local preferences and value systems. This can only be achieved if the response phase is embedded into a longer-term preparedness and risk management strategy. The first step towards such an efficient risk mitigation strategy consists in a vulnerability analysis of the (potentially) affected region that enables policy-makers and responding organizations to get an understanding of hotspots and risk drivers. During the response phase, information needs to be continuously updated and resources need to be allocated ad-hoc. As the situation is typically prone to important shifts in terms of data available, also the vulnerability assessments need to be continuously updated to inform emergency management strategy and operations if needed. Starting from a structural vulnerability assessment for risk management, I describe an approach to complement this assessment with data at runtime, and discuss the challenges of this approach both in practice and for research.

2 Measuring Vulnerability: From Disaster Risk Management to Near Real-Time Settings

Vulnerability is in itself an abstract concept, and there are as many definitions of "*vulnerability*" as areas of application. One of the most prominent concepts is linked to focusing on the structural aspects of a system, understanding vulnerability as the characteristics of a system or asset that make it susceptible to the damaging effects of a hazard [5, 6] Today, this idea of maintaining or preserving structures has led to interpretations of vulnerability and resilience to reduce risk in the broad context of sustainable development [2, 7].

These definitions neglect the dynamic nature of systems evolution *during* an emergency. Hence, in this paper I advocate understanding vulnerability as a concept related preparedness and risk management or emergency response, including changes in the needs of population and responders. Figure 1 highlights the dynamic and interlaced nature of vulnerability assessments for decision support. Whereas in the *preparedness* phase, there is sufficient time to collect and process data, in the response phase, vulnerability assessments will focus on *updates* that highlights the most drastic changes and deviations from the ex ante state or the scenarios that underlie current emergency management plans [8]. At the same time, evaluating information in terms of credibility, reliability and relevance in terms of concrete actions or plans becomes more important [9].

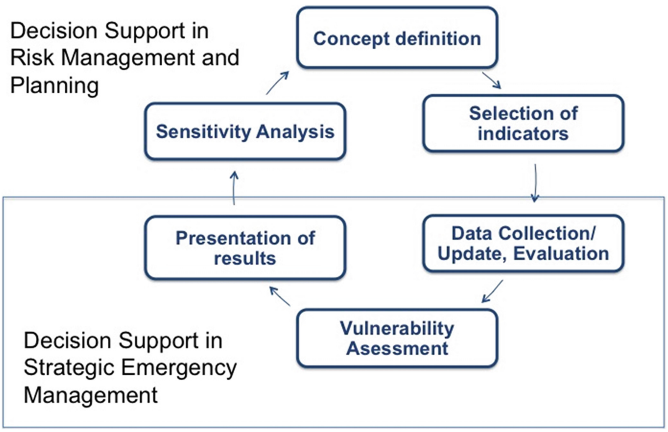

Fig. 1. Definition of a vulnerability indicator framework for risk and emergency management

Likewise, *decision-making processes* change: while in the preparation phase, there is time for consensus-building and participatory deliberation processes; the nature of emergencies implies that decision structures and powers shift. As Van de Walle and Turoff [10] stated, the unpredictable nature of a crisis implies that the exact actions and responsibilities of possibly geographically dispersed teams cannot be pre-determined. Therefore, information systems should support reassigning decision power to where the most critical operations take place, e.g., to prioritize actions dedicated to the most vulnerable sectors or regions.

To provide decision support and manage risks, there is a need for a comparable concept of vulnerability that provides clear indications for the allocation of scarce risk and emergency management resources. Typically, this is achieved via indicators, which describe qualitative and quantitative aspects of the system. Most frameworks are designed for disaster risk reduction, and therefore use static indicators derived from statistical data on a national or regional scale. Communities or societies are, however, complex systems and characterised by dynamic behaviour, non-linearity and emergence [12]. Along with the increasing pace of societal changes updating and adaptation of vulnerability assessments becomes increasingly important [13]. Moreover hazardous events themselves can be understood as shocks that drastically change a system's behaviour: natural disasters are typically characterised by their sudden onset and unexpectedness. In summary, there are three types of information that need to be combined to achieve assess vulnerability in the context of an approaching disaster:

- *Structural information:* relatively stable or only slowly evolving information, e.g., topography of a region, meteorology
- *Trends and developments:* information capturing meso-scale behaviour and predictable patterns, e.g., economic growth, infrastructure capacity or migration;
- *Characteristic local information* capturing the direct and indirect impact of triggering events and shocks

To perform a vulnerability assessment that also represents the shock and its (potential) consequences correctly, these levels of information need to be respected and combined. Beyond the temporal aspects, also the geographical scope should poses challenges. Structural and trend information will mostly come from official databases and be available on a national or state level. The characteristic information, however, will mostly be available from local sources, referring to specific places or events.

With the rise of ICT systems and Social Media, more and very heterogeneous information is available from local sources [14]. While there are several methods that exploit such data [15], there are hardly any approaches that combine local information with expert assessments providing information about trends and predictable changes or statistical data (structural information). To account for these characteristics, the vulnerability framework presented in this paper is developed to

- Provide (first) results although information is lacking and uncertain;
- Enable updates as better or additional information becomes available;
- Be scalable and adapt to various levels of decision-making (hierarchical levels, spatial & temporal scales).

3 Designing a Decision-Driven Vulnerability Framework

3.1 The Structural Dimension of Industrial Vulnerability

Vulnerability assessment is designed to provide a basis for decision-making in risk and crisis management and ideally reflects decision-makers information needs. The approach used here adapts problem-structuring techniques from decision analysis to create a hierarchical indicator model [10]. The problem structuring starts with framing the system (e.g., region, industrial sector), and determining its (most) important characteristics, e.g., critical infrastructures; service levels that must be maintained; economic goals. Second, appropriate indicators are chosen and organised into a coherent structure. The indicators selected should reflect both the appropriate granularity given the scope, and address the aims of decision makers.

Indicators can be elicited *before* an event occurs (preparedness), or run-time elicitation of the most important indicators for this very incident. The first approach has the advantage that it enables reflection and discussion. Vulnerability indicators can be used to get an understanding about the most important structural concerns and to establish a communication between all involved actors. This approach is most suitable for frequently re-occurring incidents, such as bushfires in Australia, or floods along a river. For extreme events that are outside the norms and expectations of the experts and decision-makers involved in the planning there is the risk that the indicator framework developed a priori does not reflect the emerging challenges.

Following the first approach, the CEDIM working group on socio-economic impact assessment set out to model *industrial vulnerability* in a series of workshops, which is a driver for both direct impact and longer-term recovery [16]. To structure the elicitation of higher-level criteria and measurable indicators, the dimensions *capital*, *labour*, *infrastructures* and *supply chain dependence* were used. Table 1 provides an overview of how dimensions are broken down into vulnerability criteria. This model that was developed in a two-day workshop with experts with different backgrounds such as geophysics, meteorology, and economics, policy makers (state level) and practitioners from industries in Germany and France. Note that Table 1 provides *structural* information, e.g., information about the population density.

Table 1. Vulnerability framework – a hierarchical indicator model

Vulnerability Dimension	Weight	Vulnerability Criterion	Weight
Capital Dependency	0.1	**Special asset intensity (SI)**	0.5
		Capital productivity	0.5
Labor Dependency	0.2	Labor productivity	0.5
		Degree of specialization	0.5
Infrastructure Dependency	0.5	Electricity dependency	0.3
		Water dependency	0.1
		Transportation dependency	0.3
		IT dependency	0.3
Supply Chain Dependency	0.2	Supplier dependency	0.7
		Demand dependency	0.3

For the *aggregation,* of vulnerability criteria, a used a linear approach was suggested in the workshop, for it is easy to understand and reduces the error due to wrong assumptions [17]. To avoid double counting, the weights were discounted by a factor that characterizes the interdependency of indicators or vulnerability dimension as described in [4]. The importance weights for the different criteria and dimensions are specified in Table 1.

3.2 From Structural to Local Information for Emergency Response

For the context of emergency response, the dimensions and criteria need to be made concrete and measurable with *local indicators* that reflect the context onsite. Particularly in the dynamic first phases of an emergency, these indicators need to be updated and complemented, as new information about population affected, outages and disruptions is available.

To assess the economic impact of Hurricane Sandy, the focus of work in the very early phases, before Sandy actually hit, was the identification of the most vulnerable industrial sectors against disruptions resulting from the storm, and particularly the failure of the critical infrastructures (CIs) electricity supply and transportation, which were considered most likely to fail [16, 18]. The rationale to determine sectorial vulnerability was that production down-times mainly occur due to the damage of production equipment, obstruction of workers, interruption of CIs or disturbance of supply chain processes. Using the results from the workshop (Table 1), each sector's specific vulnerability (including indirect effects) was determined with the help of indicators describing its degree of dependency on capital, labour, CIs and its connectedness in supply chains.

In these preparatory phases, data was curated from official statistics and databases, such as the US Department of Commerce.[1] For the infrastructure dependency, for instance, we worked with specific consumption rates and, for electricity, the percentage of self-provision per sector. For instance, to determine the special asset intensity, we determined the number of personnel employed (PE, full time and part time; data from 2010), the number of locations per industrial sector; the total value added (TVA) and the net cost for the private stock of assets (end of year estimate for 2010). As shown in Table 2, the value of Asset intensity (AI) varies considerably depending on how it is normalized. To ensure that the special asset intensity reflects the potential vulnerability in terms of damage to the economy, weights to average the dimensions (0.25; 0.25; 0.5) were determined by scientists and experts working remotely within CEDIM, and not by the actual decision-makers. The rationale behind was a focus on the potential impact on the spending capacity on the longer term.

Vulnerability functions v_{ij} were used, which model the relative contribution of fragility and resilience indicators x_j to the overall vulnerability of the specific sector S_i. Each of these indicators is classified according to the direction of its influence (resilience or fragility indicator). A vulnerability value of *1* indicates total vulnerability – the system

[1] http://www.esa.doc.gov/about-economic-indicators.

Table 2. Modeling special asset intensity

	PE *[1000]*	No loc. (2010)	TVA (2010) [*k US$]*	Asset (est. 2010) [*Bio. US$]*	AI by TVA	AI by loc.	AI by PE	SI
Wood products	**342**	**16868**	**21828**	35.8	1640	2122	1047	1464
Nonmetallic minerals	**368**	**17557**	**34303**	74.6	2175	4249	2027	2620
Primary metals	**362**	**4720**	**42372**	151.2	3568	32034	4177	10989
Fabricated metal	**1282**	**60895**	**117477**	145	1234	2381	1131	1469
Machinery	**994**	**26415**	**132883**	152.5	1148	5773	1534	2497
Computer and electronics	**1099**	**14602**	**251727**	290	1152	19860	2639	6572
Electrical equipment	**356**	**6286**	**42390**	50.1	1182	7970	1407	2992
Motor vehicles	**678**	**13071**	**53723**	142.7	2656	10917	2105	4446
Furniture	**359**	**21746**	**28593**	19.9	696	915	554	680
Misc. manufacturing	**570**	**32233**	**87783**	63	718	1955	1105	1221
Food and beverage	**1631**	**29435**	**205428**	263.9	1285	8966	1618	3372
Textile mills	**241**	**9666**	**14806**	38.5	2600	3983	1598	2445
Apparel and leather	**187**	**9818**	**10708**	16.3	1522	1660	872	1231
Paper	**394**	**4988**	**56012**	104.5	1866	20950	2652	7030
Printing	**491**	**33817**	**33268**	45.9	1380	1357	935	1152
Petroleum and coal products	**111**	**2283**	**169582**	168.1	991	73631	15144	26228
Chemical products	**788**	**13789**	**209669**	294.3	1404	21343	3735	7554
Plastics and rubber	**624**	**14347**	**63932**	81.4	1273	5674	1304	2389

will fail with respect to this indicator even if only minor disruptions occur, whereas vulnerability value of 0 signifies that the system can withstand any shock with respect to the respective indicator. For instance, a fully automated and autonomous system has a vulnerability value of *0* with respect to labour required. In contrast, when very specialized expertise is needed, and the production of goods requires that all experts are available, the vulnerability value for labour will be close to 1.

It was not possible to elicit weights and recommendations directly from experts involved in the response to Sandy, so we referred to the workshop results (linear scales), as our best approximation. The Aggregation can be generalised to exponential or logarithmic curves, or outranking approaches such as ELECTRE can be used [20], when more time is available. The normalization was designed such that extreme values represent maximum possible damage and vulnerability.

4 Results

4.1 Ad-hoc Vulnerability Assessment of Industrial Sectors for Hurricane Sandy

The sector specific vulnerability was calculated before the Hurricane made landfall on the basis of 17 indicators, which were on state-level based on data from 2011, mostly obtained from the US Bureau of Economic Analysis. Figure 2 (left) shows the industrial vulnerabilities of different industrial sectors in the US to power blackouts (grey) and transportation disruption (black). The maximum vulnerability is 0.92 for power (sector *primary metals*) and 1 for transportation dependency (*food and beverage*). The least vulnerable sector with respect to power is *paper* (0.39), whereas the lese vulnerable sectors with respect to transportation disruptions are *misc. manufacturing* and *apparel & leather* (0.06). The median and average vulnerabilities for power disruptions are 0.68 and 0.66 vs. 0.10 and 0.19 for transportation. This that transport dependency is more diverse than the dependency on power, and that there some sectors are much more affected than others. The higher average vulnerability to power dependency highlights the importance of electricity supply.

The right part of Fig. 2 shows the aggregated results on a spatial level: information about the importance of each sector per state (in terms of share of the state-level total value added by sector for 2010) was used to weigh the importance of the sectorial vulnerability per State. This was aggregated as suggested in [3] to determine the vulnerability of the respective States affected by Sandy. The index scales from 0 to 1, 0 and 1 being respectively the least and most vulnerable states against indirect effects of disasters on the industry. Figure 2 (right) shows that the most vulnerable states are Maine, Virginia and North Carolina. This information can be used at a policy level to allocate scarce emergency management resources and concentrate the efforts. It can also serve as a planning tool, for instance to determine location of hubs for logistics or healthcare in those states which are themselves less vulnerable to disruptions, but relatively close to the most vulnerable ones.

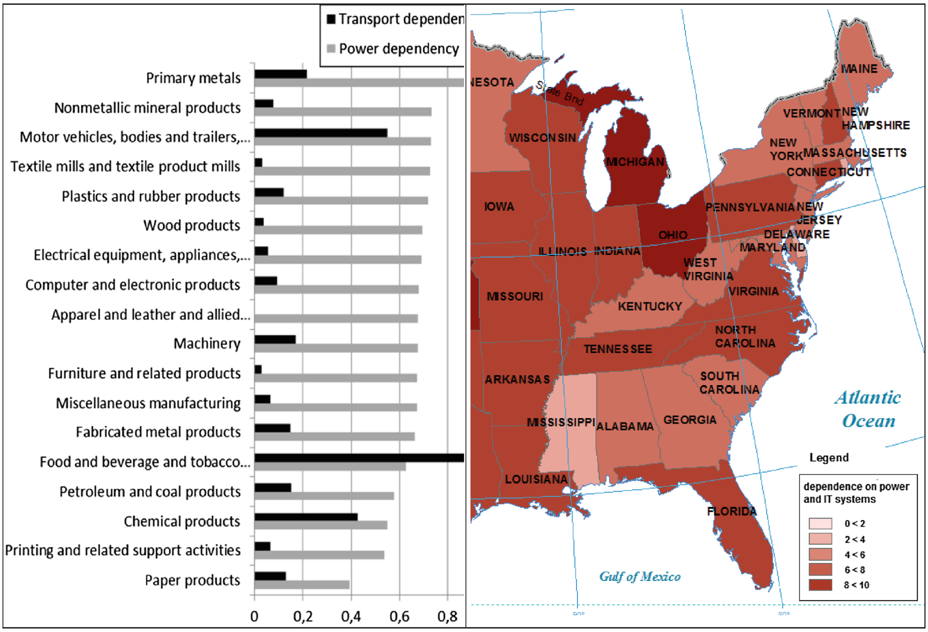

Fig. 2. Industrial vulnerability with respect to critical infrastructure failures. Left: vulnerability of industrial sectors against transportation and power disruptions. right: overall vulnerability of the states affected by hurricane sandy.

4.2 Near Real-Time Assessment of Recovery Functions and Economic Loss

In the later phases, during and up to 72 h after the storm, information from various sources was collected and the framework was adapted according to the available information. Particularly, the actual failure and disruptions of CIs and reports about the impact on economy and society, were collected, compared and evaluated, and the framework was adapted accordingly. Sources of information were well-known newspapers such as the New York Times, but also from blogs and Social Media sources. This information was weighted with a reliability factor characterising, in this case, only the medium via which it was obtained.

An accurate assessment or even the assessment of probability distributions was, however, impossible. To integrate these fundamental uncertainties, a set of scenarios was developed assuming specific paths of disruption and recovery. The consequence scenarios reflected these by specifying (i) the duration and development of disruption, (ii) the vulnerability of the respective industrial sector S_i, (iii) the importance of sector S_i for the economy. To take into account the interdependencies between critical infrastructures (e.g., power and ICT dependence) multipliers reflecting the degree of the interdependence and the importance of the infrastructures for the respective sectors were used. To quantify the extent of indirect *economic losses* I used input-output approaches [21]. These were combined with the scenarios that specified the interdependency level, the duration of the hazard event and the recovery time, as well as the vulnerability of the industry sectors. The estimated the potential impacts of Sandy on different business interruption scenarios of the US economy were split into two parts considering (i) the general disruption due to the event (across all sectors), (ii) the impact of power blackouts and transportation system.

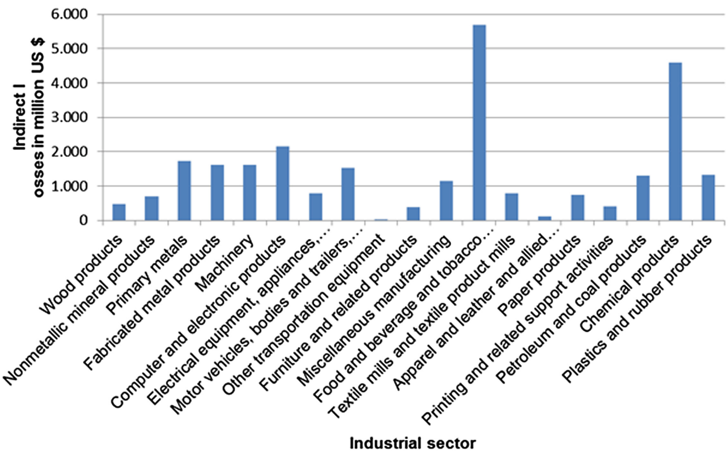

Fig. 3. Total indirect economic loss per sector

Assuming that the disruptions of the overall manufacturing sector would last for the two days of the storm in all 14 states affected by Sandy, the direct costs are approximately US $9.4 billion (initial loss assessment). However, the time needed for the industrial sectors to needed to be re-considered, as black outs occurred more frequently and longer than initially expected. Under this perspective, different scenarios of recovery were calculated, using different exponential recovery functions determined on the basis of the sectorial vulnerability (parameters varied between 1, 2, 4 and 6 over the scenarios) [14].

Depending on the recovery path, the indirect costs for the 10 days following the storm ranged from US$1.4 to US$5.6 billion. The total business interruption loss was therefore estimated to range from $10.8 to $15.5 billion. This loss needs to be added to the cost of damage and recovery, which took considerably longer than 10 days. In total, the insured losses due to Sandy were later on assessed to be $30 billion [15]. Figure 3 shows how this loss can, on the basis of the vulnerabilities and input-output tables be distributed to the industrial sectors. Here, the highest losses were expected in the food and beverage industry followed by chemical products. As chemical industry often deals with hazardous materials, this industry should get specific attention.

5 Conclusions and Outlook

In the aftermath of Sandy, the US suffered from high direct losses to residential buildings, power outages ranging between several days and two weeks, subsequent supply problems with gas, transportation problems, and business interruptions that propagated along interlaced supply chains. The question addressed in this paper is to what extent, on the basis of which data and information, and by which models can scientists analyse vulnerability in the preparation phase and in how far can this information be updated to inform decision-making during the response. This idea aims at leveraging information that has been collected prior to an event and enhancing it by information that is updated at run-time to achieve more effective and efficient response operations.

The potential use and scope of near-real time analyses has changed significantly with the rise of the Internet and social media. Modern ICT systems enable engaging in a communication with the public or specific stakeholder groups and actors, even remotely. Although large amounts of information are available today from the very onset of a disaster, there is a need to characterize the information and turn it into actionable information for emergency management authorities or decision-makers at company level.

Although remote analyses and reach-back support have become more and more important, particularly in the humanitarian space [23], the difficulties of interpreting and analysing information without direct connection to responders and decision-makers are multi-fold. Information is curated, shared and processed prior to receiving any information requests from decision-makers in the field. Particularly in the aftermath of Sandy, community response and the involvement of local NGOs has played an important role [24], making it even more difficult to assess decision-makers needs. In this context, I built on the results of a workshop on decision-makers' needs

(Gralla et al. 2013), and previous work focusing on critical infrastructure disruptions. Nevertheless, information needs, preferences and values are by their very nature subjective, and in so far remote decision-support relies on a common set of values and perceptions that is shared by a global community of responders. Today, local efforts are more and more supported by the work of volunteers that work remotely – organized in networks such as the Humanitarian Open Street Map Team or the Standby Task Force [25]. In this context, it is a new role for scientists and researchers to inform not only responders, but also steer and target the allocation of resources – remote and onsite – by providing remote near-real time assessments while reflecting the lack of information in the very early phases of a disaster or emergency.

The difficulty is not only retrieving information available, but also the lack of standardisation and comparability. Data is available on various levels, scales and formats, that need to be transformed into a standardised data set. Particularly local information sources do not meet standards of data collection in needs or damage assessments – yet they can provide vital information for some. The availability of such "messy" data is not yet reflected in standard processes – neither in science, nor in crisis response. Particularly, information reliability or lacking information needs to be addressed, and reflected in decision support tools.

Both vulnerability and impact assessment can be improved by establishing a closer link to policy makers or companies on-site, and by integrating information online. For the first option, cooperation needs to be established prior to any incident ensure that information about the actual situation and the current preferences and needs can be obtained. This can potentially be achieved via establishing early warning systems that monitor the most important trends with respect to the most vulnerable industries, or communities [26]. For the second, standardised information protocols, ontologies [27] and task descriptions that facilitate remote work need to be developed.

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A Web-Based Decision Support System for the Multiple Capacitated Facility Location Problem

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Abstract. The facility location problem is a widely studied classical operations research problem. To address this problem we implement an algorithm that calculates the exact solution for a given multiple capacitated facility location problem so long as that exists. Many issues of this problem belong to the NP-hard class of algorithms and as a result the computation time is disappointing for large networks. Therefore, we present a dynamic approximation algorithm for the solution of this problem that is capable to compute an approximation solution in an acceptable time interval. The aforementioned algorithms are integrated in a web-based Decision Support System (DSS). The DSS offers the possibility to create either a random or a custom graph and to evaluate both algorithms by performing alternative scenarios for the future development of the market. Finally, the DSS can export the results of the evaluation to a Microsoft Word document for further use.

Keywords: Decision Support Systems · Capacitated facility location problem · Location allocation problem

1 Introduction

The facility location problem is a well-known operations research problem and has practical applications in many different fields [1–6]. In facility location-allocation models, enterprises are concerned with finding the best location to install their new facilities from a given set of potential sites; another set consists of existing and already established facilities with known locations [7–9]. The main aim of the new enterprises is to obtain the largest possible share and revenue from this specific market and at the same time to avoid any overlapping between the market segments that they will serve.

The problem has been studied extensively in the literature. It contains a wide range of proposed algorithms, variants and extensions [10–12]. Many approximation algorithms have been also proposed [13–18]. In this paper, we consider a particular type of the facility location problem, called the Multiple Capacitated Facility Location Problem (MCFLP) under time constraints. To outline

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the problem, a number of existing competitive enterprises, which produce certain products or services, operate in a specific market. The market requires a specific quantity of this product or a specific level of this service in a determined time period and the already existing enterprises cover the needs of the market to the greatest degree. A number of new cooperating enterprises attempt to enter the market and seek the best locations from a number of available candidate locations. The new enterprises seek to acquire the largest possible share of this market and avoid any overlapping between the market segments served. Hence, the locations of these entering enterprises must ensure their economically viability. Each new enterprise ideally should occupy an adequate share of the market, so that its production is higher than a determined sales threshold level [19]. In other words, the enterprises aim to ensure their economic viability in order to make such an investment. Existing enterprises also aim to be economically viable; if not, they will be taken off the map [20,21]. The market surface can be simulated by a network with existing facilities nodes, demand nodes and candidate nodes.

This paper is an extension of the work of Papathanasiou and Manos [22]. We present two algorithms for the solution of a given MCFLP: (i) an algorithm that finds the exact solution of the problem so long as this exists, and (ii) a dynamic approximation algorithm that can calculate an approximation solution in an acceptable time interval. These algorithms have been proposed by Papathanasiou and Manos [22]. The innovation of this paper is that we integrate these algorithms in a web-based DSS that can assist policy makers find the best locations for their enterprises.

Only few software packages exist for the solution of this problem exclusively. In the present paper, a web-based DSS for the MCFLP is presented. The proposed algorithms have been implemented using MATLAB and converted to Java classes, while the web interface of the DSS has been implemented using Java. The DSS offers the possibility to create either a random or a custom graph. The custom graph is inserted from a valid Microsoft Excel or text file. After the creation of the market's network, users can evaluate both algorithms by performing alternative scenarios for the future development of the market. Finally, the DSS can export the results of the evaluation, including tables and animated diagrams to a Microsoft Word document for further use.

The structure of the paper is as follows. Section 2 presents the background of our work. Section 3 includes the presentation of the two algorithms. In Sect. 4, a web-based DSS for the MCFLP is presented. Finally, the conclusions of this paper are outlined in Sect. 5.

2 Model Specification

The mathematical form of the problem described in Sect. 1 can be formulated as follows (for a more detailed description, see [22]):

$$max \sum_{i} \sum_{p} DP_{ip} X_i \tag{1}$$

or

$$max \sum_i \sum_p aDP_{ip}Q_{ip}X_i \tag{2}$$

subject to

$$DP_{ipmin} \le DP_{ip} \le DP_{ipmax} \tag{3}$$

$$\sum_i X_i = P \tag{4}$$

$$Y_{ij} - X_i \le 0 \tag{5}$$

$$X_i = 0,1 \tag{6}$$

$$Y_{ij} = 0,1 \tag{7}$$

$$UP_{ij} = 0,1 \tag{8}$$

$$UM_{mj} = 0,1 \tag{9}$$

$$\sum_p DP_{ip} = \sum_p \sum_i \sum_j H_{ij}^p Y_{ij} UP_{ij} \tag{10}$$

where:

$|P|$: the cardinality number of new enterprises

$$p_n \in P = \{p_1, p_2, ..., p_k\}, n = 1, 2, ..., k$$

$|M|$: the cardinality number of existing enterprises

$$m_f \in M = \{m_1, m_2, ..., m_h\}, f = 1, 2, ..., h$$

$|I|$: the cardinality number of candidate nodes of new enterprises

$$i_s \in I = \{i_1, i_2, ..., i_q\}, i = 1, 2, ..., q$$

$|J|$: the cardinality number of demand nodes

$$j_r \in J = \{j_1, j_2, ..., j_b\}, j = 1, 2, ..., b$$

T: the time within which the market demands a specific quantity of the product in question

DP_{ip}: the production capacity in time T of the new enterprise p established in node i

DP_{ipmax}: the maximum production capacity in time T of the new enterprise p established in node i

DP_{ipmin}: the minimum acceptable production capacity in time T of the new enterprise p established in node i

DM_m: the production capacity in time T of the existing enterprise m

DM_{mmax}: the maximum production capacity in time T of the existing enterprise m

DM_{mmin}: the minimum acceptable production capacity in time T of the existing enterprise m

H_j: demand in demand node j

HP_{ij}^p: the fraction of demand in node j, which is serviced by node i where the new enterprise p has been located

HM_{mj}: the fraction of demand in node j where the existing enterprise m has been located

S_{pi}: the range of new enterprise p in node i and in time T

S_m: the range of existing enterprise m in time T

Q_{ip}: the production cost of new enterprise p in node i.

Q_m: the production cost of existing enterprise m.

a: the profit percentage.

$$X_i = \begin{cases} 1, \text{ if the new enterprise is located at the candidate node } i, \\ 0, \text{ if not} \end{cases}$$

$$Y_{ij} = \begin{cases} 1, \text{ if the demand in node } j \text{ is serviced by a new enterprise in node } i, \\ 0, \text{ if not} \end{cases}$$

$$UP_{ij} = \begin{cases} 1, \text{ if node } j \text{ is within the range of } i \text{ in time } T, \\ 0, \text{ if not} \end{cases}$$

$$UM_{mj} = \begin{cases} 1, \text{ if node } j \text{ is within the range of } m \text{ in time } T, \\ 0, \text{ if not} \end{cases}$$

The total number of nodes of the network is $|I|+|J|+|M|$. Objective function (1) refers to the maximization of the product that was produced, in the event that the cooperating enterprises choose the aggressive tactic, while objective function (2) deals with the conservative approach of the maximization of profit.

3 Algorithms' Presentation

In this section, the two algorithms for the solution of a given MCFLP are presented: (i) an algorithm that finds the exact solution, and (ii) a dynamic approximation algorithm that can calculate an approximation solution. These algorithms have been proposed by Papathanasiou and Manos [22] (Tables 1 and 2).

4 Decision Support System Presentation

Figure 1 presents the decision making process that the decision-policy maker can perform using the DSS. Firstly, the decision maker formulates the problem

Table 1. Exact algorithm

Step 1. Locate the new enterprises p_n at random positions from the set of candidate nodes i_s.
Step 2. Share the demand of each demand node j_r to the new and existing enterprises, p_n and m_f, respectively, with the lowest sales value GP_{pij} and GP_{mj} as a criterion.
Step 3. Find the enterprises p_n and m_f that are ecomomically viable (an enterprise is economically viable if $DP_{ip} \geq DP_{ipmin}$ and $DM_m \geq DM_{mmin}$, respectively. If all enterprises are economically viable, then go to Step 7.
Step 4. If one or more new enterprises p_n are not economically viable, then the enterprise which has the greatest difference $DP_{ipmin} - DP_{ip}$ moves to another position from the set of the candidate nodes i_s. If it is not possible, then the enterprise which has the next greatest difference $DP_{ipmin} - DP_{ip}$ moves. Demand is re-shared and the algorithm goes to Step 2. If all possible combinations of new enterprises p_n in candidate nodes i_s have been tested, then the problem is rendered impossible and the algorithm stops.
Step 5. If one existing enterprise m_f is not economically viable, its demand is re-shared and is taken off the map. If there is still another existing enterprise that is not economically viable, then the Step 5 is repeated until all remaining existing enterprises are economically viable.
Step 6. If one or more new enterprises p_n are not economically viable, then algorithm goes to Step 4.
Step 7. Calculate the objective value and if it is better than the previous one, keep this value.
Step 8. The new enterprise p_n which has the greatest difference $DP_{ipmin} - DP_{ip}$ moves to another position. If it is not possible, then the enterprise which has the next greatest difference $DP_{ipmin} - DP_{ip}$ should be moved and the algorithm goes back to Step 2.
Step 9. Repeat Steps 2-8, until no further improvement of the objective function is possible or all possible combinations of new enterprises p_n in candidate nodes i_s have been tested.

under examination. Then, the data acquisition, validation and verification phase follows, so, the decision maker may upload the input data to the DSS and preview the market mapping and analysis, in the next step. Then, the algorithms' evaluation and execution step follows. The last step includes the presentation and the analysis of the results. Finally, the decision maker validates the results and if necessary provides feedback on the operation and the updated decision making process is performed again.

Table 2. Dynamic approximation algorithm

Step 1. Find the economically and time distances for each demand node j_r from each candidate node i_s.
Step 2. Each demand node j_r consumes from its nearest in terms of time node and only from that. If a demand node j_r is equidistant to two or more nodes, then demand node j_r consumes from its nearest economical node.
Step 3. Candidate nodes i_s are classified based on the number of demand nodes j which are assigned to them.
Step 4. For the candidate nodes i_s, the total demand which they serve is found. The new enterprise p_n which has the greatest possible production at node i_s with the highest total demand is located at that node. Then, the new enterprise p_n which has the next greatest possible production is located at one of the remaining nodes i_s with the highest total demand is located at that node and the process is repeated until all enterprises p_n have been assigned to a candidate node i_s.
Step 5. Find if the solution is acceptable; if it is, the algorithm terminates.
Step 6. If not, the new enterprise p_n which is economically viable and has the biggest difference between the total demand of demand nodes j_r that it serves and its minimum production at that candidate node i_s. Furthermore, the demand node j_r, which is the closest to the enterprises p_n that do not survive and which has the biggest respective difference, is withdrawn from the total of demand nodes which that unit p_n serves. If no unit p_n survives, then then the location cannot be found and the algorithm stops.
Step 7. Find if the solution is now acceptable. If it is, then the algorithm terminates, otherwise go back to Step 6.

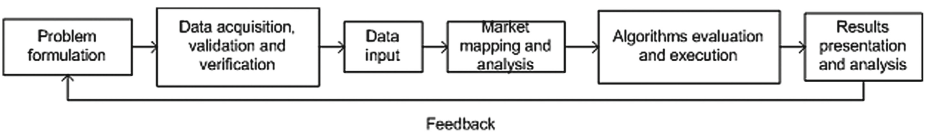

Fig. 1. Decision making process

Both algorithms have been implemented using MATLAB R2013a and have been converted to Java classes using the MATLAB Builder JA version 2.2.6. The web interface of the DSS has been designed using jsp and multiple users can access it through a web browser.

The screen for creating random graphs is shown in Fig. 2. The decision maker can fill out the form or press the 'Load Default Values' in order to create a random graph. Furthermore, the decision maker can press the 'Upload Data From

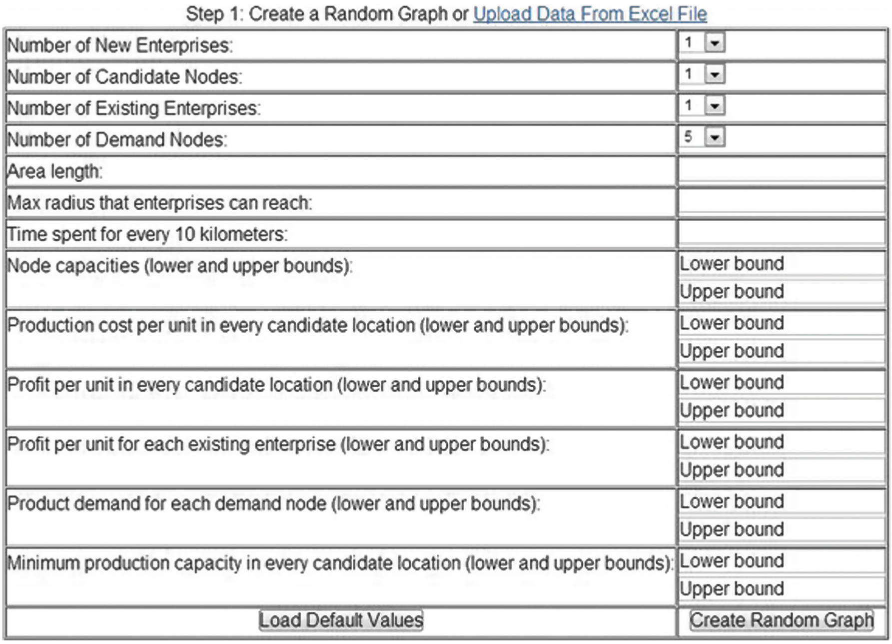

Fig. 2. Screen for creating random graphs

Excel File' option in order to upload an excel file with the appropriate data (Data input step in the decision making process). An excel template file is available to the policy makers in order to format their data. Then, a screen with the market representation is presented, as shown in Fig. 3 (Market mapping and analysis step in the decision making process). By pressing the 'Execute algorithms and collect the results' option (Algorithms evaluation and execution step in the decision making process), the report page with the results is presented, as shown in Figs. 4 and 5 (Results presentation and analysis step in the decision making process). For each algorithm the following information is available: (i) total product consumed by the demand nodes, (ii) the execution time needed to solve the given problem, (iii) the number of iterations performed by the algorithm, and (iv) a figure showing the allocation of the demand nodes to the existing and new enterprises. Figures 3, 4 and 5 present a case study with 10 demand nodes, 3 existing enterprises, 4 candidate nodes and 2 new enterprises. Both algorithms found the same solution where all new enterprises and one existing enterprise are economically viable; the other two existing enterprises do not survive and will be taken off the map. The dynamic approximation algorithm is 5 times faster and performs 4 times less iterations than the exact algorithm. In Figs. 4 and 5, the lines connecting the red points with the blue points represent the demand nodes that are served by existing enterprises. The lines connecting the yellow

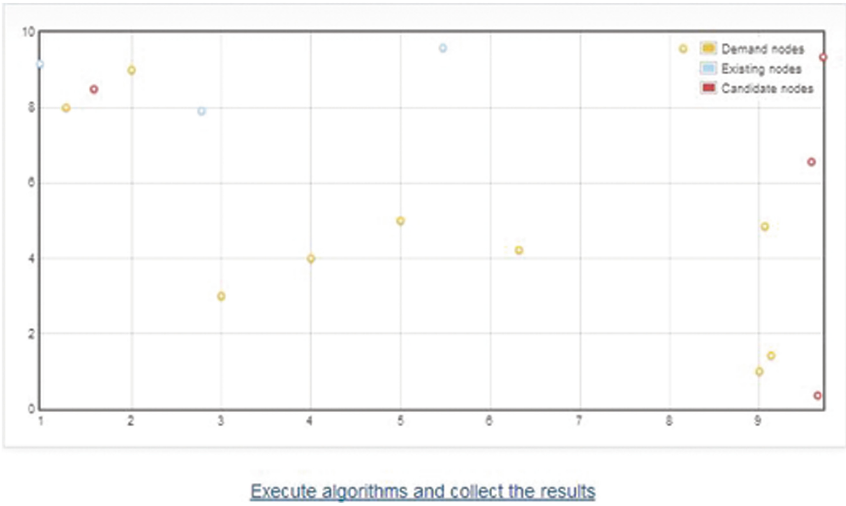

Fig. 3. Market representation

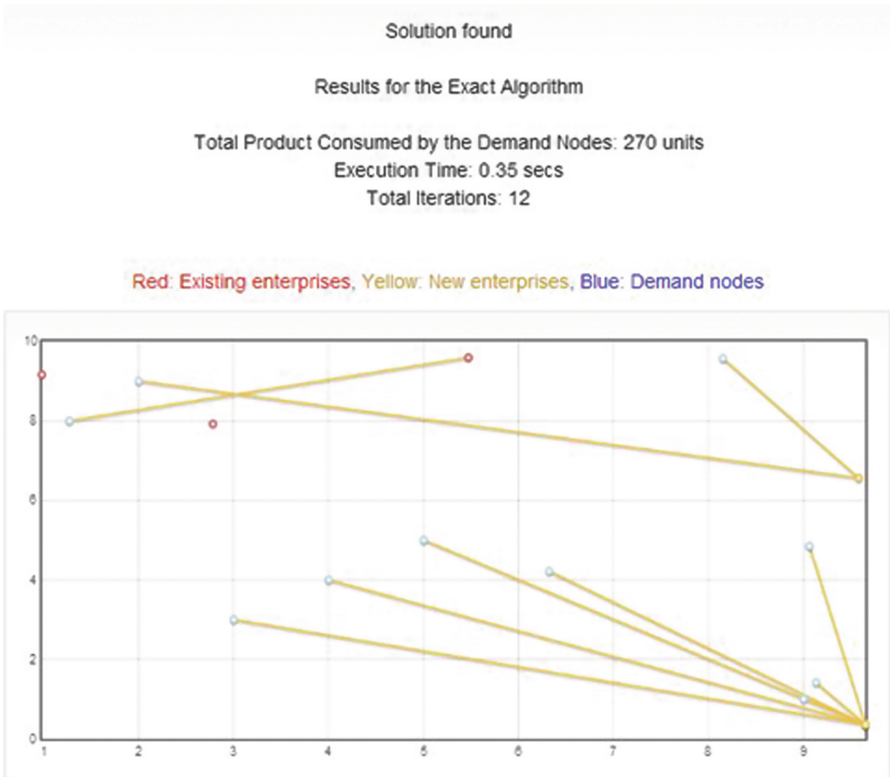

Fig. 4. Report of the Results for the algorithm that finds the exact solution (Color figure online)

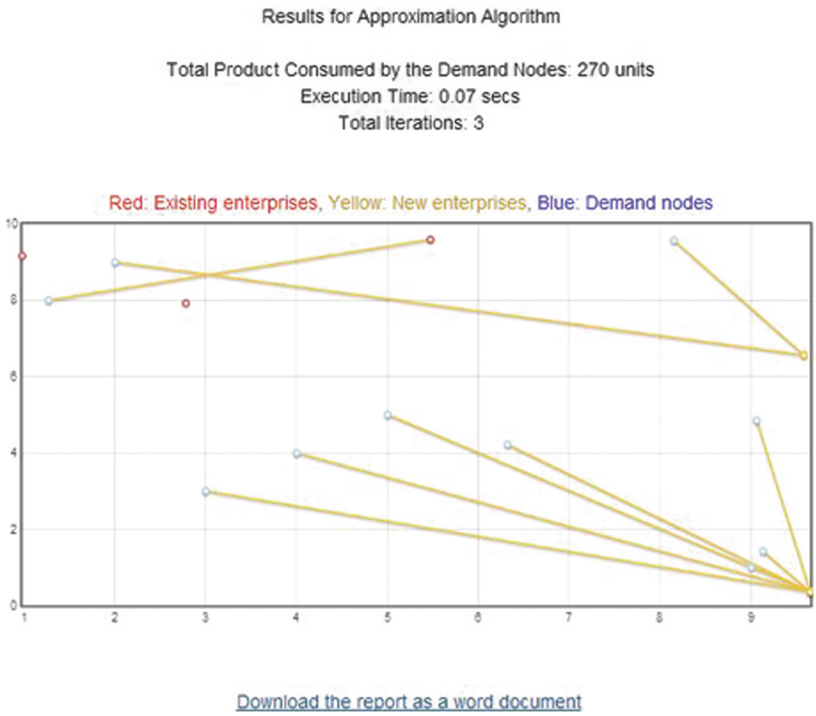

Fig. 5. Report of the Results for the dynamic approximation algorithm (Color figure online)

points with the blue points represent the demand nodes that are served by new enterprises.

A computational study was also conducted in order to highlight the speedup obtained from the dynamic approximation algorithm over the algorithm that calculates the exact solution. Table 3 presents the execution times of the two algorithms for 4 new enterprises, 7 existing enterprises, 7 candidate nodes and varying numbers of demand nodes.

The proposed web-based DSS has important managerial implications. First, decision makers can formulate their case studies and get a thorough analysis on if their enterprises should enter a market or not. The upload of the input data is a straight-forward procedure and the report of the results is user-friendly and comprehensive. Moreover, the decision makers obtain an overview of the accuracy and performance of the dynamic approximation algorithm.

Some limitations exist on the proposed DSS. First, some input data referring to the existing enterprises and the demand nodes may not be available to the decision makers. A second potential limitation of the proposed DSS is that it does not provide information about the improvements that the new enterprises should do in order to either obtain the largest possible share and revenue from a specific market or be economically viable, if they are already not.

Table 3. Execution times and speedup obtained from the dynamic approximation algorithm over the algorithm that calculates the exact solution for 4 new enterprises, 7 existing enterprises, 7 candidate nodes and varying numbers of demand nodes

Demand nodes	Algorithm that calculates the exact solution (sec)	Dynamic approximation algorithm (sec)	Speedup
10	0.81	0.22	3.68
20	2.10	0.45	4.67
30	4.22	0.88	4.80
40	7.48	1.52	4.92
50	12.34	2.57	4.80
60	20.03	4.12	4.86
70	28.55	6.04	4.73
80	37.89	8.20	4.62
90	46.80	10.48	4.47
100	57.12	12.75	4.48
Average	21.73	4.72	4.60

5 Conclusions

In this paper, we presented two algorithms for the solution of the MCFLP. The first algorithm finds the exact solution of the given problem, while the second is a dynamic approximation algorithm that calculates an approximation solution in a small time interval. Although, the facility location problem is a classic operations research problem and many algorithms have been proposed for its solution, only few software packages exist exclusively for the solution of this problem. This paper presented a web-based DSS that assists decision-policy makers in the evaluation of their enterprises' economic viability when entering a new market. All algorithms have been implemented using MATLAB, while the web interface of the DSS has been designed using jsp and users can access it through a web browser from their PC/laptop or their smart device.

In future work, we plan to enhance the DSS with other options that will give decision makers the opportunity to get some alternative scenarios to investigate in order to obtain the largest possible share and revenue from a specific market. Finally, we plan to present real application case studies for which the proposed DSS can be utilized.

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A Web-Based Decision Support Platform for Multidimensional Modeling of Complex Engineering Systems

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Abstract. Complex decision making is an important aspect in planning large man-made systems. These systems tend to be of high complexity, which requires an automated, intelligent approach to realize all dimensions of the problem. Decision Support Systems (DSS) are one approach to automate this process by providing modeling and analytical capabilities that assist users in making decisions. In this paper, we present the architecture of a web-based DSS platform for multidimensional modeling (including functional, spatial, and temporal dimensions) of complex engineering systems. We describe the breakdown of the modeling process of such systems in a multidimensional hierarchical manner. We present a case study for power planning in Saudi Arabia.

Keywords: Decision support systems · Complex engineering systems · Power planning · Software architecture · Agent based modeling

1 Introduction

Modern day activities are conducted across both international and global settings. The end of a business day in one part of the world signals the start in another. In an ever increasingly competitive world, it is easy to get caught up in short-term dealings while neglecting to take the bigger picture into account. In order to meet the growing demand, organizations are growing and becoming more and more part of this global setting. Long gone are the times when decision makers would meet together in one gathering in order to discuss various strategies. In fact, gathering key stakeholder under one roof is a big challenge today. In addition, planning for complex engineering systems requires access to multiple sources of data that are large in volume, diverse, potentially under different jurisdictions and domain knowledge. This highlights the importance of leveraging the emerging web-based technologies in order to enhance the collaborative effort, thus allowing key decision makers to come to clear and concise

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decisions and policies regarding pressing issues. Decision support systems (DSS) are interactive software-based applications used to enhance the user's ability in decision making by utilizing data, models, knowledge and communication technologies [1,2].

The importance of complex engineering systems is shown by their large impact on the social, environmental, and economic health of society and are critical for the quality of life [3]. Such complex systems evolve over time from a current state into uncertain future states as a consequence of different decisions and policies. During the planning phase, decision-makers are faced with the daunting task of choosing the 'right' decisions and evaluating their different impacts, gains, and repercussions in terms of sustainability. In a more relevant context, these decisions lend themselves to various applications such as, the electricity grid, water distribution networks and transportation systems. As global population continues to grow, so does demand on these man-made systems, resulting in increasingly complex and interlinked infrastructure networks. Understanding these complexities requires new approaches that allow for these multi-layered interconnected systems to be analyzed. Relying on heuristics and intuition in solving problems of such magnitude, in the long term, is far from optimal. The decision support web-based technology presented herein presents structured approach to such tasks.

In this paper, we present a decision support platform for multidimensional modeling of complex engineering systems. The platform supports a collaborative decision making environment. Additionally, we describe the breakdown of the modeling process of such systems in a multidimensional hierarchical manner. Finally, this paper presents a case study in which the decision support platform is utilized to investigate different conventional generation capacity expansion portfolio to complement the Kingdom of Saudi Arabia's renewable and nuclear energy plans.

2 Background

2.1 Decision Support Systems

Decision Support Systems (DSSs) were initially used in the business and marketing fields. Later they emerged into multiple fields and became a well-established method to address complex problems such as health care [4,5], agriculture [6], transportation [7], energy [8], and water management [9]. Many classifications and taxonomies exist for DSSs in the literature. Some classifications are based on the number of users interacting with the system (single-user DSS, and group-based DSS), or the type of platform it runs on (web-based DSS, and thick-client DSS). One of the most well-known classifications of DSS is the one by Daniel Power [10]. He divides the DSS systems into five classifications: Communication-driven DSS that enhances decision-making between groups of people working on a shared task. Data-oriented DSS which focuses on providing access to, and manipulation of, internal or external company data in order to assist in the decision-making process. Document-driven DSS that are designed to manage, retrieve, and manipulate unstructured documents and transform them into useful business data. Knowledge-driven DSS are systems designed to give actions recommendations to users by offering them specialized problem-solving expertise. Model-driven DSS incorporates the ability to manipulate and access data to aid decision makers in evaluating a given situation by generating different kinds of models, such as simulation and optimization models, as well as, statistical and financial models. Most of existing DSSs are either domain-specific or platform-dependent. The proposed DSS platform provides a framework for planning different complex engineering systems. It is a model-driven DSS that is developed as web-based and supports group cooperative decision making.

2.2 Complex Engineering Systems

Complex Engineering Systems are multi-dimensionally complex. One dimension of such complexity is the functional complexity denoting the linkages and interdependencies between different infrastructure networks [11]. Another dimension of complexity within complex engineering systems is spatial complexity. For example, large scale infrastructure networks could be distributed and disaggregated over different spatial segments, such as regions, cities, or even neighborhoods. Finally, another dimension of complexity that needs to be considered is the temporal dimension, where each point in time for the system is determined by historical decisions and events. However, since time flow is unidirectional, most models simplify the problem by the Markov assumption; "the future is independent of the past given the present" [12]: $(S_{(t+1)} \perp S_{(0:(t-1))}|S_t)$. The modeling framework [13] utilized in the DSS platform takes a holistic approach to modeling complex engineering systems. It integrates several modeling techniques to accomplish the task at hand, including System Dynamics (SD) and Agent Based Modeling (ABM), which in recent years has been gaining traction, and has now sufficiently matured [14].

3 The Modeling Framework

Within the Multidimensional Hierarchically Integrated Framework (MHIF) [13], a system is represented by a series of States $(S_{t0}, S_{t1}, ..., S_{tn})$. Each state S_{tx} consists of four main components; Decision Variables (DVs), General Drivers (GDs), Model Variables (MVs) and Key Performance Indicators (KPIs). Inputs to the model are both the DVs and GDs, while KPIs are outputs, and MVs are internal model variables(see Fig. 1). DVs are within the control of the decision maker and define the plans that need to be evaluated; the 'what if scenario' to be tested e.g. production capacity. GDs are parameters that affect the state of the system, but are exogenous and out of the decision maker's control, e.g. population growth. MVs are internal model variables that are not observed by the user, but are calculated for certain equation needs of the model. A state at time t in the model is therefore defined as the values of DVs, GDs and MVs (the time span of the time steps is defined by the user). On the other hand

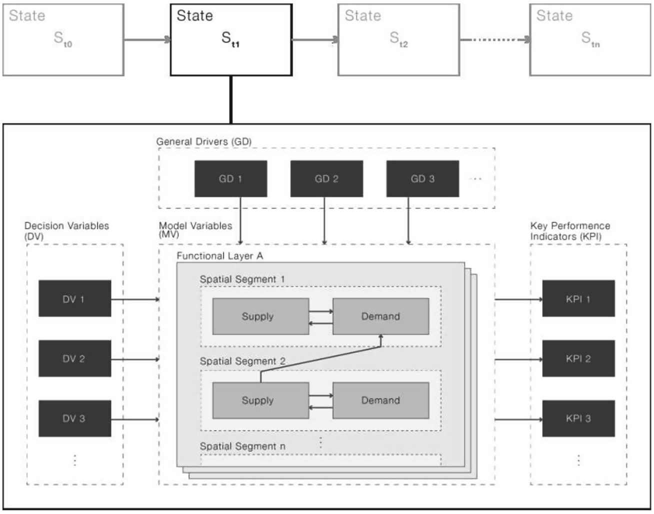

Fig. 1. An illustration of a system state in the conceptual MHIF model

KPIs are predefined indicators that are calculated within the model and are exposed to help evaluate the system at a particular state e.g. CO2 emission levels. The KPIs can include different metrics (economic, environmental, social, or technical), and these metrics could be correlated based on the variables that contributed to their calculations. This enables decision makers to evaluate and compare different simulation runs and choose the appropriate plan, or define new DVs. This is an iterative process, where different plans and scenarios are tested, evaluated, and compared leading to a more robust planning process.

In terms of the multi-dimensional complexity described previously, the functional complexity is handled by decomposing the different systems into different functional layers. In the spatial decomposition, the functional layers are distributed spatially into segments; such that some of the functional components in different spatial sectors could have different parameters (e.g. different spatial regions have different production capacities). The temporal complexity is captured in the different states of the system. At this stage, within a specific functional layer and spatial segment, the governance of resources and their flows need to be maintained. Figure 1 illustrates that sub components can cross feed allowing for the network to be represented and simulated while still keeping the hierarchical decomposition intact (i.e. supply from a specific spatial segment feeds demand from another segment). Figure 1 contains only spatial cross feeding (e.g. water being pumped from region A to region B), while functional cross feeding is possible as well (between functional layers, e.g. diesel fuel required to power irrigation pumps).

After hierarchically decomposing and identifying the scale and the building blocks of the model, the next step is to implement them as autonomous integrated agents in an Agent Based Model (ABM) environment. This enables us to separately model each component, and define the rules by which it will interact with other homogeneous or heterogeneous agents. The cognitive structure of the agents can be modeled in different ways. In our framework, System Dynamics (SD) models are chosen to represent the abstract high-level dynamics of the system component. The values of an agent's SD represent the agent's state, and they can depend on endogenous or exogenous agent variables which constitutes some of the links between interdependent agents. The benefit of ABM is the replication capability within different spatial or functional segments. In addition, it is possible to have different agents containing uncertain random variables to simulate uncertainty (e.g. population growth can be probabilistically distributed and have different random values within different agents).

4 The DSS Framework

4.1 Architectural Design Model

The DSS framework is designed in a Client/Server model with a Model/View/Controller (MVC) architecture. The View component is shifted into the user front-end to utilize the client computing power and remove the overhead of creating dynamic web pages from the server. This separation of concerns allow for server-side development to be more focused on data retrieval, models execution, and performance optimization with improved scalability, while front-end development deals with templates, style sheets, and visualization with improved portability. Figure 2 presents a high level architecture of the decision support platform. The client side consists of the user interface (the web portal) which captures the user's inputs and provides multiple visualization components for visualizing the simulation outputs. The server side consists of three main components: Models which represent the simulation models, Data Stores for storing the data that feeds into the models, and the Abstraction Layers which represent the core of the platform. All communication messages exchanged between these different components are of JavaScript Object Notation (JSON) format. This architecture allows for portability of the platform, such that it can be accessed from different devices (e.g., desktop, laptops, notepads, etc.,) and across multiple platforms. This is due to the use of web-friendly technologies as well as the lightweight, scalable protocols of the web.

4.2 The Abstraction Layers

The abstraction layers are the core component of the platform. They include: GUI Abstraction Layer (GAL), Data Abstraction Layer (DAL), Model Abstraction Layer (MAL), and Director [15]. The GAL is responsible for providing different visualization and communication methods to users to assist them in comparing different input policies and output KPIs. It interacts with the interface visualization elements (plots, charts, and Google maps for representing geospatial data elements) as well as communicates with real-time audio and video

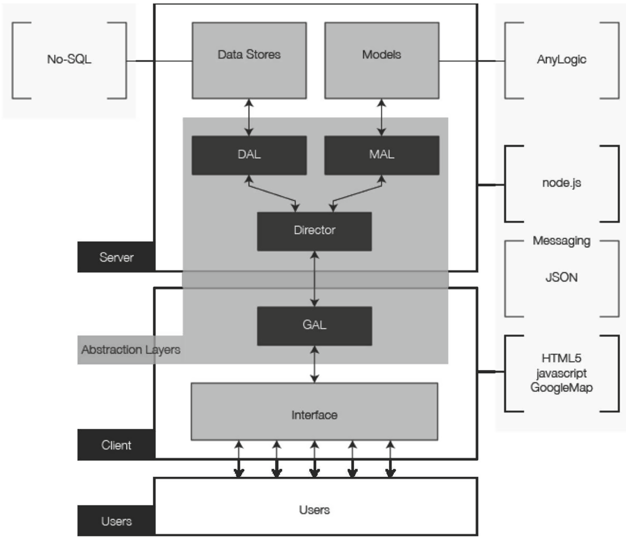

Fig. 2. DSS architecture and technologies

tools to support negotiation between decision makers. This layer handles the exchange of data inputs represented as different policies from the users, as well as the visualization of the output KPIs from the simulation models. When dealing with complex systems with many processes running in a distributed environment, data elements are generated with heterogeneous format. The DAL is responsible for transforming the data into a uniformed format. This layer handles the extraction of the data from its original sources, cleaning and transforming it into a common format (JSON format), and finally storing the cleaned version in the database. Decision Variables (DVs), General Drivers (GDs), Model Variables (MVs), and Key Performance Indicators (KPIs) all are data elements managed by the DAL. The MAL, on the other hand, manages the different simulation models designed following the MHIF framework. It is responsible for coordinating with the Director the gathering and pre-processing of the input data that feeds these models. Before the MAL executes a given MHIF model, it requests from the Director the model inputs to be retrieved from the database (GDs, MVs) as well as getting the user's input policies (DVs) from the front-end. After all inputs are processed, the MAL acts as a wrapper that executes the simulation models and sends the generated results (KPIs) back to the Director. The Director is the orchestrator of the communication between the back-end and the front-end components. Any request sent from the user browser is passed through to the Director for data and model states retrieval. The Director keeps track of each execution session (using session ids) and synchronizes data between users participating in a given session. When a new message is received, it is handed over to a new thread that processes the message. Thus, messages are processed in parallel as the Director is always listening for new messages.

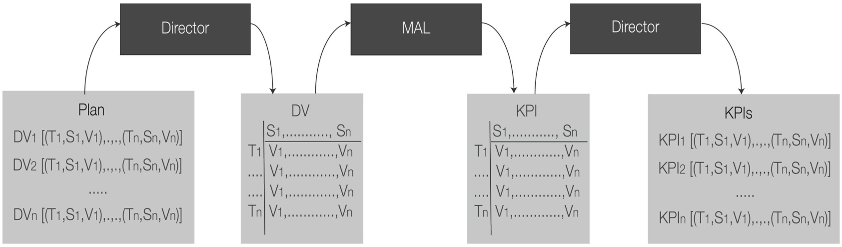

Fig. 3. Transmission of DVs and KPIs between layers

Each data point (V) entered into the system, has a temporal (T) and a spacial (S) stamp. The DSS transforms these input data into time series format to capture the time dimension. Similarly, the system keeps track of all generated KPIs from each state of the model execution. Thus, the DSS captures the time dimension by presenting decision makers with a view of the KPIs during each chosen time interval. Figure 3 presents the format of the DV/KPI while in transit between different abstraction layers.

The concept of having abstraction layers provides the DSS with a set of flexible features that are important especially when providing support to multiple decision makers for collective planning of complex systems. Having a central component (i.e., Director) that coordinates the communication between users provides the ability to feed the simulation models with input plans originated from different users. Being able to detect and then resolve any conflicts arising from having two users attempting to submit different values for the same DV is crucial. In such scenario the Director alerts the conflicting users and asks them to vote which decision maker will take precedence over this DV in this particular simulation run. Since the process of decision making is an iterative process, several simulation runs may follow until all users reach a policy that produces a satisfying set of outcomes (KPIs).

4.3 Distributed Platform

Since the platform runs completely on lightweight, scalable protocols of the web, each of the DSS components can be located anywhere in an organization network or even, for wider accessibility, anywhere in the Internet. You can consider the abstraction layers as web services. They communicate through JSON messages sent over HTTP protocol. Additionally, the platform can be integrated with any simulation model and any data store that have a web interface. Not only the platform supports connecting with distributed resources, but it also supports having multiple users (decision makers) experimenting with different decision variables (plans and policies) in a common session. In such case, the users are considered to be in a collaborative environment session, where the platform provides two methods of collaboration execution: parallel and sequential. Sequential execution scenario is when decision makers take turns to submit their chosen decision variables to the platform. Decision makers may negotiate a voting mechanism through real-time communications (audio, video) to determine the turns of input submissions. After each decision maker submits his/her DVs (plans), the Director executes the simulation and returns the results back to the participating users before the next decision maker's turn. Thus, each simulation run represent the plan (policy) of a single decision maker. In a parallel execution scenario, all decision makers submit their own DVs (plans) at once regardless of the others' inputs. The Director waits until all inputs from all participants are submitted (by sending a user-ready signal), performs a consolidation process of the submitted DVs to detect any conflicting values, and then starts the simulation. Thus, a single simulation run represent a collective set of input plans (DVs) from all decision makers.

5 Case Study: DSS for Power Planning

The DSS architecture described in this paper is developed and tested on the Integrated Energy Decision Support System (IEDSS) project which is developed as an integrated modeling framework to assist stakeholders make informed policy decisions related to the Energy sector in Saudi Arabia. In IEDSS, both the electricity supply and demand technology and policy options are investigated. Simulating scenarios comprised of these options help the Kingdom identify the best energy mixes, both conventional and renewable. The supply and demand options are studied across two dimensions i.e. time, and space.

Looking at the Power generation slice in Saudi Arabia, we find that it is broken into four operational areas: Eastern, Central, Western and Southern. The kingdom's generation fleet has always been, and still is, entirely fossil-fuel reliant; approximately 50 % is fueled by natural gas and 50 % by crude and its derivatives, including diesel and heavy fuel oil (HFO). The steam turbines (ST) in Saudi Arabia, located only in the eastern and western regions (due to need for large quantities of cooling water) operate predominantly on HFO. The gas turbines (GT) (simple cycle combustion turbines) and combined cycle (CC) power plants run primarily on natural gas, but also on crude and diesel.

The simulation results for this case study cover 30 years and represent an aggregated look at the possible energy mixes for the kingdom as a whole. The simulation begins in 2010, which is the reference case used to calibrate the model. For more realistic results, IEDSS leverages the King Abdullah City for Atomic and Renewable Energy (KACARE) 30 year plan for both renewable and atomic energy. The results from the simulation allow energy planners to further examine a wide range of complimentary (load-specific) conventional capacity portfolios that work hand-in-hand with the existing renewable and alternative efforts to achieve the overall desired energy mix.

5.1 Simulation Inputs and Output

The IEDSS platform is situated on the server side of the DSS. User inputs, such as renewable deployment schedules for example, are passed along to the client

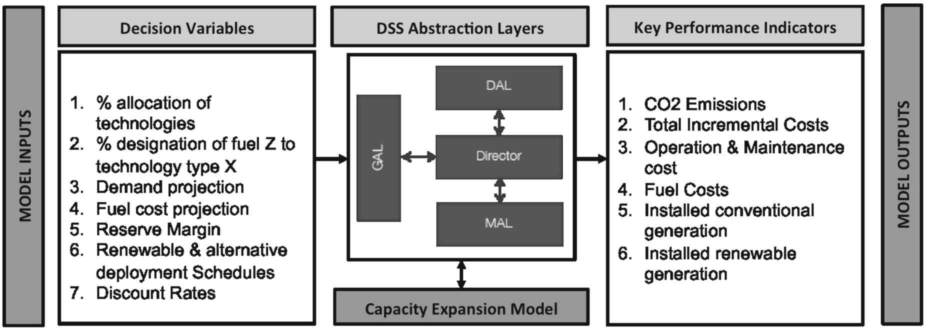

Fig. 4. IEDSS model architecture

through the user interface. The abstraction layers communicate such DVs from the client to the server where the model is situated. Internal model parameters such as the planning reserve margin, capital and operational costs exist in Data Stores on the server. When all the required DVs are entered by the user, calculated KPIs are then passed back to the user along the same path. Figure 4 illustrates the IEDSS platform as part of the overarching DSS platform.

5.2 Results

The following figures give an overview of the preliminary IEDSS results and how they can be used to facilitate stakeholders in selecting robust technology options based on selected performance attributes. In order to enhance the decision support experience, the KPIs for various policies are aggregated in order to perform trade off studies that narrow down the solution space of technology options which can be further scrutinized.

Figure 5 shows a trade off of the Total Incremental Cost (TIC) vs total CO2 emissions. TIC is a measure that accounts for capital recovery, operation and maintenance and fuel costs. Capital recovery is the annual equivalent of the capital cost of a generation unit and is a function of both the interest rate and the useful life of the capital [16,17]. The figure shows the simulation outputs of 900 scenarios color coded by different fuel price schedules. **R** represents the current assumed cost of $2 per barrel of oil, **D** represents scenarios where the cost is increased to $4 per barrel of oil and **I** is a liner increase from $2 to $18 per barrel of oil over the entire study period. The technology mixes are defined as follows: CBA- high Combined Cycle deployment, CBD- Combined Cycle with Gas Turbine mix, CID- heavy Gas Turbine deployment, R- current technology mix, SIA- Steam Turbine with Combined Cycle deployment.

The horizontal spread of the data points shows the effect of fuel price on the scenarios. At a glance, the solution space can drastically be reduced by focusing on the dominant strategies that minimize cost in terms of CO2 emissions [16]. Upon closer inspection of Fig. 6, we find that the scenarios are grouped into

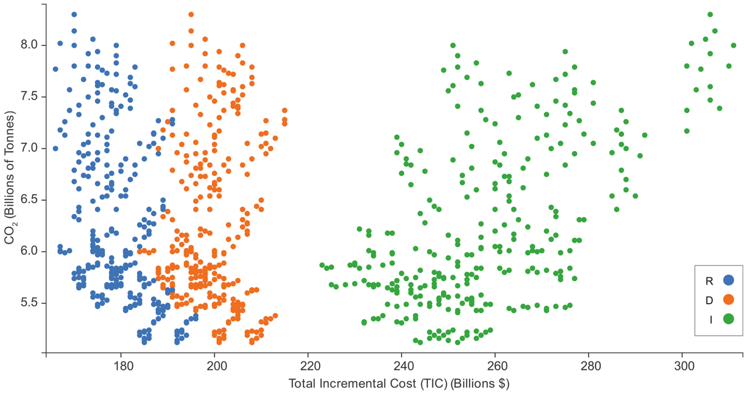

Fig. 5. Total Incremental Cost vs. CO2 (fuel price comparison)

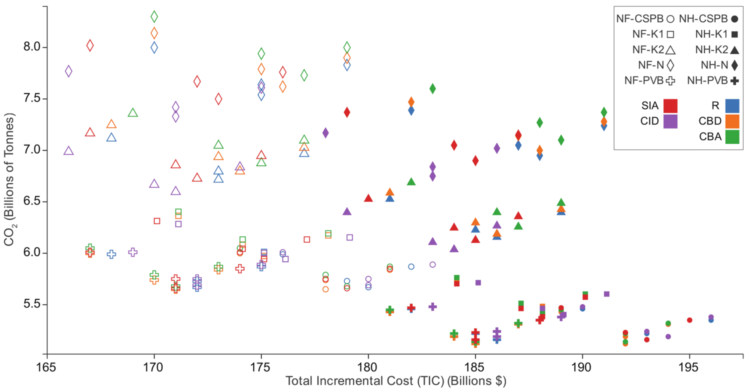

Fig. 6. Total Incremental Cost vs. CO2 (technology option comparison)

two clusters. The hollow points on the graph represent the scenarios without nuclear deployments while the filled points show the scenarios with high nuclear deployment schedules. When looking at the lower cost solutions (i.e. no nuclear deployments), the strategies that employed heavy photovoltaic deployment with heavy combined cycle (with natural gas as a primary fuel) schedules dominate the solution space [16].

Figure 7 shows the overall performance of the dominant scenarios in terms of CO2 emissions over the total study period. The scenarios in the legend are defined as: DM- medium demand, NF- no nuclear, CSPB- Concentrated Solar Power (CSP) deployment, K1, K2- KACARE plans, R- current mix, PVB- Photovoltaic biased deployments. In the figure we can see that the policies which combined PV power with Combined Cycle/Gas Turbines with natural gas yielded the most desired results, when looking at metrics such as CO2 emission and Total Incremental Cost (TIC). The results from this analysis show that,

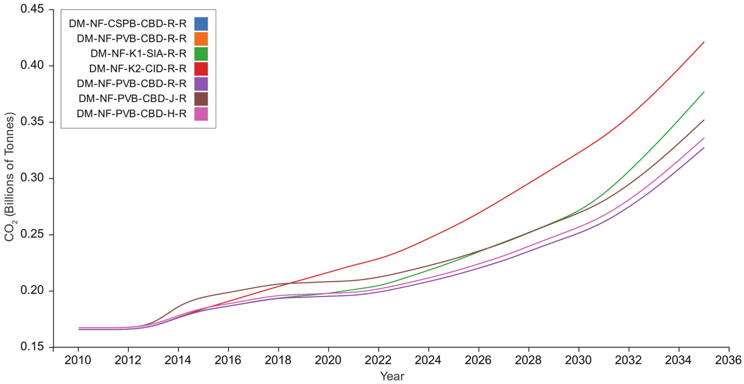

Fig. 7. Total CO2 emissions

depending on certain KPIs, some scenarios outperform others. As was shown, the scenarios that included heavy combined cycle deployments with PV solar technology achieved close CO2 emission reduction as the scenarios that included nuclear deployments, however, at a lower cost.

6 Conclusion

In this paper we proposed a web-based decision support platform for multidimensional modeling of complex engineering systems. The DSS framework is designed on open-standards and built from a collection of new open-source platform-independent technologies and protocols. This architecture allows for interoperable, scalable, and accessible system from multiple platforms. Additionally, we presented a multidimensional hierarchically integrated modeling framework which is utilized to tackle the functional, spatial, and temporal complexities that are inherent in complex engineering systems. Using both frameworks we present the Integrated Energy Decision Support System (IEDSS) as a case study aimed to help decision makers better plan for the power system in Saudi Arabia. The IEDSS software was used in multiple usability tests with different stakeholders in Saudi Arabia and it showed great potential. Future work will focus on multiple enhancements regarding the collaborative aspect of the framework as well as providing real-time results to stakeholders during simulation execution.

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Purchase Decision Processes in the Internet Age

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Abstract. This work explores the online purchase decision-making behaviour of consumers. It investigates how purchase decision-making processes unfold and how they vary for different groups of individuals. Drawing from the decision analysis and consumer behaviour literatures, a typology of online consumers is introduced to define four distinctive groups based on two individual characteristics: decision making style and knowledge of product. Video recordings and interviews of 55 participants have been conducted in two online settings (retail banking and mobile networks) in order to capture the purchase decision-making process. The archetypal behaviour of each typology is identified. Our results show variations in the flow of the decision-making process and process outcome for different groups.

Keywords: B2C E-commerce · Online purchase decision-making processes · Online shopping · Decision making style · Consumer prior knowledge

1 Introduction

It is now widely accepted that online purchase behaviour is different from traditional behaviour. There are still significant gaps however, in our understanding of consumer decision-making processes on the Internet [1]. A number of studies propose models of online purchase decision making. They mainly seek to improve the existing models of traditional purchase by introducing factors that influence the online purchase. The purchase process stages, however, are merely based on the traditional problem-solving view, following the sequence of research, evaluation and purchase stages. Complexities of the online purchase decision have not been taken into account [2].

This research proposes a conceptual model of online purchase decision making, by synthesizing theory from three disciplines: consumer behaviour, decision analysis and information systems. This model is able to explain the complexities and dynamic nature of real-life decision-making processes by including the two additional decision analysis stages of formulation and appraisal [3] as well as the stages of the classical consumer decision-making process: problem recognition, information search, evaluation of alternatives, purchase decision and post-purchase behaviour [4–7]. In addition, the model depicts the complex iterations between the different stages (see Fig. 1).

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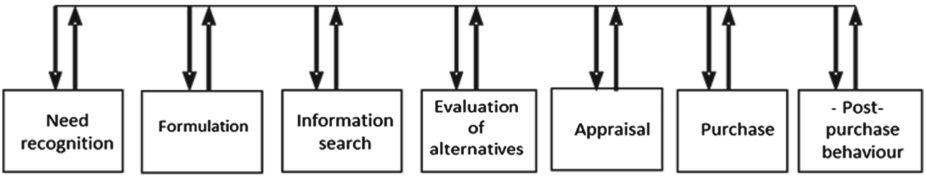

Fig. 1. Purchase decision-making process

Online purchase processes are shaped through the interactions of consumers with the Internet. Individual variations should also be taken into account. Therefore, consumers' individual characteristics are among the main factors that influence the purchase decision-making process [2, 8]. In the last few years, several studies have focused on individual characteristics and their impact on specific behaviour of consumers [9, 10]. Nevertheless, limited research (see for example Chowdhury, Ratneshwar and Mohanty [11]) has examined the differences of the purchase decision-making process for different consumers. It is not yet clear whether different archetypes of consumers exhibit distinct purchase decision-making behaviour during the process. However, two key constructs that affect decision making behaviour are evident from the literature: the prior knowledge of the product and the decision-making style of the consumer. These are used to develop a typology of four archetypes (i.e. four distinctive groups) that is shown in Table 1.

Individual decision-making style affects the purchase decision process [11] and results in diverse behaviour of consumers. Online consumers have access to a great amount of information and are constantly making decisions on how to interact with the online environment. Therefore, their decision-making style has a great impact on the purchase process as they direct the process by their interrelated decisions. Consumers with different decision-making styles are expected to behave differently, particularly in the online environment where there are more alternatives available [11]. For example, more options generate problems for maximizers because they often feel that they must examine all available alternatives in order to be satisfied with their decision.

Decision-making style was first introduced by Simon [12] as a pioneering distinction between individuals based on their decision making strategies of maximizing or satisfying. Schwartz et al. [13] then suggested that individuals habitually differ in their tendency to maximize or satisfy. Since then, studies of decision-making style have categorized decision makers based on their orientation to maximize the outcome of a

Table 1. Consumer archetypes

	Knowledge of product	
Decision-making style	Low	High
Satisficer	Satisficer with low knowledge of product	Satisficer with high knowledge of product
Maximizer	Maximizer with low knowledge of product	Maximizer with high knowledge of product

decision in a choice setting. Decision makers might seek the best possible result (maximizers) or opt for a good enough choice that meets some criterion (satisfiers). This in fact, can result in a more diverse behaviour of consumers. This research proposes that consumers' online purchase decision-making process is dependant on consumer's decision making style and illustrates how maximizers and satisficers behave differently when encountered with a product choice problem.

The impact of consumer knowledge on the decision-making process has also been demonstrated [14–16]. Online shopping is highly affected by the product and market knowledge as consumers are bound to search and evaluate the information on their own. Knowledge also affects the way a process unfolds. Consumers start the process from different stages according to their knowledge of the market and product [17]. If they are unfamiliar with a product, they will enter the 'concept-forming' stage where they learn about product attributes, develop the appropriate choice criteria and generate alternatives [17, 18]. Consumers with knowledge of product start with the collection of brand information and those with knowledge of product and market only require a set of situational attributes [18].

The differences are not limited to the purchase process, but they can also be observed in the post purchase stage. Satisfaction with the purchase decision-making process is particularly important in the Internet age where consumers are actively sharing information. Prior research shows that decision-making style influences satisfaction with the purchase process. Maximizers tend to be less satisfied with real world experiences and might regret their choice afterwards [13]. Knowledge of product also has an impact on satisfaction. As Xia and Sudharshan [19] point out consumers' prior knowledge affects satisfaction with the process. This research explores the impact of diverse decision-making processes for different typologies of consumers on satisfaction.

In addition to constructs of individual characteristics, other factors include frequency of purchase and level of risk influence consumer behaviour [17, 18]. There is a different level of risk associated with different product categories [18]. However, perceived risk is well studied in online research whereas the focus of this study is the impact of individual characteristics and archetypes of consumers on the purchase decision-making process.

2 Research Design

Answering the research objectives requires modelling of the purchase processes and measuring of their outcome. Therefore, video recording sessions, think-aloud methods, interviews and questionnaires have been used to capture the dynamic decision-making process, segment consumers and measure the outcome of the process at individual level. Video material can capture all the stages that consumers go through and identify those steps that might be repeated or skipped. Therefore, video recordings can be used to examine the stages of the purchase process and verify the proposed model.

Individual experiments involving fifty-five participants were conducted. Participants sat at a computer and were administered with a printed booklet containing two questionnaires and a task description. The first questionnaire aimed to classify participants into one of the four archetypes, containing questions on their decision-making style and knowledge. Afterwards, participants were introduced to the task description. Twenty-five participants were asked to choose a current account and thirty individuals were tasked with the selection of a mobile phone package. Their entire decision-making process was recorded by a video camera. It was then followed by individual interviews. Approximately 19 h and 7 min of video and 9 h and 57 min of interview data were collected. Combining video recordings with a think-aloud method generated very rich data and many instances of behaviour. This approach enabled the researchers to investigate the decision-making process in great depth, generate insights and identify general patterns based on very detailed analyses of individual behaviours. In this study, the analysis of 55 recordings led to the coding of a very large number of items (3083 activities and 1874 transitions). Similar research that has captured the purchase behaviour by videoing interactions with IT equipment involves smaller samples (see for example Benbunan-Fich [20]).

The output of the process, in terms of intention to purchase and satisfaction with the choice and process, was established by the second questionnaire and follow up interviews. Measures for satisfaction with the choice and process have been developed by Fitzsimons et al. [22]. Their study has clearly separated these two types of satisfaction while both contributing to the overall satisfaction. Adoption of the decision has been previously examined as the output of a process and its measure of success [23] was measured by a single item.

3 Analysis

All video sessions were coded and modeled by adopting a business process modelling approach combined with a path configuration method. Activity diagrams enabled detailed and systematic coding of the video data. An activity diagram (process model instance) was generated for each individual, illustrating all the activities performed and the flow of the process. An adaptation of path configuration was then applied to the activity diagrams to illustrate the differences in process flow patterns exhibited by different individuals.

According to Petrusel and Mican [21] “people prefer to work in chunks” and therefore a decision-making process can be divided into several sets of related activities that share a main objective. We refer to these sets of activities as phases of the decision-making process.

Activities in one phase have the same overall objective. For instance, a participant’s short-term aim is to find alternatives; to do so he/she will perform search and evaluation and as a result re-formulate the decision problem. The aim at a given point of time can only be understood through the analysis of participants’ own explanations. In our study, the think-aloud method was applied so as to identify phases. Each process model was analyzed along with the verbal protocol in order to define the critical points where the transition to other phases occurred. Interviews were used for confirmation. In this way the whole process was decomposed into phases [20]. Five phases of behaviour were identified: initial formulation, initial evaluation, main evaluation and formulation, refinement and choice.

Figures 2 and 3 illustrate the process instances of two subjects whose behaviours are representative of two of the archetypes: satisficers with high level of knowledge; and maximizers with low level of knowledge. These two archetypes have the most distinctive behavioural patterns. It can be seen that satisficers with a low level of knowledge perform a much less intensive decision-making process than maximizers with a high level of knowledge. A more detailed discussion of the four archetypes with a particular focus on the process flow and outcome is presented below.

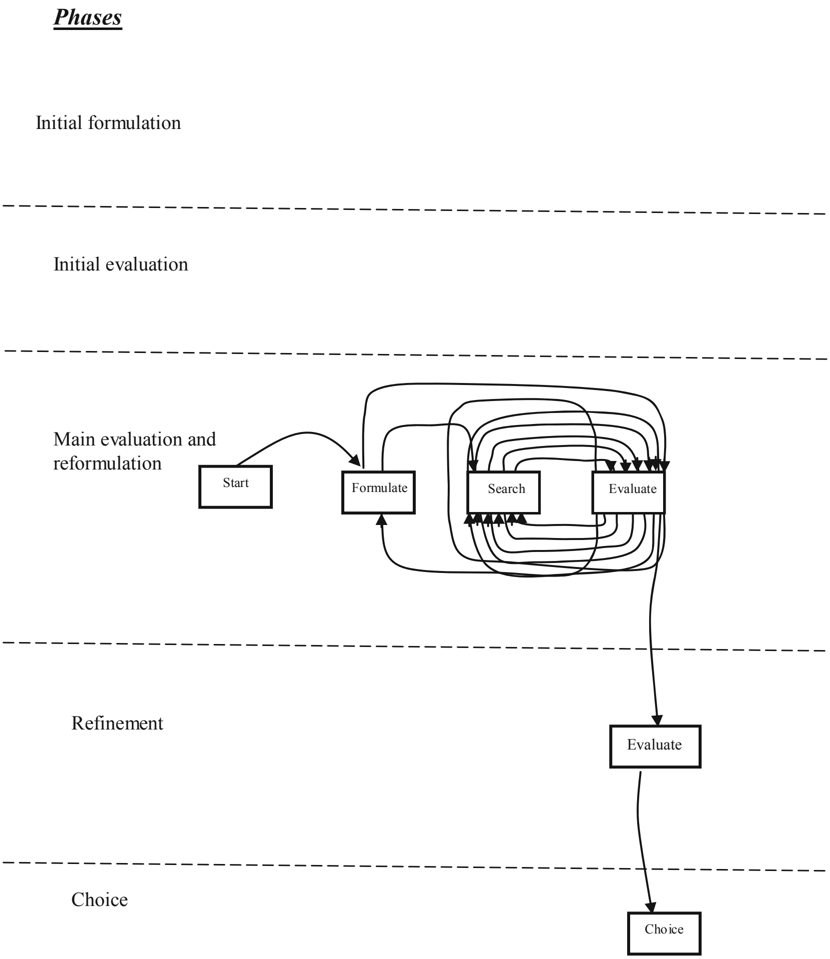

Fig. 2. A process model instance for a satisficer with high level of knowledge

The mapping of the process model instances indicated that those with a low level of knowledge for both decision making styles perform an initial formulation and an initial evaluation. Consumers with high level of knowledge start the process from the main evaluation and formulation stage (Fig. 4). The number of transitions between stages was higher for maximizers than satisficers and higher for the low knowledge group

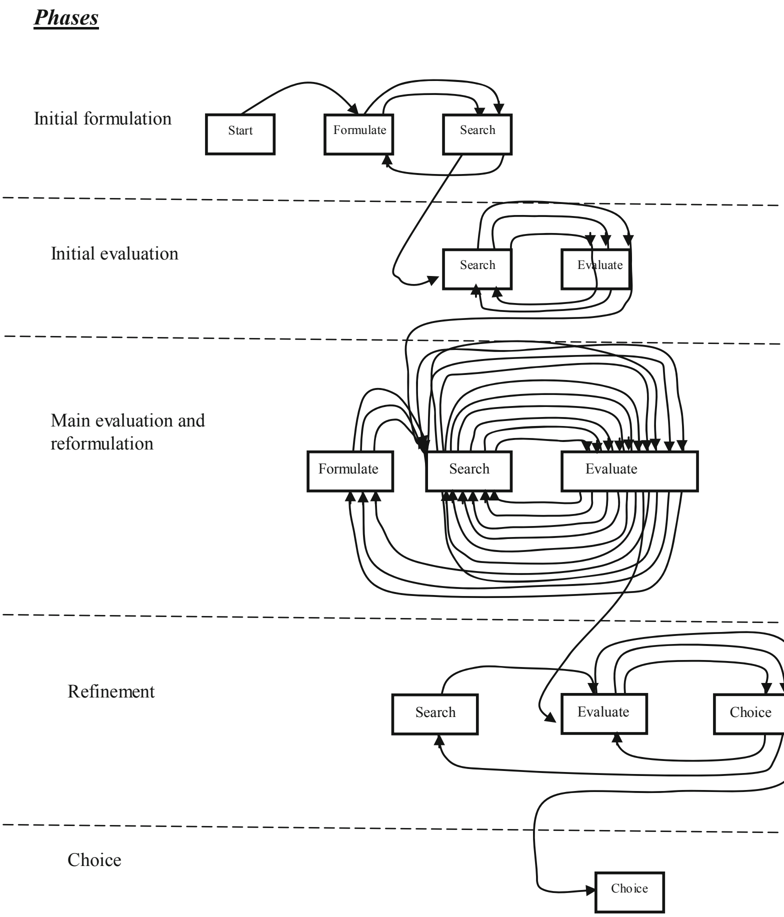

Fig. 3. A process model instance for a maximizer with low level of knowledge

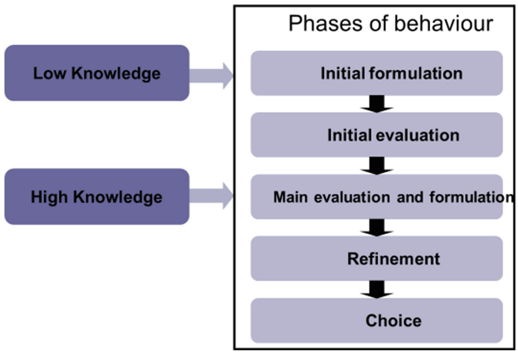

Fig. 4. Variations in the flow of the process

Table 2. Average number of transitions based on two individual characteristics

	Decision making style		Knowledge of product	
	Maximizers	Satisficers	Low	High
Number of transitions	38.4	29.2	37.5	30.9

compared to the high knowledge group. Table 2 shows the average number of transitions according to decision making style and knowledge of product.

The results for intention to adopt the decision are shown in Table 3. This shows clear differences between maximizers and satisficers, and between those with a low and high level of knowledge. Maximizers are more likely to adopt the decision than satisficers, and those with a high knowledge of the product are more likely to adopt the decision than those with a low level. The intention to adopt is an indicator of the level of confidence in the decision, and it is plausible that maximizers will be more confident than satisficers because they have conducted a more exhaustive search and evaluation. Similarly, those with a high level of knowledge are likely to be more confident about taking a decision than the low knowledge level group.

Table 3. Intention to adopt the decision based on two individual characteristics

	Decision making style		Knowledge of product	
	Maximizers	Satisficers	Low	High
Intention to adopt the decision	76 %	58 %	52 %	82 %

Satisfaction levels (with process and choice) were measured at the end of the sessions. Table 4 illustrates the results. After engaging in intensive decision-making processes, the vast majority of maximizers (93 %) appear to be satisfied with their choices but not necessarily with the process they followed. Similarly, 81 % of consumers with low levels of knowledge are satisfied with the choices they made but only 63 % of subjects in this category are satisfied with the process.

Table 4. Satisfaction with process and choice

	Decision making style		Knowledge of product	
	Maximizers	Satisficers	Low	High
Satisfaction with choice	93 %	73 %	81 %	86 %
Satisfaction with process	62 %	73 %	63 %	71 %

Preliminary analysis of the qualitative data collected indicates differences between the two sectors. In the mobile sector, satisfaction with choice and process is high. However, in the banking sector satisfaction with process is low, due to the complexity of the process. The nature of the banking products and websites do not support the consumer decision-making process. Network providers' websites, on the contrary, are relatively mature in assisting consumers and providing appropriate presentation of information.

Due to the nature of lab experiments, the decision-making process has been examined to the point where participants reached the choice stage. As we explain above, the output of the decision-making process was then measured in terms of intention to adopt the decision and satisfaction with the decision-making process and choice. However, post-purchase behaviour which includes satisfaction with the product and retention can only be examined after the purchase and consumption of the product/service and is beyond the scope of this paper.

4 Results

The results show that the synthesized model (see Fig. 1) has an enhanced descriptive power. The formulation stage is a crucial and intensive stage as shown from the flow of the process. It does not follow a linear structure. Including 'formulation' in the purchase decision-making model increases its explanatory power. Appraisal is another stage which is overlooked in the consumer research literature. The analysis found evidence of its occurrence by consumers, particularly among maximizers.

The process is found to be influenced by both individual characteristics (decision-making style and knowledge of product). The flow of the process is different for different consumer archetypes. Maximizers' decision-making process is more complex, including more transitions. The finding of the higher number of transitions for maximizers is in line with the results of Chowdhury et al. [11] in an online shopping context. In general, the same result is found for those with a low level of knowledge. Therefore, satisficers with a high level of knowledge and maximizers with a low level of knowledge exhibit different behaviour in terms of number of transitions. On the other hand, those with a low level of knowledge perform additional phases to develop an understanding of the decision problem (concept formation). Consumers with high level of knowledge skip the first two phases of initial formulation and initial evaluation.

Our results indicate that the outcome of the process (intention to purchase) varies for each archetype. The overall results for satisfaction are also different for the two decision making styles (maximizers/satisficers) and consumers with high/low levels of knowledge of product. Although this study highlighted the variations, further research into the relationship between individual characteristics, intention to adopt the decision and satisfaction is required.

5 Implications

Based on the results of this study the decision making style and level of knowledge can be used to define four archetypes of decision maker, and each archetype displays different characteristics in terms of how they formulate, evaluate and refine their decision-making processes. There are also significant differences in both the intention to adopt the decision and satisfaction with the outcome. It is therefore important for e-businesses to segment potential customers. Our model can be used to identify customers early in the process and this can be used to provide them with customized interactions. This can be achieved by understanding the way individuals follow the stages, reach a decision and the individual characteristics that influence the outcome of their decision-making process.

The results also emphasized that satisfaction with the choice and the process are different for each archetype. Web-based tools supporting consumers need to consider factors that improve the quality of the decision in addition to enhancing user experience. Consumers' evaluations of experiences differ according to decision making style. Satisficers value the straightforwardness of the process whilst maximizers require an information intensive process to suit their style and be satisfied with the outcome.

Finally, the research suggests that marketers need to focus on simplifying the phases of the process. In order to assist consumers to go through the phases, it is crucial to simplify the concept formation (initial formulation and initial evaluation). Based on the results, maximizers would benefit from the use of online decision aiding tools that display information in tabular form and help consumers directly compare products. Those with a low level of knowledge should be presented with basic information and the main criteria at the very beginning. It will help them understand the concept faster, reduce the number of cycles and simplify the process.

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Supporting Business Process Exception Management by Dynamically Building Processes Using the BEM Framework

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Abstract. Business process management systems aim at ensuring an efficient chaining of the tasks composing a business process. Their activity relies on process models representing sets of business scenarios. Unfortunately, these models cannot take all the possible states of the environment into account, especially when a process is executed in a dynamic environment. The BEM (Business Event Manager) framework has been designed and developed in order to support dynamic process redesign at run-time in situations where incompatibilities with the predefined model occur. The heart of the solution combines a business process engine, a Complex Event Processing engine and an abductive planner. This paper describes the support offered by the BEM framework and presents a generic description of the architecture together with its implementation.

Keywords: Business process management · Context awareness · Resources · Exception management · Process re-design

1 Introduction

Most commonly used Business Process Management Systems (BPMS) aim at ensuring an efficient chaining of the tasks composing a business process. These process-oriented BPMSs rely on process models mainly describing control-flows within the modelled processes. Regarding resources management and context awareness, the modelling languages mainly describe role-defined human resources allocation. Most of these languages involve artefacts to describe possible exceptions in the process execution, and the management procedure associated with each of them [1].

These models are very efficient for many business processes being executed in well-known and well-controlled environments, such as administrative workflows

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or in-house product-lines. Indeed, in this type of contexts, exceptions and their management are well documented and resources management can be considered as an orthogonal concern, out of the scope of the business process management system and in charge of other systems.

Other business areas face more dynamic context and/or have to deal with uncontrolled resources or have to share them with other actors in the environment. This is often the case, for example, in health-care and crisis management. Logistics also, in particular transport, faces other typical dynamic and uncontrolled contexts. In these domains, exceptions are less commonly involved in the model exhaustively. Many causes can lead to such a situation: unexpected resource failures, situations considered as too infrequent to be introduced in the model or resources concerns considered as too external to the business. In many cases, the set of the exceptions and their multiple possible locations in the process make their exhaustive explicitation non feasible. Moreover, the explicit operational description of each of their specific management processes would require an impressive amount of work, often neglected in the abstraction induced by the modelling process. Following the "keep the model simple" approach, their possible management is post-poned at run-time.

The notion of exception has already been largely discussed previously (see for instance [2]). With respect to the previous observations and in the context of this paper, we here consider "exceptions" to be situations that may occur at run-time but that are not covered by the operational running process model. Such situations may take place for good or bad reasons, the latter not being necessarily limited to inefficient modelling processes.

The BEM (Business Event Manager) framework aims at offering a support to address with a minimal work overload at design-time huge sets of exceptions in business processes. Its implementation involves, at design-time, the declaration of an activities library and, when an exception occurs at run-time, automatic building of a scenario to tackle it. The solution is a set of modules working in a business environment that involves a business process engine and a Business Activity Monitoring (BAM) system. The development of the exception management scenario is ensured by an abductive planner implemented using the event calculus. In addition to the limited overload in the design effort, it is worth to note that the calculation of the solution at run-time allows the inclusion in the reasoning of all the actual parameters of the situation including the precise state of the resources.

The paper is as follows. Section 2 presents related work and enhance the specific needs addressed by the BEM framework: supporting unexpected situations, in particular environment changes or resources default (unavailability, insufficient level,...), in business process management. Section 3 describes the main modules involved in the framework and their orchestration to generate a solution at run-time. Then, Sect. 4 details the key components supporting the computation of a scenario: the activities library which has to be defined at design-time and the abductive planner. Finally, the complete process is illustrated on an example in Sect. 5, before concluding the paper in Sect. 6.

2 Changes Management: Related Work and Challenges

There have been multiple publications about workflow exception management. It would be out of the space limit of this paper to draw a complete survey of the domain, the interested reader would usefully refer to [1] and its bibliography. Let us introduce here the key concepts to position our contribution. The literature about the adaptation of workflows usually distinguishes two domains: *expected exception* adaptation and *unexpected exception* adaptation.

Adaptation in reaction to an expected exception consists in the migration of a workflow to a predefined specification. In this adaptation, the alternative workflow is modelled manually at design time. Several pieces of work have been done in order to propose approaches that allow to manage and handle the expected exception adaptation [3–6]. Summarizing the domain in [1], the authors, involved in the *Workflow Patterns Initiative*, propose a typology of 135 exceptions patterns to support five exception types. They assess a set of modelling languages and workflow engines accordingly and propose a generic workflow exception language. This language, able to cover all the identified patterns, allows for the operational description of management processes associated with predefined exceptions.

Adaptation to unexpected exception aims to handle the execution of a workflow when an unforeseen event occurs at run-time. Usually, this kind of adaptation requires human intervention by using their knowledge and skills [7]. Unfortunately, these human interventions increase the cost of the management particularly in terms of time.

To overcome this limitation, several approaches have been proposed in order to automatically support the unexpected exception adaptation by avoiding human interactions as much as possible. For instance, ADEPT2 [8] proposes to conduct a semantic correction in order to evaluate whether events can prevent processes from completing successfully, using semantic constraints (e.g. over pre- and post-conditions of tasks).

Another example of the unexpected exception adaptation is SmartPM [9]. This approach is based on a declarative workflow modelling and the use of a planning technique. The declarative modelling focuses on the specification of the pre-conditions and effects of tasks. When an unexpected exception occurs, a planning process (based on the declarative modelling) is launched in order to help recovering the workflow execution from unexpected exceptions, without relying on domain experts' intervention.

The BEM framework aims at supporting unexpected situation, in particular environment changes or resources default, in business process management. As we will see, this will usually be achieved by process adaptation at instance level, but can also lead to a new process creation with the goal of restoring a system property at a global level.

The first specificity of the proposal is to address this huge set of exceptions without requiring a complete design-time specification of their management process but with a limited work overload at design time.

A second specificity of the BEM exception management consists in its dynamicity: the exception management process is built at run-time. This allows not only to cover a broad set of the exception strategies at instances level but also a management of exceptions at the system level.

Finally, note that usual control flow oriented BPMSs involve undeveloped consideration for resource management. A notable exception is the recent version 2.3 of Yawl [10] where resources are not anymore limited to roles and actors that are in charge of managing tasks, but also involves a new notion of secondary resources (human or not) that are required to the realisation of a task but to not manage it. At design-time, resources management can actually appear as secondary or out of the scope of the process design. However, at the age of the internet of things, even non-human resources can provide real-time information about their state, their location, their availability... This is another specificity of the proposal that, designed at run-time, the scenarios provided by the BEM system take resources into account on the basis of their actual availability and/or level.

3 The Framework Architecture

Figure 1 summarizes the structure of the framework and the interaction between the modules. The execution of the business process engine (BP Engine) is independent from the other components of the BEM-system. However, it offers the interfaces described in [11], hence providing capabilities to check the current state and parameters of on-going processes, to suspend, kill, restart them and to upload and launch new processes.

Two modules incorporate pieces of knowledge which have to be specified at design time: the Complex Event Processor (CEP) and the Knowledge Manager. We describe in the next paragraphs the knowledge contained in these modules

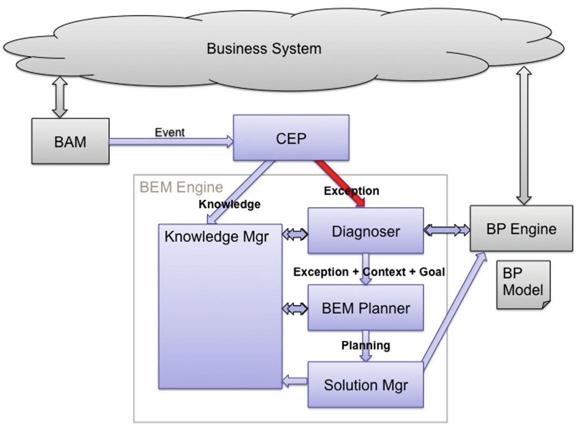

Fig. 1. BEM framework architecture

and summarize the methodology (detailed in [12]) that supports the knowledge acquisition process. Then, the rest of this section describes the process that elaborates a solution to manage an exception.

In association with a Business Activity Monitoring (BAM) module, in charge of observing the global system states and changes, the **Complex Event Processor** (CEP) has the responsibility of identifying states, events or combinations of events which lead the system in a state that will not allow the predefined behaviour of the business process instances, and requires a specific management. Multiple types of CEP have been proposed in the literature; a recent survey [13] examines 34 of them. Most of them could be used in the architecture, if considered as relevant at design time. In our developments, we use a CEP with the double capability of, on the one hand, detecting the violation of invariants declared on the system, and, on the other hand, catching the exceptions thrown by the running cases in the business process engine.

The **knowledge manager** module gives access to two types of information. The main information consists in a library of activities that can be used by the planner in order to built the exception management process. They are not combined in process, but each of them is presented in a declarative fashion relying on an enhanced activity model involving resources requirement and impact which has been described in [14]. It is discussed with more details in Subsect. 4.1.

Secondly, the knowledge manager involves knowledge about the state of the system, the resources and actors. This is either provided by CEP or collected on demand through interfaces of the system, whatever they are. In particular, this module is in charge to contact any resource that can for instance be associated with a RFID tag or an agent on the web and interrogates it on its properties (location, level, availability,...). This run-time access to the state of the resources is one of the key factors to provide an accurate solution.

Given the relative complexity of the meta-model, a **methodology** has been developed to support its instantiation according to a given case of application. This methodology relies on a template to interview stakeholders in order to address the fundamental design-time aspects of the meta-model for the case of application, while specifying the rules and constraints that the BEM engine must take into account at run-time to generate solutions adapted to problematic events.

Basically, the analyst(s) in charge of the requirements phase shall meet the different persons involved in the project, and discuss each of the following aspects through a set of specific questions, until an agreement is reached on the specifications:

1. Structuration of the different activities within the processes.
2. Necessary roles to manage the activities and assignation strategy for each activity.
3. Types and instances of resources.
4. Theoretical occupations and modifications of resources for each activity.
5. Structuration of the organisations "owning" each resource (including human participants).

6. Rules for starting each activity.
7. Transversal rules for allocating roles and resources (e.g. the resource used for activity A must also be used for activity B, but not for activity C).
8. Exceptions and predictable events.
9. Links between events and impacted resources.
10. Management of events through recovery procedures: If possible, explicit definition of recovery processes and activities (typically resulting from preliminary risk analysis). Otherwise, state that the whole system or some of its specific elements should reach.

Moreover a tool has been developed that supports the formal expression of the analysis and translate it in a declarative language accepted by the modules described above.

The **exception management process** computes as follows. When the CEP identifies an exception, the diagnoser receives the related information and collects from the business process engine the (relevant) information related to the (concerned) running cases. Its analysis determines the goal to the exception management. It can be the initial goal of a failing case or a diminished version of it. In case of a global invariant violation, it can consist in the restoration of the invariant. Ultimately, the goal fixed by the diagnoser is basically formulated as an assertion about resources and actors.

Knowing the current state of the system, the BEM Planner builds abductively a scenario to reach the target goal. Its computation process is described in Subsect. 4.2.

Receiving the exception management process built by the abductive planner, the Solution Manager is in charge of its implementation. By interacting with the Business Process Engine, the Solution Manager suspends or kills the concerned case(s), uploads the computed process, launches it and, if appropriate, unsuspends the suspended case(s).

4 Specific Modules

Two components of the system described in the previous section have required the development of specific tools: the declarative specification of activities and the planner. The two following subsections present them in a rather abstract way. Details about their implementation can be found in [15].

4.1 The Declarative Activities Library

Each activity in the library is presented in a declarative fashion with its pre and post-conditions, specifying the involved actor(s)/role(s), the required (level of) resources, and, if applicable, their modification resulting from the execution of the activity.

Figure 2 illustrates two of the activities involved in the airport example developed below. On the left side, the `Landing` activity requires that the plane is

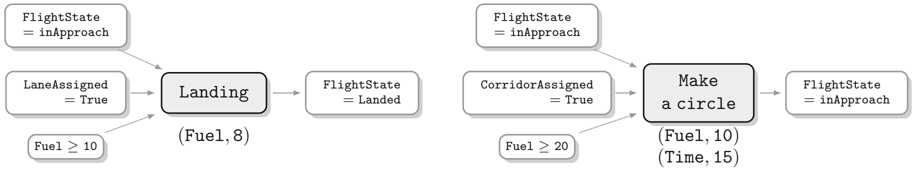

Fig. 2. Example of activities and their related resources

in approach, a landing lane is assigned and the fuel reserve is greater than 10 units which is expressed by the preconditions: `FlightState` is `inApproach`, `LaneAssigned` is `True` and `Fuel` is greater than 10 units. Landing will consume 8 units of fuel and results in a plane landed which are express the `(fuel,8)` impact information below the activity and the postcondition `FlightState = Landed`. Similarly, the figure on the right expresses that making a circle requires that the approaching plane has more than 20 units of fuel and an assigned corridor. This activity will consume 10 unit of fuel, increase the time of 15 min and, when finished, the plane will again be in approach.

It is to note that the underlying meta-model [14] allows a rich and well-structured definition of the activities and involved resources. The more complete is the library, the richer is the reasoning process. The specification of the activities library for a given business is one of the outputs of the methodology described above [12]. It aims to provide a description of the activities and their relationships with the resources in a format suitable for the planner tool.

4.2 The Abductive Event Calculus Planner

As *"a narrative-based temporal logical formalism to reason about events and their effects"* [16], the *Event Calculus* (EC) is well suited to model activities and resources presented previously. The EC is a many-sorted logic extended with equality that augments predicate calculus with three sorts: *events*, *fluents* and *time*. A fluent is defined as a time-varying property whose truth value depends on the occurrence of certain events.

The EC used for the research presented in this paper is the one of Murray Shanahan [17,18]. It supports a great variety of events as non-deterministic or compound ones and offers a robust solution to the *frame problem* by using *circumscription* [19–21].

As illustrated by Fig. 3, the EC takes two sources of information as input. On the one hand, the *What the events do* is specified by the *Domain dependent axioms* (Σ) which *"explains the effects of the events of the domain"* [22]. And on the other hand, the *What happens when* is specified by the *Narrative* (Δ) which gives a partially ordered sequence of actions occurrences. It is associated with the *Initial State* specified in the set Δ_0. This information is treated by the *Logical Machinery* specified by the *Domain independent axioms*, or *EC Axioms* (ECA), which *"formalises the correct evolution of the fluents via formulae telling the value of a fluent after an arbitrary action has been performed"* [22].

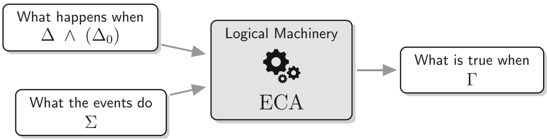

Fig. 3. Event calculus

And the output results in knowledge about the evolution of the system also called the *What is true when* which states in the set Γ what is true at the end of the execution of the narrative.

Formally expressed, EC deduces the set Γ such that the formula (1) holds.

$$\Sigma \wedge \Delta_0 \wedge \Delta \wedge \mathsf{ECA} \;\models\; \Gamma \tag{1}$$

Relying on the EC, Shanahan (in [21]) developed an Abductive Event Calculus Planner (AECP) which, conversely, *abduces* the *what happens when* (Δ) from the *what is true when* [23,24]. The *abduction* is a form of reasoning where *assumptions are made to explain observations*, that is given a set of domain axioms Σ, an eventual Δ_0, and a goal Γ, find a narrative Δ such that the logical formula (1) holds.

Shanahan's AECP is an *abductive SLD theorem prover* implemented as a *Prolog meta-interpreter* using *proof by negation*. It supports *integrity constraints* and, as it is a *hierarchical planner*, specification of *compound* and *recursive activities*. Its *iterative deepening search strategy* associated with the abductive resolution of the goals ensures its *completeness* and *correctness*. If it exists, the planner will always find the minimal explanation for a given goal [23,25] as effectively as ad-hoc tools dedicated to planning [26]. The plan returned by the planner, called the *residue* of the abduction, is constructed progressively all along the iterative deepening search by the addition of the literals necessary to make the current goal consistent with the domain theory. Those literals that cannot be proven from the specified theory are the activities to perform and the order in which they must be performed in order to reach the specified goal.

We transformed the planner of Shanahan so that the choice of the activities to be added to the scenario is only based on the satisfaction of resource constraints, that is such that it becomes *resource-driven*. The way the AECP works was globally preserved but we modified it at several places to make it compliant with the satisfaction of resource constraints. Let us hereafter present some of the main modifications. All others, duly commented, can be found in the sources themselves together with some examples of use of the planner (available at http://offenbach.info.fundp.ac.be/LNBIP2013/).

First, we implemented new axioms to specify the life cycle of activities which says that an *activable* activity becomes *active* when started and *completed* when it terminates. The choice of the activity to abduce is made on basis to the current resource constraint to satisfy: the planner looks for an activity with one post-conditional resource constraint that satisfies it. Once this activity founded, it must be proven to be activable, which leads to satisfy new resource constraints.

Second, as the scenario is built backward, that is from its end, the effects of the abduction of an activity on numerical resources must be recorded in order to ensure that conditions satisfied before adding it to the scenario are still satisfied after. Moreover, this history of the activities abduction effects must dynamically follow the backtracking of the SLD resolution of Prolog. This entails the definition of some history management stuff, compliant with the backtracking of Prolog, that uses ad-hoc dynamic literals to store and retrieve information from the execution database. This task induced the specification of numerous new predicates at different levels of the original planner.

Another adaptation consists in the definition of a new intermediary step before the refinement one of the AECP. Indeed, as in our domain an activity has two related actions, its starting and ending, both with different time points, the original refinement step fails when it processes the scenario to search for compound activities. For each compound activity, the new predicate replaces the two problematic actions with a new one, containing the two different time points, compliant with the refinement step. In addition, a completely new process has been created at the end of the scenario generation to convert the residue in something meaningful and usable by the other modules of the framework.

Finally, the use of tuProlog (http://tuprolog.alice.unibo.it) that is available as a Java Library archive, allowed the direct embedding of the planner in a Java Web Service without installing Prolog and its deployment in any Apache Server.

5 Example

Let us complete this presentation with an airport example, highly simplified for the sake of brevity. It concerns a small local airport modestly frequented where the support process of a plane arrival is as simple as described in Fig. 4. When a new plane approaches, the availability of the landing lane is checked and the lane booked. Then, the plane lands, receives a parking assignation, releases the lane and reaches the parking, which terminates the case.

Whatever the case, the goal to achieve when a plane is announced to the control tower is to give him a landing road map such that, once completed, a new plane could be supported as presented in Fig. 4. However, if for any reason (cleaning, presence of another plane ...) the landing lane is not available, the `check lane availability` activity fails and the above elementary process is not able to deal with the current plane arrival. An exception is then thrown

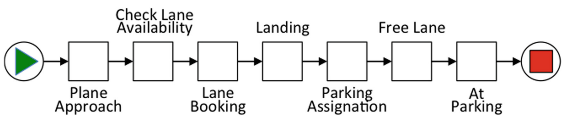

Fig. 4. Simplified airport plane management process

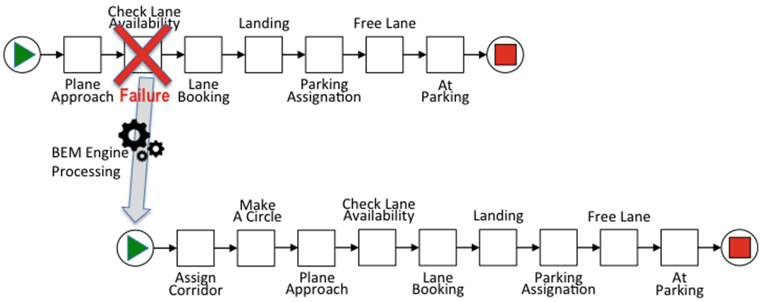

Fig. 5. Plane management exception process

and the available pieces of information about the current case are retrieved. In this example, they are the flight number (`FlightNumber`), the state of the flight (`FlightState`), the assignation (or not) of a lane (`LaneAssigned`), if any, the assigned lane number (`LaneNumber`) and the plane fuel level (`Fuel`).

On the basis of this information, either the plane will be sent on a corridor to circle for a given time and announce again later, or rerouted to another airport. Let us now detail how the BEM system build the solution presented in Fig. 5.

The abductive planner receives the collected information about the state of the system (the Δ_0 knowledge), in our example `FlightState` = `inApproach`, `LaneAssigned` = `False` and let's consider `Fuel` = `35`. The available activities, their conditions and effects (the Σ knowledge) are described in the activities library. Among them, are the activities presented in Fig. 2 in previous section and a derouting activity. The goal of the initial workflow is the landing of the plane and its arrival at parking, this is kept as the goal of the workflow to build. The planner built abductively (starting from the goal) a new scenario. The queue of the story is the same as for the initial one. However, as no lane is currently assigned, the "lane booking" activity cannot be the first in the scenario, it has to be prefixed with some steps which will guarantee that this point will be reached with a positive line assignation. This is achieved by introducing a circle in the story. It is to note that this prefixing can only be done if the current state of the resources (for example the fuel level) is compliant with the scenario (in this example greater or equal to 20). As compatible with the situation of our example, the scenario proposed in Fig. 5 will then be uploaded and launched in the system. If a condition should not be satisfied, the BEM planner would backtrack in order to find another solution, the rerouting of the plane in this example.

6 Conclusion and Future Work

In this paper we have addressed the need for a resource-aware business process exception management computing the solution process on-demand. The BEM-framework has been presented and its response to this requirement has been illustrated on a small example. The architecture mainly relies on an integration of services. Required for this integration, the main innovation of the proposal relies on the development of two specific components: on the one hand, a declarative description of the activities which can be invoked to manage the exception and, on the other hand, an abductive planner developed on top of event calculus.

At the time of writing this paper, the implemented version of the BEM-framework is limited to the redesign of processes taking the new environment conditions into account. This paper shows that the solution could easily be extended to the creation of new processes in order to restore some characteristics of the environment. Indeed, the only required adaptation consists in configuring the CEP module in order to identify the violation of the given environment characteristic as a relevant "exception" to be transmitted to the BEM engine.

Other extensions are under consideration. Let us mention first the involvement of a human interaction in the solution manager module in order to validate the proposed solution, in particular for critical processes. One step further for the decision support tool would be the generation of not only one, but multiple solutions. As the planner relies on declarative programming, this extension can be reached at small cost, namely with a few changes in the coding. Finally an additional module should be introduced in order to assess each of them and/or support a human choice and make it feasible in the limited time available for critical situation management.

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An Agent Architecture for Concurrent Bilateral Negotiations

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Abstract. We present an architecture that makes use of symbolic decision-making to support agents participating in concurrent bilateral negotiations. The architecture is a revised version of previous work with the KGP model [12,23], which we specialise with knowledge about the agent's self, the negotiation opponents and the environment. Our work combines the specification of domain-independent decision-making with a new protocol for concurrent negotiation that revisits the well-known *alternating offers* protocol [22]. We show how the decision-making can be specialised to represent the agent's strategies, utilities and preferences using a Prolog-like meta-program. The work prepares the ground for supporting decision-making in concurrent bilateral negotiations that is more lightweight than previous work and contributes towards a fully developed model of the architecture.

Keywords: Negotiation architectures · Interaction protocol · e-Markets

1 Introduction

Electronic marketplaces (e-marketplaces or e-markets) are typically construed as inter-organizational information systems that allow participating buyers and sellers to exchange information about prices and product offerings. The organization operating an e-marketplace is normally referred to as an intermediary, which may be a market participant - a buyer or seller, an independent third party, or a multi-firm consortium [6].

E-marketplaces provide an electronic, or online, method to facilitate transactions between buyers and sellers, and will typically support all of the steps in the entire order fulfilment process. In recent years, we have witnessed a huge number of successful e-marketplaces on the Web, such as E-Bay, Amazon, or Gumtree. E-markets of this kind have become popular because they support mechanisms such as advertising, buying/selling, and paying for goods online, thus providing an efficient and convenient way to perform commercial activities on the Web.

However, one problem with the existing e-marketplaces is that a market participant must repeatedly be online in order to follow the progress of an activity

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such as buying a product, especially if such a product requires bargaining. In addition, the duration of some market mechanisms (e.g. auctions) can be long, so e-marketplace activities can often become tedious and tiring for a participant. What is worse, buyers and sellers come and go, they have different goals and preferences. Thus pursuing best deals in an e-marketplace requires from participants to engage in multiple, possibly conflicting, activities at the same time, sometimes in different e-marketplaces.

To deal with the dynamic and complex environment that e-marketplaces give rise to, we follow a multi-agent systems approach [24] whereby agents negotiate bilaterally with other agents on behalf of their users. The idea here is that agents can satisfy user preferences by isolating emotions and feelings when they negotiate [11] as well as save users time. In this context, the issue becomes how to build models that support such agents to engage in multiple and dynamic market environments concurrently, take accountable decisions in these environments, and produce results that are approved by the users they represent.

We revisit previous work with the KGP model [23] applied to decision making [12] to equip it for decision-making in multiple and concurrent negotiations as required by an agent's participation in multiple markets. We represent markets explicitly via the introduction of an environment model, we profile other participating agents by introducing an opponents' model, and we also keep a representation of self [5]; none of these models were available in [23]. The focus of this paper is to integrate the models of the environment, the opponents and self in a revised agent-architecture to aid the symbolic representation of decision making in negotiations. Our longer term goal involves how to support an agent wishing to acquire a product decide first in which market to buy it and then what offers to make to a seller at different stages of the negotiation.

The paper is organised as follows. Section 2 is a brief overview of negotiation and decision-making. In Sect. 3 we present our agent architecture. Section 4 is a discussion of the protocol. The skeleton of decision making is discussed in Sect. 5. We conclude with Sect. 6.

2 Negotiation and Decision Making

Negotiation is the process of agents communicating with one another in order to reach agreements or solve conflicts on matters of common interest. As in [10], the negotiation process is like bargaining by which a joint decision is made by two parties. The parties first verbalise contradictory demands and then move towards agreements. Negotiation of this kind has recently gained a lot of attention in multi-agent systems, especially in e-commerce [23] but also in other application areas too, for instance, service selection and composition [7], virtual organisations [18], supply chain [13–15], service-oriented [19] and cloud computing [9].

To enable multiple agents participate in the negotiation process we assume a negotiation protocol that is often construed as the rules of encounter [21] between the participants. Such a protocol states who can say what, to whom and at what time. Given a protocol, an agent strategy then defines the model that the individual participants apply to act in line with the protocol in order to achieve their negotiation objectives. However, in our setting it is not possible to pre-compute an optimal negotiation strategy at design time, as in classical mechanism design. Rather the agents need to adopt a heuristic and satisfying approach for their strategy.

As argued in [10], when the assumptions of classical mechanism design do not apply, we need to seek to develop a distributed approach where solutions are sought when agents do not know the other player's preferences for negotiation outcomes, their reservation values, or any other resource constraints. Also, agents are computationally bounded in both time and resources. Moreover, agents may engage in a multi-criteria decision problem whose interactions follow the rules of an alternating sequential protocol in which the agents take turns to make offers and counter offers [22]. This protocol terminates when the agents agree or when one of them withdraws from the negotiation. In the most complex form, the negotiation is conducted concurrently via a number of bilateral negotiations rather than sequentially [10]. Here the agent may be required to apply different strategies for different opponents in order to achieve its goals with the advantage of overcoming slowness of human negotiation.

Unlike [10], however, we want to develop a heuristic approach that combines efficient reasoning techniques and approximate decision models to develop negotiating agents. We look at an agent architecture that interprets the negotiation process as consisting of three main stages: initial, middle and final. In the initial phase, planning and preparation for the negotiation is taking place. The goal of negotiation is set by the agent's user in the initial phase and consists of specifying the required product and its properties, such as price range and deadline. In the middle phase, the actual negotiation takes place, which includes deciding the agent's offers, evaluating the opponent offers, modelling the environment and/or opponents' behaviour changes, and measuring the performance of the negotiating position. In this phase, a number of questions arise: what changes should the buyer take into consideration in order to maximise its negotiation outcome? How it will behave in the light of these changes? In the final phase, the negotiation agreement is implemented.

3 Agent Architecture

To specify our problem, a negotiating agent architecture must be presented. In brief, there are two types of architecture. The first is an agent architecture that provides a clear demonstration of the agent structure without declaring how the agent behaves during negotiation because the agents are autonomous in nature [26]. The second is an architecture that combines both agent structure and behaviour [5]. The agent's behaviour addresses the process of deciding what actions to perform at each stage.

In Fig. 1, we develop an agent architecture with four components: Physical Capabilities, Domain Knowledge, Current State, and Cognitive Capabilities. The following is a brief description for each component:

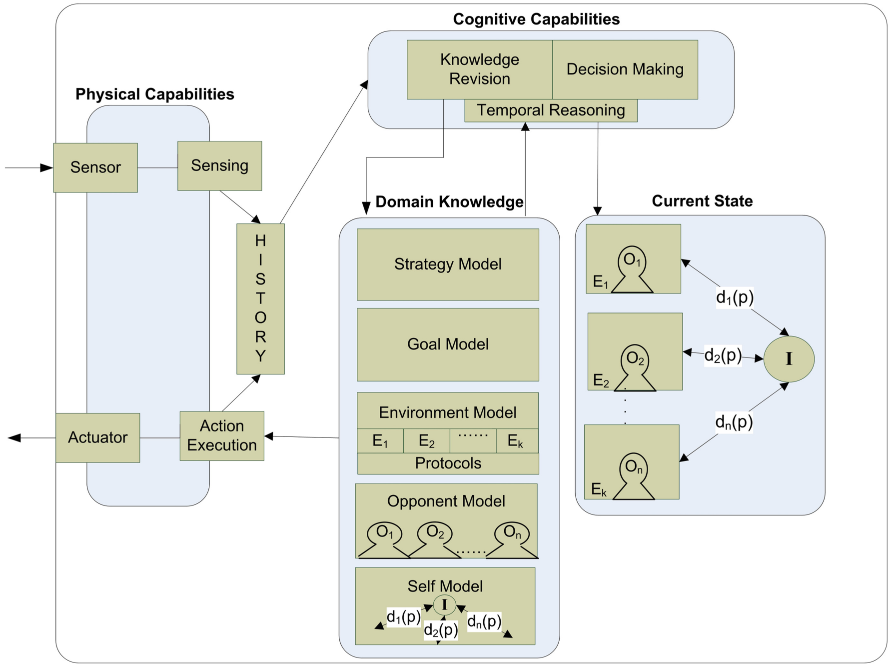

Fig. 1. Architecture of negotiating agent I that is interacting concurrently in different sub-environments $E_1, E_2, \ldots, E_k$ with opponents $O_1, O_2, \ldots O_n$.

The *Domain Knowledge* represents generic and dynamically changing knowledge about the negotiating application at hand. It consists of five sub-components: a *Strategy Model* detailing how the agent selects actions in the application domain, a *Goal Model* outlining which goals the agent can achieve and how they can be achieved using the strategies, an *Environment Model* representing knowledge about classes of different types of environments and the protocols they require, an *Opponent Model* detailing classes of different opponents and a *Self Model* representing information about the agent itself and its preferences.

The *Current State* contains instances of the on-going negotiations in terms of the participants for each negotiation, the protocol used for each negotiation, and the progress made in these so far.

The *Physical Capabilities* situate the agent in an environment by connecting the agent's sensors and effectors to its internal state. It consists of two sub-components: a *Sensing capability* that captures environment information via the sensors and an *Action Execution* capability that performs the actions in the environment via the actuators. Both capabilities operate on the *History* of the agent, another component that holds the experience of the agent represented as a series of events that have happened, either in the form of observations (events from the Sensing capability) or actions (events from the Action Execution capability).

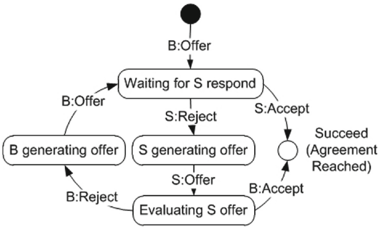

Fig. 2. Alternating offer state diagram

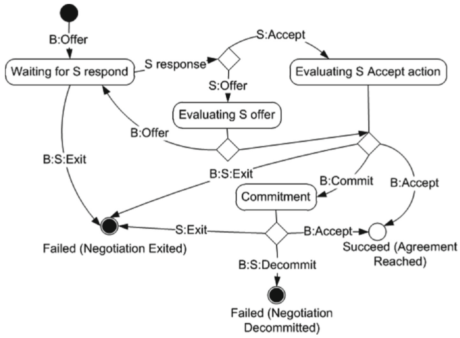

Fig. 3. Concurrent alternating offers state diagram

The *Cognitive Capabilities* allow the agent to reason about the negotiation and take decisions. This component consists of three subcomponents: *Decision Making* is responsible for evaluating the *Current State*, and uses *Domain Knowledge* to decide what to do next, *Knowledge Revision* updates the *Domain Knowledge* component either through simple revisions or through learning over time, and *Temporal Reasoning* supporting changes in the *Domain Knowledge* due to events happening in the *History* of the agent.

Finally, the *Control* component details how the capabilities are being invoked and under which circumstances, represented by the outer container and the arrows in Fig. 1. The typical control cycle is an instance of the more general framework described in [16]. It involves the agent sensing an event from the environment, updates its history, which in turn causes a revision of the knowledge and the current state, then the agent makes a decision to act, and the action is executed in the environment and recorded in the history.

4 Concurrent Alternating Offers Protocol

We study a practical concurrent negotiation setting where a buyer agent engages in multiple bilateral negotiations in order to acquire a good. In doing so we experimented with the alternating offers protocol [22] due to its simplicity and wide use. As shown in Fig. 2, in this protocol a buyer and a seller take turns to negotiate with possible actions: *offer, accept* and *reject*. The negotiation terminates either because the agreement is reached (buyer/seller accept) or the negotiation has terminated (buyer/seller reach their deadlines).

However, the alternating offers protocol is not sufficient to handle the complexity of concurrent negotiation due its limited actions. In Fig. 3, we extended the protocol allowing for: *offer, accept, commit, de-commit* and *exit*. Commit provides the buyer with opportunity to hold a preferred offer for a certain time until they find a better one, reflecting what happens in practice. If an agent (buyer/seller) finds a better agreement then it can de-commit from committed offer(s). If an agent reaches its deadline, it will accept one committed offer, thus an agreement is reached. The agent may maintain a number of committed offers at the same time. However, the de-commitment process is subject to a penalty that asserts fairness by avoiding unnecessary de-commitments.

There have been two previous attempts to extend the alternating offers protocol. In [2], confirm action is presented, which comes after an accept; a buyer cannot de-commit from confirmed offers. In [25], a concurrent protocol is proposed but does not distinguish between the commitment and agreement actions (both are represented by confirm). In our protocol, we have commit and accept instead. In addition, de-commitment in [25] happens after the agreement has been made, which can be inefficient in real time applications. In contrast, the de-commitment in our protocol occurs before the agreement is finalized.

5 The Skeleton of Decision Making

To test our negotiation protocol we study the development of agent strategies with emphasis on the strategy of a buyer agent in a multiple market setting. Existing literature (e.g. [3,20,25]) provides answers only on when to offer or accept and what to offer, since the protocol used does not allow for concurrency. In addition, offers are computed using an opponent's model but ignore both the environmental and self models [20,25], while some work assumes complete and certain information about the negotiation environment and the opponents [20]. In most approaches the agent strategy is an isolated component without clear illustration of how the model is designed and how different component interact with each other [3,20,25]. Consequently, the produced offers are inadequate for our purposes. To overcome these shortcomings, in Sect. 5.1 we developed a heuristic negotiation strategy and demonstrate an example run in Sect. 5.2.

5.1 Representation Framework

We represent the state of an agent during negotiation as a temporal logic program. We specify the rules of such a program in Prolog, which we assume the reader is familiar with. Prolog uses the convention that a constant is an identifier starting with a lower-case letter, while a variable is an identifier starting with a upper-case letter. A constant stands for a specific entity, and different constants stand for different entities. On the other hand, a variable can stand for any entity, and different variables can stand for the same entity. The predicate name must be a constant, while each argument can either be a constant or a variable. As Prolog program can be used to answer queries, or to achieve goals, the prompt "?-" denotes a query whose truth will be judged by the program.

The temporal part of the logic is represented using the Event Calculus (EC) [17], a logical language for reasoning about actions and their effects. We will use a dialect of the EC based on temporal variables known as multi-valued fluents due to the fact that these variables can take different values at different times. At a time T a fluent is represented in the form F = V to denote that it holds at T that F has value V [1]. For instance, to query that the initial price of specific laptop, say `laptop12`, costs `1200` at the current time `15`, we write:

```
?- holds_at(initial_price(laptop12) = 1200, 15).
```

The state of the agent will generally contain many other fluents to represent information about negotiation threads, information about other agents and knowledge about the environment.

From a representation of state as the one above, we develop a strategy as an action selection policy whose specification is defined by Prolog rules of the form:

```
select(Thread, Action, T):- Conditions [T].
```

Such rules state that given a negotiation `Thread` that the agent is engaged in at time `T`, the `Action` is selected if the `Conditions` hold at `T`. For example, the rule below shows how the agent exits a negotiation thread if the agent's deadline for the `Thread` has passed:

```
select(Thread, exit, T):-
     holds_at(self_deadline(Thread, Td)=true, T), T > Td.
```

Our model allows the agent to make decisions using utilities over actions. The top-level decision process finds the most promising `Thread` in the current time `T`, generates all the `Options` that the agent is capable of performing at this time, evaluates the options and returns the one with the highest utility:

```
decide(in(Thread, Action), T):-
    promising(Thread, T),
    generate(Thread, Options, T),
    evaluate(Thread, Options, Evaluation, T),
    return(Thread, Evaluation, Action, T).
```

The way we measure that a `Thread` is promising at time `T` is by measuring the eagerness of the user for obtaining a negotiation item and how well the opponent has behaved during negotiation. Lack of space does not allow us to explain in detail how these concepts are formulated, however, we plan to elaborate them in our future work. We discuss next how we generate all the options within the most promising `Thread` as shown below:

```
generate(Thread, Options, T):-
    findall(Option, select(Thread, Option, T), Options).
```

`findall/3` is a Prolog primitive that finds every `Option` that can be selected by the agent in the `Thread` and storing it in a list of `Options` to be returned.

Once generated, the `Options` are evaluated by the program:

```
evaluate(_, [], [], _).
evaluate(Thread, [Option|Options], [(Option,Util)|Pairs], T):-
       utility(Thread, Option, Util, T),
       evaluate(Thread, Options, Pairs, T).
```

The first clause defines the termination conditions of the evaluation. The underscore sign '_' indicates that we do not care about a variable. The second clause of the evaluation defines the main procedure that computes for each `Option` a utility `Util`. The result returned is a list of pairs `(Option, Util)`. A utility `Util` is obtained via a dynamic domain-specific function evaluated at run-time. For example, we calculate the utility of an offer act as:

```
utility(Thread, offer(Price), Utility, T):-
    holds_at(product(Thread, Product)=true, T),
    holds_at(initial_price(Thread, Product)=IP, T),
    holds_at(reservation_price(Thread, Product)=RP, T),
    Utility is (RP-Price)/(RP-IP).
```

The preference process of the agent then returns the option with highest utility, once it orders the options in increasing order:

```
return(Thread, Evaluation, Action, T):-
    order(Evaluation, Ordered),
    choice(Thread, Ordered, Action, T).

choice(_, [(Option,_)|_], Option, _).
```

Other definitions for `choice/4` are possible, to deal with options having the same utility, but discussion on this issue is beyond the scope of the paper.

5.2 Example Run

We have prototyped a small agent market in the GOLEM platform [8], which acts as a proof-of-concept of our architecture. GOLEM supports experimenting with Prolog agents like ours and endows them with additional features such as agent communication and interoperability. We have focused on how a user specifies an item to be bought by a *buyer* agent. Table 1 illustrates how the *buyer* agent interacts with *sellers* in the market in order to purchase a laptop. The scenario is presented from a buyer's perspective and assumes the user has specified that (a) the laptop's price to be in the range [700, 900] and (b) the maximum negotiation duration to be 5 min. At time t1, *buyer* is negotiating concurrently with $seller_1$ and $seller_2$. At time t2, $seller_1$ sends a counteroffer to *buyer* while at time t3, $seller_2$ sends back an offer to *buyer*. In t4, *buyer* will follow the skeleton strategy in Sect. 5.1 to select the best action.

Table 1. Observations, deliberations and decisions of *buyer* during a negotiation.

Time	Observation	Deliberation	Decision
t1	$seller_1$ & $seller_2$	Make offer to all visible sellers	Offer(700)
t2	$seller_1$ offers 950		
t3	$seller_2$ offers 920		
t4		Active threads: $seller_1$, $seller_2$ Options for selected thread $seller_1$: [offer(750), exit, commit, accept] Utilities for $seller_1$: [(offer(750), 0.8), (exit, 0.5), (commit, 0.6),(accept, 0.1)] Highest Utility Action: offer(750)	Offer(750) to $seller_1$

6 Conclusion and Future Work

We have outlined the components of an agent architecture to support the deployment of negotiating agents participating in negotiations of multiple electronic markets. The architecture is influenced from previous work with the KGP model [23] revisited here to contain an explicit representation of environment, opponent, and self models for the purposes of negotiation. The newly proposed model also provides a light version of the cognitive capabilities of the agent to aid decision making in multiple concurrent negotiations for which we have provided a protocol. We have also described the skeleton of the decision making capability and we have shown how it links to utilities and preferences.

Future work involves developing the heuristic negotiation strategy that involves the environment, opponent and self models to decide the market to negotiate in, what, how, and when to offer, and whether to accept or exit. Finally, we will also develop a test bed [4] to compare our agent's performance in negotiation with other negotiating agents (e.g. [3,20,25]).

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Integrating Environmental Policies into Business Strategy: The Problem Structuring Stage in a Framework for Decision Support

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Abstract. Companies are increasingly including their corporate social responsibility into their business strategy. The environmental issues assume here a priority role. In order to get a balance in economic, social and environmental trade-offs, companies need to consider multiple objectives, namely related to the allocation of resources and investments, which can cause contradictory opinions among diverse stakeholders. Companies should incorporate into the decision-making process tangible and intangible elements, identifying and structuring objectives in a consistent way, in order to choose sustainable options for the company and create compromises between stakeholders. The main motivation of this paper is to present a methodology or framework to support decision-making and appraisal of corporate environmental strategies and subsequent management approaches. In order to gain a closer view over the proposed approach, we will present the preliminary results illustrated with examples from an ongoing case study within a public passenger transport company.

Keywords: Business strategy · Decision-making · Problem structuring · Stakeholders · Corporate sustainability

1 Introduction

"Around 80 % of the world's primary energy today is carbon based (…) We will need to shift to no- or low-carbon energy by mid-century" [1]. The need to construct a low-carbon future where renewable sources of energy and greater efficiency should be present in an intensive way will provide a great help to accelerate the transition to sustainable energy sources and use. The alternatives may vary and the options to carry may assume mixed combinations, and although "movers may pay a slightly higher price today for these strategies (…) they and the world will reap long-term economic and environmental benefits" [1]. When companies evaluate their external context they should pay attention to the fact that "the natural environment shows potential shortages

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of certain raw materials, instable cost of energy, increase pollution levels and a growing movement to protect the environment" [2].

From the 1970s and until the middle eighties, companies went only as far as to comply with centralized regulatory measures that commanded them to internalize environmental costs. Firms resisted as there were no incentives for them to assume higher levels of environmental responsibility. In the following decade, between 1985 and mid-1990s, some new developments emerged. Dialogue between legislators and industry began, business accepted some responsibility for solving environmental problems and new regulatory mechanisms were created. The standardization of some environmental management systems was a response both to consumers and to public demand for environmental protection. In the second half of the 1990s, economic incentives for the incorporation of ecological issues into business practices became more evident. Ecological requirements started to be seen as an integral part of quality management principles and potential sources of competitive advantage. Since then, finding hidden opportunities to profit from environmental strategies and determining the role of business in promoting sustainable development became appealing themes.

Today, there is a widespread acceptance that sustainability requires coordination of prerequisites at the industry and societal levels. The research about organizational strategies and practices leading to ecologically sustainable systems of production and consumption constitute one of the main environmental challenges for organizational and management studies in the early decades of the new millennium.

The sustainability of companies includes not only the needs of the present generation, but also safeguarding without compromising the satisfaction of the needs of future generations. Therefore, a company strategy should be structured towards economic, social and environmental pillars. Companies are increasingly including corporate social responsibility into their business strategy not only to fulfil legislative regulations but also in a voluntary way. So, companies establish sustainability goals and targets in order to address significant environmental challenges. Their performance embraces a more effective use of natural resources, like energy, reducing operating costs, response to consumer preferences, and taking steps to reduce the environmental impact of their products and services as well as their supply chains [1].

This path has two major consequences: (i) companies have to integrate environmental policies into their strategic management and (ii) companies assume implicitly the responsibility to promote a more active relationship with their internal and external stakeholders. This means that companies, in order to achieve their organizational purpose – which is influenced by corporate sustainability – need to rebuild their strategic management taking into account both environmental policies and stakeholders' expectations. And the way companies now make decisions naturally changes.

After introducing in this section the context and motivation for this study, we outline in Sect. 2 the main purposes of the broad research work and the reasons for the choice of the application area. In Sect. 3 we introduce a reference to relevant literature concerning problem structuring and analysis of stakeholders. In Sect. 4 we describe, in a brief way, the proposed framework to address the problem of decision support with the goal of integrating the environmental policies into business strategy. And in the following section, the analysis relies on covering the methodology in a more detailed way and providing some examples related to the case study. Finally, conclusions state concisely the most important aspects of the work presented in the paper.

2 The Research Work

2.1 Motivation

Environmental decision-making requires an explicit and coordinated structure in which it must be possible to articulate the involvement of different stakeholders, incorporate multi-disciplinary knowledge, integrate different and complex criteria involving trade-offs to combine different factors at the same time (economic, environmental, social, technological, socio-political), and join heterogeneous information of both quantitative and qualitative character.

There is a need to assist complex decision processes within organizations in order to achieve the development of corporate objectives. Problem structuring approaches enable the creation of conceptual models to support the strategic development of organizations, contributing to an explicit formulation of feasible goals. This implies a greater depth of analysis and a framework for developing objectives for policy decisions. These objectives will provide the basis for quantifying values. The process requires considerable creativity in discussions with decision-makers and stakeholders concerned with the decision.

2.2 Purpose

Our purpose is threefold: (i) to develop a methodology or framework to support and evaluate corporate environmental strategies and management approaches; (ii) to propose a methodological approach for structuring multi-objective problems involving multi-stakeholder decision-making in a participatory context, searching for value co-creation from both societal and corporate perspectives; (iii) to apply the theoretical conclusions drawn from the previous objectives to a case study in the context of a public bus company.

2.3 Case Study

Integrating environmental policies into corporate sustainability is strongly dependent on the area of intervention.

Public transport companies play a quite visible role in the dimensions of corporate social responsibility, namely because of two reasons: (i) they provide daily services crucial to mass customers' mobility and (ii) their investments are usually of high value. This sort of companies is strongly dependent upon macro-policies and rather sensitive to technological development. They play an important role in the energy sector, both upstream and downstream. These were the main reasons to the choice of a bus transport operator as the case study for our academic research.

3 Background Literature

Most environmental decisions, like Life Cycle Assessment and Emission Reduction Strategies, share the same characteristics – many stakeholders, uncertainties, conflicting criteria, impacts which extend far in the future – but they may need different analytical approaches, given the differentiated environmental decision contexts [3]. The literature provides a wide range of different frameworks regarding decision-making towards sustainability, with environmental concerns (for further details, see [3–6]). We will limit this short review to two topics - problem structuring and analysis of the stakeholders – and, due to the lack of space, we will just mention the studies that contributed furthermost to the reflection leading to the development of the proposed framework.

Problem Structuring. In literature we found the use of Soft Systems Methodology (SSM) to structure a Multi-Criteria Decision Analysis (MCDA) model in order to appraise energy efficiency initiatives [7]. The adoption of SSM helped not only to define the decision problem context, but also to reveal the main objectives of the selected stakeholders and discerning the relevant criteria of each. The Keeney's Value Focused Thinking methodology (VFT) was also introduced by these authors to "structure a hierarchy of fundamental objectives for each potential evaluator of efficiency initiatives." A similar methodology is presented by [8] at a local level, in urban energy planning.

A different approach, proposed by [4], relies on a decision-support framework that provides a suitable tool for integrated decision-making sustainability, addressed for corporate and public policy. There are three stages: Problem Structuring, Problem Analysis and Problem Resolution. In the Problem Structuring stage there are six steps: identification and involvement of stakeholders, problem definition, identification of sustainability issues, identification of decision criteria, identification of alternatives, and elicitation of preferences.

Analysis of Stakeholders. In business management an increasing attention has been paid to stakeholders once they may affect (positively or negatively) the performance of a company. This fact leads to the development of several approaches in order to analyse stakeholders. Stakeholders can be defined as "groups or individuals: (a) that can reasonably be expected to be significantly affected by the organization's activities, products, and/or services; or (b) whose actions can reasonably be expected to affect the ability of the organization to successfully implement its strategies and achieve its objectives. (…) Stakeholders may be individuals, interest groups, government agencies, or corporate organizations." [9].

There are a number of principles, advantages and risks that need to be present in order to implement successful stakeholders' participation in environmental themes [5]. Additionally other factors should be taken into account such as "cultural, political and historical contexts" as these authors also emphasize. In literature there are different frameworks for stakeholder participation whose accent varies according to the authors' aim: a general approach for working with evaluation of stakeholders [10, 11]; for environmental projects [5]; for the resolution of sustainable development dilemmas within a public organization [6]. The approach of the latter is based on a multi-criteria decision aid methodology for the implementation of a participative democracy model in two steps. In step one - the "outlining and structuring problem" – they use the Organizational Analysis technique together with a contextual diagnosis. And, in step two, aggregation procedures are chosen and applied according to the available information for "each action with the aim of reaching an overall conclusion" to give support to the decision.

Our aim is to provide a framework for supporting decision-makers at the company level and its field of application in a public transport company. The novelty of the proposed framework relies on the application of different approaches and diverse methodologies and techniques presented in this section (and duly detailed in the next section), with the goal of supporting decision-making on the specific context mentioned above. The literature reviewed doesn't present the necessary links between the diversity of elements drawn within such context.

4 A Framework for Decision Support

The proposed framework is depicted in Fig. 1. The integration of environmental concerns in company's mission involves redesigning business strategy. In this field we adopted the philosophy of Johnson and Scholes. In our "journey", our "starting point" is based on the inputs provided by strategic analysis and our "destination" is the strategic choice. In order to meet the study purpose, we combine several methods and techniques which are integrated along the three major stages "borrowed" the backbone from [4].

Problem Structuring is divided in two parts: Problem Formulation and the application of VFT. Problem Formulation has four steps: the first one related to the stakeholders' analysis and the other three to strategic analysis.

Strategic analysis involves the examination of the external and internal contexts and [12] present several techniques that provide different insights for (and about) the company. Although these insights are relevant, there are two specific techniques that play a special role: *value chain* (in the internal context) and *benchmarking related* (i) *to environmental strategies* and objectives followed by other companies (in the external context), (ii) *to the identification of corporate sustainability issues*. These analyses are helpful for a first definition of the boundaries of the problem.

Concerning the stakeholders, we focus specifically on how and why managers might use stakeholder identification and analysis techniques, in order to meet their organization mandates, fulfil their missions and create public value [10]. In this context, we organize stakeholders' participation in interviews and workshops gathering researchers, senior executives and representatives of several stakeholders. Our approach follows, as in [7], the stream of cultural analysis [13] and its main results are compiled into a rich-picture (see Fig. 2). In this step the main actors, their main roles and concerns are identified.

The ill-structured nature of the problems under analysis, "multiple actors, multiple perspectives, incommensurable and/or conflicting interests", and the existence of "important intangibles and key uncertainties" [14] suggests the adoption of Problem Structuring Methods (PSM). PSM models may be expressed in a visual form, and "mostly use participants' own *language* rather than mathematics or quantitative data" to represent complex problematic situations [15]. Hence they are a natural choice to help unveiling a cloud of objectives to be subsequently structured as a hierarchy.

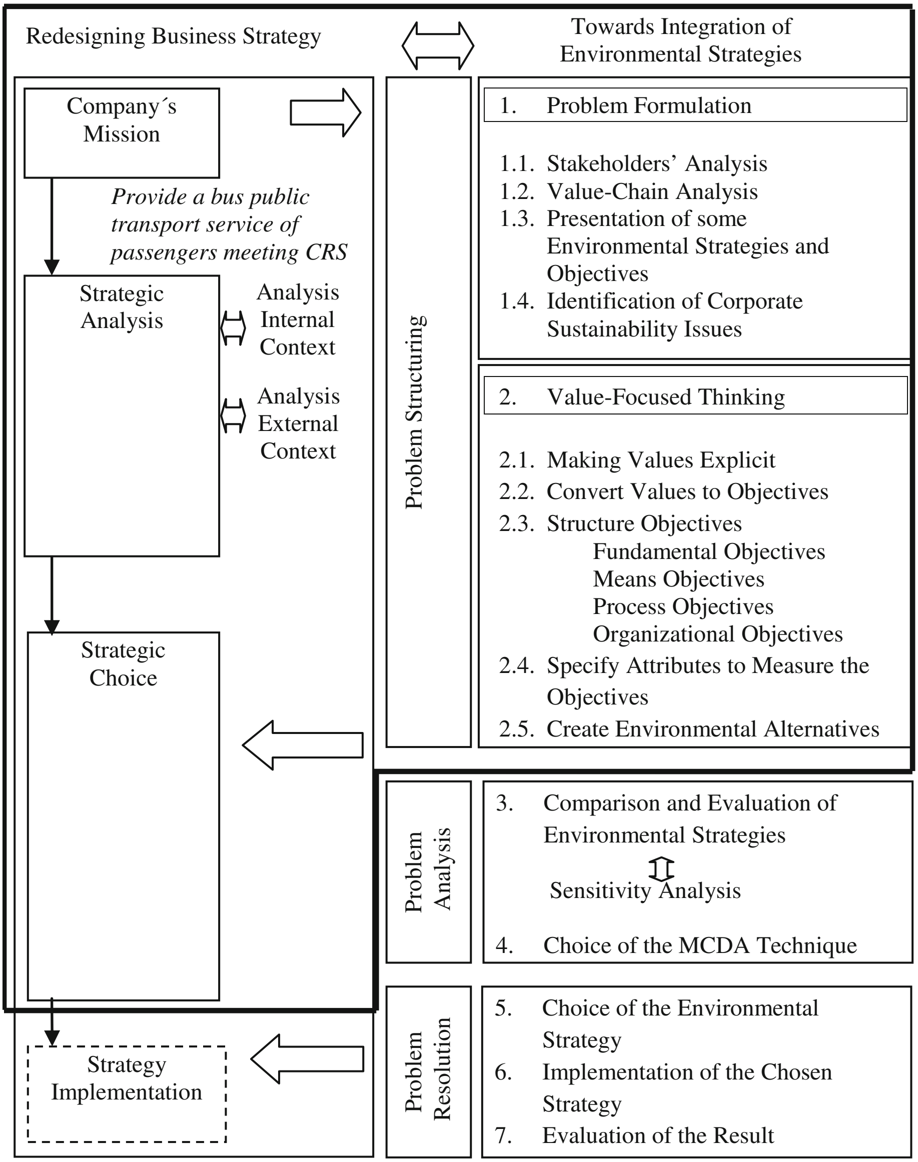

Fig. 1. The proposed framework

When companies want to include corporate social issues into their business strategy, they are promoting responsibility with their stakeholders. Thereby, the company needs to balance trade-offs between economic, social and environmental decisions between its stakeholders. These trade-offs decisions are supported on values. And therefore, stakeholders' values need to be articulated in order to provide strategic choices and thus drive the company towards sustainability. Although may be shared

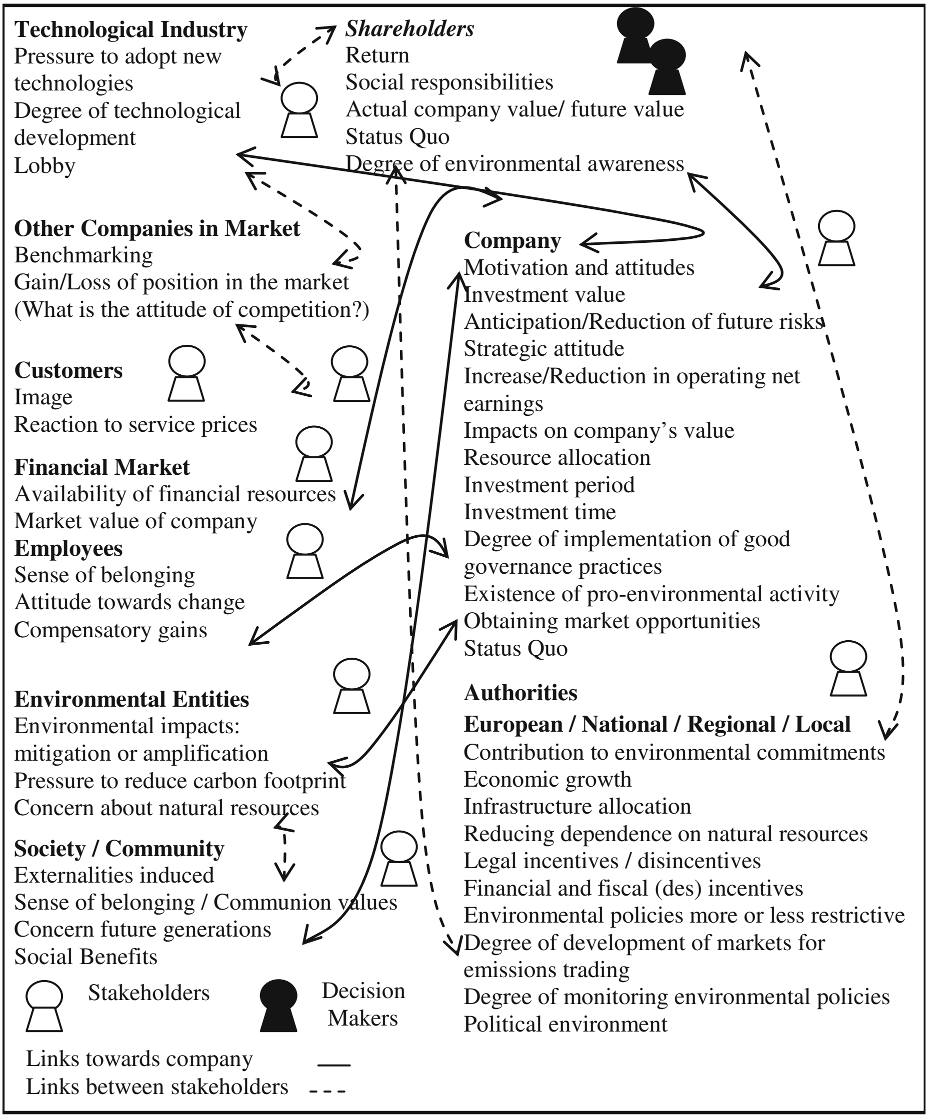

Fig. 2. Rich picture

values between all stakeholders, each stakeholder has its own system of values and each strategic choice may have different implications on each of them. The stakeholders' values provide the initial input to create strategic choices. For our purpose, we use Keeney's methodology: VFT [16]. For each stakeholder we also propose the construction of fundamental objectives trees that can be transformed into criteria and thus provide the input for the application of MCDA.

Shortly, SSM is used to elicit individual or group objectives from an initial messy situation and VFT is used to structure the fundamental objectives to be used in an MCDA problem with the goal of defining a hierarchy of criteria to each potential decision-maker, reassessing the roles played by the multiple stakeholders and the way of considering their points-of-view.

So, at the Problem Analysis stage, out of the scope of this paper, we have a set of strategic choices that need to be scored or ranked by the shareholders. Descriptions about aggregation of individual preferences can be found in literature [17–19]. Our problem has a finite set of decisions, thus being a discrete choice problem. In the current case, due to its nature, probably there are criteria defined into different units. The selection of the MCDA techniques will be made taking into account the nature of the strategic choice, once different environmental decision contexts are addressed differently.

5 Case Study: A Public Transport Operator

The case study takes place in STCP (Oporto Public Transport Society), the main bus operator in Oporto Metropolitan Area. The shareholders of STCP, a public transport company, are willing to integrate the environmental component into the company's strategy in order to promote its sustainability and meet the principles set out in its corporate social responsibility. In this sense, the shareholders (by wishing to change the current posture of the company in the market for a different approach in the future), reveal the existence of a problem and, thereby, they are the problem owners and thus the decision-makers.

Alongside the revaluation made by the Portuguese public transport sector in the later years about its role in the society, STCP has been adapting its strategy and structure to the achievement of new challenges. This modernization focused on the customer orientation as a crucial point in the activity of the company. The company's mission statement is now expressed in the form of a written document approved by its shareholders: "STCP's mission focuses on the provision of urban passenger transport in its operating area, contributing to the effective mobility of people, providing a competitive alternative to private transport and generating, by its activity, social and environmental benefits within a framework of economic rationality and financial health." This is a critical input to the intervention described in the remaining of this section.

In our study, the company is composed by shareholders, by a board of directors and subsequent organizational structure. Nevertheless, in smaller companies the owner(s) of the company may be part of the board of directors. So, the flexibility of the approach remains.

5.1 Problem Formulation

Stakeholders' Analysis. The ability to foresee the behaviour of passengers and society contributes to reaching objectives more efficiently. This is particularly important when there is a permanent attention of the media to the activities of the company, as it happens in the case of public transport operators. Understanding the salience and social relations of stakeholders contributes to increase the likelihood of success in anticipating the responses of society to the company's decisions [3], and consequently improves the awareness of decision-makers.

There is a varied set of stakeholders that may be involved in sustainability issues: employees, trade unions, contractors, suppliers, customers, shareholders, creditors, insurers, local communities, local authorities, governments and NGO's [20].

At this stage there are key strategic choices to be made by the owner of the problem about who should be involved, how and when. The answers to these questions have implication along the whole process. For instance, the definition of the degree of stakeholders' involvement is relevant because it may assume different ways: information, consultation, collaboration, co-decision, and empowerment [5]. Another factor to reveal is the democratic paradigm that owners want to assume [6].

In a first stage this work has been done by the analyst, one shareholder and one board member, in order to initiate this process but simultaneously deciding and establishing the boundaries and levels of participation across the problem formulation. In a second stage a broader group of stakeholders should be involved in order to refine the results of the previous work done.

Organizing Stakeholders Involvement. A comprehensive knowledge about the company allows the owners to get a deeper inside and to delineate within relevant stakeholders the kick off about strategic choices to adopt in order to gather the objectives of a sustainable company. Involving stakeholders is important for their contributions and commitment to the success of strategic management.

The first step is being accomplished by promoting individual interviews with all the listed stakeholders to meet namely their objectives, norms of behaviour, concerns, and values. This will be followed by the realization of a major workshop for exploring the implications on service provision and activities of introducing the environmental policies into the mission statement of the company, and help defining the implementation process of the environmental strategies.

The first step of this approach allowed to build a rich picture (see Fig. 2) that will facilitate the debate [21].

Strategic Analysis at the Company Level. In order to integrate environmental policies into strategic management, it is helpful to develop a strategic business plan in order to balance the pillars of sustainability: society, economy and environment.

Strategic management combines strategic analysis, strategic choice and strategy implementation. For the purpose of this article, our focus will be on the first one.

Strategic analysis involves the analysis of external and internal contexts in which a company operates [12]. The analysis of the external context is being done in different and complementary ways: by understanding the nature of the external context; by auditing contextual influences and by identifying the organization's competitive position. In terms of internal context there were several available tools that could help identifying the resources, competences and strategic capability of the company, e.g. comparative analysis and benchmarking, resource audit, value-chain analysis, identification of core competences, analysis of cost efficiency and value added, among others. A SWOT analysis provides a summary of "the relationship between key [contextual] environmental influences, the strategic capability of the organization and hence the agenda for developing new strategies" [12].

In a complementary way, the use of Balance Scorecard (BSC), as a management system tool that aids companies to operationalize its strategy, provides insights into the discussion, especially from internal stakeholders. Prior to the implementation of the BSC in STCP, an analysis of the management control system of the company was conducted based on the collection of internal written information. The central document is the management contract formalized between the board of directors and the government. Internally, this contract is complemented by departmental management contracts between the board of directors and the heads of the departments, used as a basis to the boards of drivers. Each board of drivers entails the performance indicators of the departments and the respective quantitative targets. We learned that key performance indicators may be used as interactive and diagnostic controls, with stakeholders' influences being integrated into the corporation through its beliefs system [22].

A strategic map helps to translate this new approach in an easier language, facilitating the discussion inside the company [23, 24]. The result is represented in Fig. 3.

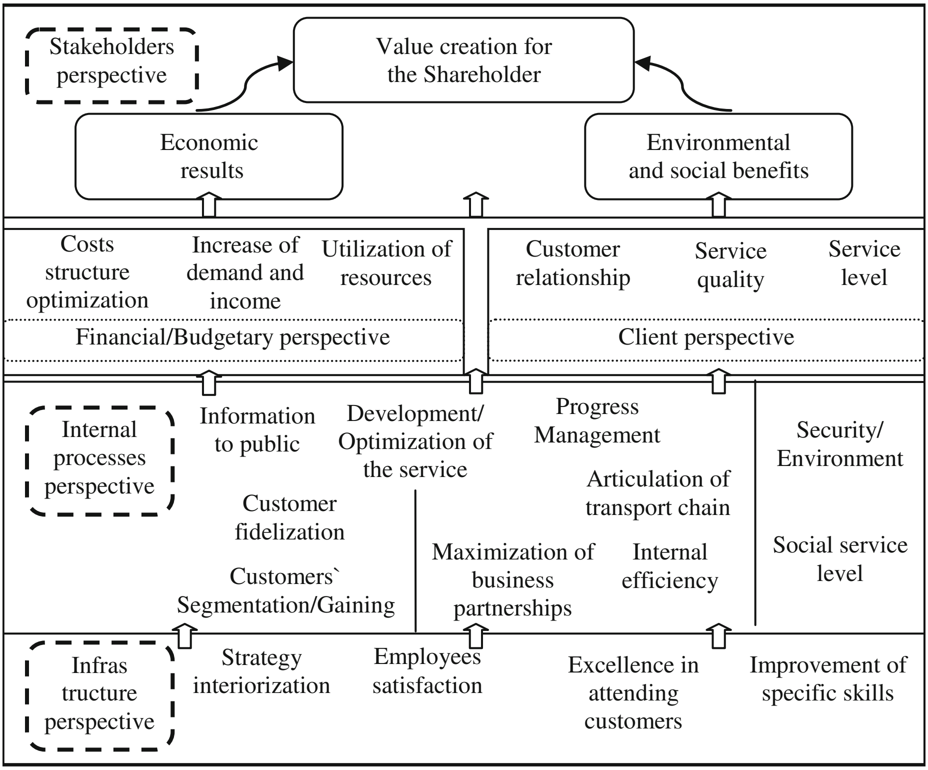

Fig. 3. STCP strategic map

Value-chain. A company may achieve sustained competitive advantages but first has to make a diagnosis of its position, namely by analysing its value-chain. Value chain analysis describes "the activities within and around a company, and relates them to an analysis of the competitive strategy of the organization" [12]. These activities can be primary – those directly involved with the provision of the service, or secondary (company's support activities). In the value-chain of a bus public transport company the main activities are: operations, maintenance, marketing (and sales) and after sales service. These activities are supported by areas like human resources, financial services, purchasing or procurement, research and development.

Identification of Environmental Strategies and Objectives. One technique for analysing external context is benchmarking. There are transversal corporate environmental strategies that can be applied: implementing eco-efficiency; eco-expense reduction; value chain eco-efficiency; eco-risk control, eco-design; eco-sales and marketing, intangible value (building corporate reputation and trusted banks); inspiring an eco-advantage culture [25]. Bus transportation companies play a special role in different environmental areas in order to mitigate their impacts: by managing carbon in energy use; by improving resource use and waste management, by managing noise and potential pollution and by improving air quality. Thus, some environmental strategies may embrace the promotion of technological efficiency towards its fleet, the redesign of its support areas in order to increase energy's efficiency, improving eco-driving, managing water resources and solid waste resulting from its activity. Several environmental objectives may be established: to reduce greenhouse gas emissions, to reduce energy use, to reduce fossil fuel use, to adopt comprehensive product life cycle, to reduce pollutant emissions to air, to reduce noise, to reduce resource consumption, to improve green procurement, to reduce or substitute materials.

Identification of Corporate Sustainability Issues. In order to identify corporate sustainability issues in other companies in the external environment we apply the same technique as previously (benchmarking). Some examples of sustainability issues relevant to a public transport company are presented in Table 1.

The implementation of SSM methodology has thus been initiated through these activities that allow entering and expressing the problem situation.

Table 1. Sustainability issues in a public transport company.

Economic	Environmental	Social
Value added	Air emissions	Safety
Investments	Use of energy	Employment
Competitiveness	Global warming	Equal opportunities
Shareholder value	Resource use and availability	Stakeholder involvement

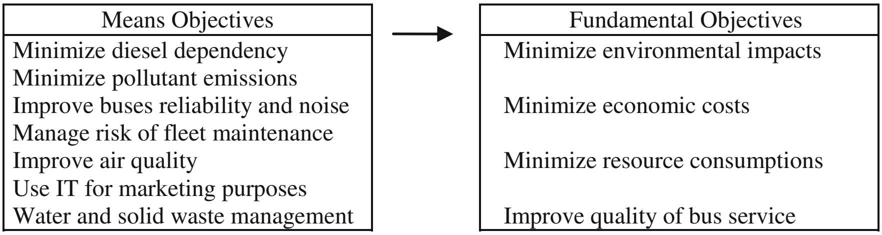

Fig. 4. Influence of means objectives in fundamental objectives for a bus company

5.2 Value Focused Thinking

Value-Focused Thinking is a methodology that has "been used to structure objectives and create decision opportunities in several firms" [26]. This methodology and its procedures are expressed in a summary way in the next steps providing some case study examples.

Making Values Explicit. According to VFT the creation of "a useful set of values requires the following steps: developing a list of values, convert each of these values to an objective, structure these objectives to clarify relationships among them" [26]. In order to develop a list of values, these authors provide in the same book a range of techniques.

Convert Values to Objectives. This initial list of values will become "messy" and, in order to achieve consistency, each item has to be converted into a corresponding objective respecting three features: the decision context, the object and a direction of preference [26]. One example in our case study may be, for instance, "minimize diesel dependency". The bus transport company has one objective concerned with minimizing environmental impacts. Therefore the decision context, the object and the direction of preference in the present case are, respectively: the bus service provided by the transport company, the diesel dependency and its minimization.

Structure Objectives. The resulting list of objectives may contain four kinds of objectives: fundamental objectives, means objectives, process objectives and organisational objectives. Fundamental objectives "concern the ends that the decision makers value in a specific context" while means objectives "are methods to achieve those ends" [26]. The process objectives are "objectives concerning how the decision is made rather than what decision is made" and organisational objectives are "objectives influenced by all the decisions made over time by the organisation with the responsibility for making the policy decision at hand" [27]. An example in a bus transport public company between means objectives and fundamental objectives is provided in Fig. 4.

6 Conclusion

This paper outlines a methodological framework for decision support in a micro level of application. The decision context of our problem refers to corporate strategic options. Our findings indicate that firm`s resources and competitive advantage may act as mediator variables for a positive relationship between environmental benefits and economic results, with the aid of the captured values from internal executives and external stakeholders in a public transport operator. Together with the main inferences obtained so far from the research project, some achievements of the first steps of this methodology, namely the rich picture and the strategic map, are illustrated in the paper, based on a case study in progress in STCP. The case study, as a method that has extensively been used in social research, will be able to provide new insights into the problem. The criticism regarding its reliability and validity can be avoided by focusing the research on current examples in the public transport domain in order to ensure the validity of extrapolation.

Concerning the methodology itself and the comparison to other existing ones, we tried to evidence their distinctive features along the text. As in [28], we note that the approaches are somewhat similar enough and the differences in the choice of their application may be based more on familiarity and available opportunities than solely on the merits of the different methods themselves. There have been few attempts reported in the literature at evaluating across methods and across interventions. Perhaps the field would benefit if the various tools were better integrated while keeping as variations those process differences that provide distinct benefits. Moreover, in any particular intervention, contextual factors, the skills of the researchers and the purposes being pursued by stakeholders affect the perceived success or failure of a method. The use of standard criteria for comparing methods is therefore made problematic by the need to consider what is unique in each case, even if longer-term comparisons between methods are suggested [29].

Increasing interest in stakeholder participation in companies' strategic definition emphasizes the need to avoid the risks of incorrect use of the methodology. We definitely need more experience on the behavioral aspects of different weighting procedures on multi-attribute decision analysis. "Moreover, the political aspects of the different ways of directly involving the stakeholders also need to be studied. The computer implementation of the decision analytical methods is also an important issue since we need to have easy interactive and practical ways of working with stakeholders in eliciting their priorities" [30].

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A Web-Based Decision Support System for Supply Chain Operations Management Towards an Integrated Framework

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Abstract. Operations management deals with the design and management of products, processes, services and supply chains. Supply chains integration and manufacturing operations management can benefit highly from the use of web-based technologies by ensuring a smooth connectivity and interoperability between software components, especially in a real-time basis by reinforcing the use of multi-agents combined with web service based technologies. The more the accurate and dynamic is the update of the information in a company, the more the enhancement of the manufacturing decision-making process will be over the whole company's performance. Moreover, web-based technologies combined with multi-agents provide gains in agility and flexibility for building versatile supply chain management systems. Therefore, the purpose of this paper is to present and propose an integrated web-based framework to cover the main integration requirement from a system point of view, this within the main purpose of supporting the supply chain management and operation in supply chain environments. For this purpose, an automotive supply chain industry is considered to illustrate the applicability of this proposed framework.

Keywords: Web-based decision support system · Supply chain and operations management · Enterprise integration · Multi-agent systems · Automotive industry

1 Introduction

Due to the use of many technology approaches in the recent decade, more and more organizations, as depicted in [1], are seeking to develop more effective integration links with partners' technologies to improve the partnerships outside the traditional enterprises' boundaries. This issue has covered particular relevance in complex manufacturing enterprise environments, such as supply chain networks. For instance, Meixell

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and Gargeya [2] concluded that integrated supply chain models must address the composite supply chain design problem to include both internal manufacturing and external supplier locations. There is a wide acceptance concerning the strategic importance for integrating the operations among customers and suppliers, in supply chains, especially due to the relevance and high impact over the involved manufacturing management processes and decisions. The latter should be concerned with the efficient organization of the manufacturing process of products and/or services, to ensure a robust and reliable delivery of products in an interactive and collaborative way with customers [3]. In a fact, as established and demonstrated by [4], effective business process collaboration between companies operating in a supply chain can bring about important benefits, but several barriers need to be overcome. For this, the use one key technology is required to support the integration of many technologies information systems. This in a way these barriers will be overcame and solutions will be easily replicated across different functional units. One of the well accepted and known technologies are the multi-agent systems, which uses a standard structure for handling information flows and mechanism as well as variety of behaviours representation in complex environments [5]. On the light of this, this paper proposes a framework-based system considering the combined use of multi-agent systems and web-based services as main technologies. The purpose of this is to obtain an efficient and effective supply chain management and operations process. The system aims to continuously update the manufacturing decision-making information for enhancing the performance of the supply chain parties. Hence, and for supporting this proposal, the structure of this paper is as follows. In the first place, a brief review about web-based information technologies and their links to the supply chain integration and manufacturing operations management is covered. Next, and based on a real-life automotive industry case study, the proposed framework-based system is described by addressing some of the main technologies that underline this framework. Finally the main conclusions and further research are presented.

2 Background

From the information technologies and communications point of view, the greatest obstacle between web and desktop interaction is created by clouding facilities because the traditional PC desktop is now populated by widgets such as the Mac Dashboard, web fast-download apps such as Java Web Start or Adobe Air, and expanded browser functionality such as Chrome [6].

Gartner [7] establish that strategies in information technology and communication (ITC) are one of the potential elements for generating a significant impact over the enterprises in the next years. In this context, factors that will denote a significant impact will include: a high potential for disruption in the ITC or business processes, the need for major investment and the risk of being late to adopt continuous modification in requirements or constraints. Gartner [7] has also identified the top ten technologies that will be considered as strategic for organizations, and what ITC leaders should consider into their strategic planning processes over the following years. These technologies are: Mobile Device Battles, Mobile Applications and HTML5, Personal Cloud, Enterprise

App Stores, The Internet of Things, Hybrid IT and Cloud Computing, Strategic Big Data, Actionable Analytics, In Memory Computing and Integrated Ecosystems. Organisations may follow these directions for supporting and covering their ITC management requirement for implementing collaborative actions or mechanism, were multiagent-based technologies will also play an important role. The selection of the right ITC-based tool will be another challenge for the organisations since it can be only one, many or a combination of some of them or even all of them. Hence, it is possible to say that internet-based solutions and technologies, such as the web-based technologies are increasingly appealing in manufacturing environments, which increases the diversity and scalability of integrated manufacturing systems across supply chain networks [5].

Numerous new information and communication technologies are being developed, by both private and public sectors, which are continuously trying to exploit Internet based applications. Thus, large investments are every day a more common practice for supporting web-based e-services, such as: e-business, e-banking, e-government and e-learning [8].

The high and exponential spread of e-business process has rapidly and completely changed the styles of enterprise transactions used in peer-to-peer (P2P), specifically when transaction moves from off-line to on-line modalities. E-businesses are flourishing, mostly resulting from the simplicity and efficacy with which we can access and explore huge quantities of knowledge and resources on the internet [9].

In connection to this, websites based on web services and related technologies are receiving more attention by manufacturing companies [10] such as Oracle[1] based technologies as key enterprise resource planning (ERP) database support. Most enterprise websites and portals contain large knowledge base manufacturing information, such as design, application services and enterprise data. Web-based enterprise databases and application platforms provide all kinds of manufacturing and extended logistic resources as well. In fact, by observing the main problems related to policy-based activities in projects management and the types of web service technologies linked to them, it should be possible to build specialized supply chain management systems to deal with the difficulties associated to large data sets and sequential flows of information. The central idea of using web service based technologies is to ensure the connectivity and the interoperability of software components over the web [10].

In terms of the web-enablement of supply chain management activities, from the study of [8], it has been revealed a strong positive influence of supplier synergy, information intensity in supply chain environment, managerial ITC knowledge, interoperability and formal governance mechanisms on the degree of web-enablement of supply chain activities. Because of this, Aryee et al. [11] proposed metrics for evaluating the supply chain integration performance such us: financial measures (return on investment, sales growth and market share) and operational measures (production cycle time, new product time to market and percentage of supplier getting forecast or demand data). Hence, considering the results from [11], it has been possible to establish that the organisational performance is dependent on levels of maturity in supply chain process

[1] http://www.oracle.com/technetwork/java/javase/documentation/index.html

integration. In addition, by having real-time information available at any time, web-based systems can increase the information transparency, which in turn, makes it easier for project managers to identify potential risks.

One well-known and accepted technology to support the aforementioned requirements and web-based environments are the multi-agent systems. Some important benefits from multi-agent systems are their scalability and robustness for implementing, specially, decision support systems in complex environments. Therefore, systems whose behaviours and parameters are expected to be modified and updated over the time can also take advantage from the use of multi-agent systems. For an extended review on multi-agent systems applications, readers are suggested to access [5] and [4].

Considering the aforementioned premises, the aim of this paper consists in presenting a framework for supporting the supply chain integration and manufacturing operations management considering an automotive industry scenario, based on web services and related technologies, such as multi-agent systems. Further, we propose a method to update an enterprise data warehouse system based on a scheduling ETL (Extraction, Transformation and Loading) tool by considering, mainly, a real-time on-demand scenario. This "on demand" based ETL tool, will allow managers to access updated valuable data, through a web service and a multi-agent based system. At the current stage of the proposed framework agent-based technology is just considered conceptually and implementation details are expected to be published further. Next a summarized view across software agents and multi-agent systems and XML and web service based technologies combined with multi-agents is presented.

Software Agents. Software agents are defined as atomic computer programs that can accomplish a task or activity on behalf of the user and without constant human intervention [12]. These software modules can be bound to a specific execution environment - stationary agents - or they can have the capacity to transport themselves to other execution environments, along with supporting data - mobile agents [12, 13].

Genersereth and Ketchpel [14] proposed three categories for software agent classification: deliberative agents (that support their decisions on symbolic reasoning, using a symbolic model of the environment; they engage in planning and negotiation in order to achieve coordination with other agents); reactive agents (that do not have any internal symbolic models of the environment, and act using a stimulus/response type of behaviour); and hybrid (a mix of deliberative and reactive models, based on a hierarchy of behaviour layers, that can be further increased in response to external events).

Nwana [12] enumerates a list of three primary attributes that agents should exhibit: autonomy (so that it executes its tasks without human intervention); proactiviness (in order to make decisions based on opportunity); cooperativeness or social ability (in order to interact with other software agents or human users); learning ability (agents should learn as they react and/or interact with their external environment). From these three key characteristics they derive four types of agents: collaborative agents, collaborative learning agents, interface agents and smart agents.

Multi-agent Systems. Several authors propose using Software Agents to model distributed supply chains. The supply chain can be modelled as a set of intelligent software agents that interact in planning and executing processes, each one being assigned to different tasks and responsibilities. A system built upon a set of multiple agents that interact this way is a multi-agent system (MAS). A multi-agent system is a loosely coupled network of software agents that interact to solve problems that are beyond the individual capacities or knowledge [15]. Rocha et al. [16] define MAS as a set of agents that combine their individual competences and work collaboratively, in order to fulfil a common objective.

Lu and Wang [15] propose a framework for supply chain management using multiple agents. The authors assign each agent to one of four different categories: customer centric agents (responsible for managing customer information), product-centric agents (responsible for utilizing the customer information and identifying what the customer needs), supplier-centric agents (responsible for choosing the best suppliers for acquiring raw materials or components) and logistic-centric agents (responsible for dispatching materials and products for the manufacturer).

Jennings [17] considers that multi-agent systems can form the fundamental building blocks for software systems, even if the software systems do not themselves require any agent-like behaviour. Huhns [18] enumerates several key characteristics of multi-agent systems: agent based modules more closely represent real-world things; modules can negotiate with each other; modules can enter into social commitments to collaborate; modules can volunteer to be part of a software system: modules can "change their mind" about the results of collaboration.

XML and Web Services Combined with Multi-agents. XML is nowadays the universal integration language. In 2001 Bill Gates wrote "just as the web revolutionized how users talk to applications, XML transforms how applications talk to each other" (http://www.microsoft.com/presspass/misc/06-18BillGNet.mspx). The web evolved into a transactional platform, with an architecture geared towards intelligently exchanging information between applications. Web services play a key role in this transactional behaviour, working as loosely coupled software components that provide business functionality through the Internet using standard based technologies (like SOAP and XML). Web services are considered as self-contained, self-describing, modular applications that can be published, located, and invoked across the web.

Web services can be used along with software agents. For example, a software agent can analyze requests and determine how to fit them with web services. Web services would, in turn, interact with external software systems (for example, internal ERPs or APS systems). Software agents can also interpret and contextualize results of invoked services.

Agents are typically cooperative and communicative, knowing about other agents and being able to interact with them, whereas web services are essentially passive until they are invoked, knowing little about its consumers. There are several contributions for incorporating agents into web service based systems [19–21] and this work intends to put forward a framework were multi-agents interact based on web services.

The relationship between web services and software agents can be symbiotic. Web services can help software agents by proving further encapsulation and broader integration capabilities [22] standards based description and execution of methods, web based architecture and ease of deployment. The dynamic creation of software agents, their mediation and reasoning capabilities, their flexibility and robustness [23] allow for a cleaner management of web service sets. Moreover, reinforcement learning [24] is another important feature for enabling an appropriate collaborative-based integration among business partners and systems during a virtual enterprise life-cycle [16], which can be enabled by using web services combined with agent technology.

3 Illustrative Automotive Based Case Study

In this section we describe a simple case study of an automotive industry that will be improved with the proposed web-based framework system. For this, and based on [25] a traditional supply chain that contains suppliers, manufacturers and clients is considered (Fig. 1). This system is composed by an old Electronic data interchange system (EDI) and the clients are associated with the system by making orders considering a long-term production-planning horizon. This environment can be considered as a make-to-order where the manufacturer puts forward the orders including pull-type operations.

From Fig. 1, is depicted that the EDI data system is used for managing the client orders for supporting a build to order environment. Hence, when orders information arrives to system, the internal orders are created considering the stock level information available as well as the, working time window, lead times and other logistics concerns. Within this, the corresponding production planning decision-making is supported. Nevertheless, and due to the big amount of data to be considered in this whole process, decision-makers may face many difficulties if the data is not available on-time. In addition, these difficulties might be enhanced if the ITC decision support systems are not performing as fast as required in order to produce agile and reliable responses for supporting the enterprise decision-making. Thus, a mature information flow is required for enabling fast, accurate and dynamic information updates to be processed on a real-time basis. Moreover, even if the ERP system is well implemented, due to its traditional information management approach, it can be still a not as fast as desired tool for supporting the extraction, transformation and loading for extracting the data from databases. This implies that information bottleneck in the company are constantly expected, which generates barriers for making agile decisions. Due to this fact, ETL-based tools will only work under a low workload periods. As a result, users are not able to access real-time data information loaded in both, the business and the operational databases, and consequently this will imply lacks on decisions due to the information availability and visibility.

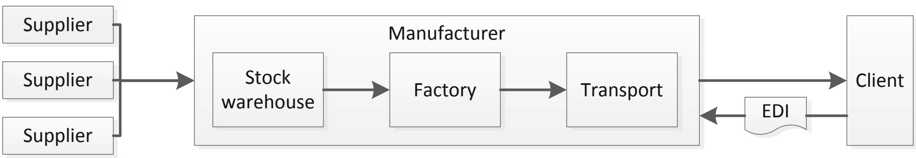

Fig. 1. Make-to-Order (MTO) pull-type manufacturer schema (based on [25]).

4 Overview of the Proposed Framework

Based on the previous information, the goal of this proposed framework is to provide up-to-date information continuously under a real-time basis for enhancing the enterprise decision-making process. With this in mind, a different type of ETL tool is required to allow such a dynamic updating process of the databases (DB) and enabling to update, on demand, the DB tables from the Data Warehouse (DW). Hence, a new On-Demand ETL (ODETL) is considered in the proposed framework as can be seen in Fig. 2.

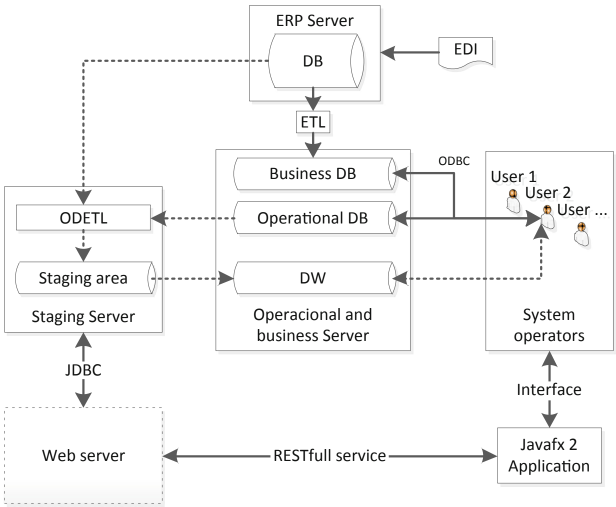

Fig. 2. Global view of the proposed framework (based on [25]).

Therefore, Fig. 2 shows the interactions among automated clients, which includes Scripts based various languages, such as Java, Ajax, Flash, JavaFX, GWT, blogs, and wikis. These languages are considered for running inside the browser and act as RESTfull web-service consumers [26].

Automated web service clients send HTTP-based requests to the 'Resource Request Handler' (RRH) through the web layer. The stateless requests from the client contain the method information in the header, namely POST, GET, PUT, and DELETE [26], which will be mapped to corresponding operations of the resources in the RRH. Each request contains all the necessary information including credentials for the RRH to process it.

To use web services as a standard communication layer and a web server with connection to the proposed ODETL and subsequent data stores (Fig. 2), will also allow using dash-boarding methods, as a way for users to request and monitor their requests in a real-time basis. This will allow the supply chain described in Sect. 3 to be more flexible and fast, which in turn will also benefit and increase returns.

5 Improved Case Study Within the Proposed Framework

In addition to the proposed ODELT and associated data stores previously mentioned, the framework proposed in this paper for supporting the supply chain management and operation in an automotive industry is also based on a multi-agent distributed architecture, using software agents and web services.

The use of multiple agents that cooperate as members of a virtual workforce will support distributed order management, production scheduling and monitoring. In order to execute these functions the agents will need to implement bi-directional communication with each business partner. The agents will need to obtain capacity information from factories, assign production schedules, receive exception notifications, and so on. This means that part of the information the system needs will be distributed among several systems, potentially heterogeneous, that live inside each participating business. Agents will communicate with these systems by using XML, for storing important information, namely production orders data, and another important role in terms of communication, combined with web services and multi-agents. Therefore, an extended view of the proposed framework and main underlying functionalities is presented next.

Extended Framework. Based on previous work [27], Fig. 3 illustrates an extended enterprise framework view for supporting the supply chain management and operations in an automotive industry. The system's main components are the Web Service Layer, that handles incoming requests from customers; Order Agents, that process orders received from customers; Production Agents, that identify outsourcing/supplier candidates and perform negotiation with them; Local Agents, that implement a communication interface between local business partner systems and production agents and Data Brokers, that control how data import and export is managed, promoting system encapsulation.

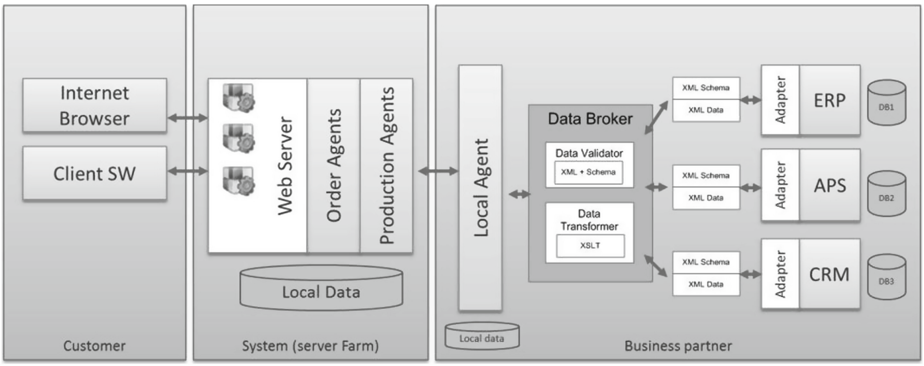

Fig. 3. Extended view of the framework.

In order to maximize system's reusability customers will interact with the system using HTTP for data transfer. A set of web services is available for servicing customer applications. These applications can range from locally installed software packages (that post-order information by calling web service methods) to server pages that are viewed using standard browser clients. Messages will be formatted using SOAP and RESTFull technology and XML [28]. Proxies will be used to support the integration of mobile equipment.

Integration with local systems from constituent Business Partners is a key component of a dynamic and distributed platform. The proposed framework includes modules that support the integration of heterogeneous production management systems in the distributed management process. These modules provide a consistent abstraction of the actual data structure and functional details of each local system. As long as each business unit system can accept the input data, process it and return output data, it can be integrated in the proposed framework. By allowing each business unit to integrate their existing systems, the proposed framework supports the preservation of each factory’s autonomy. The abstraction also allows for the sharing of limited amounts of information, using controlled software components. Business units can join or leave the network without changing their internal systems.

The enterprise architecture includes local agents that interact with the production agents. They are the only visible communication endpoints, encapsulating the details from local internal systems. Production agents will not have to deal with system heterogeneity and will implement a unique and standardized communication protocol to communicate with all local agents.

Integration with local systems will be built using connection modules called adapters. Several adapters will be available for reading and writing information from/into external systems (ERP, SCM, APS, among others). These modules feature Read and Write connectors. Each read connector is responsible for reading the information available in a backend system and transform this information into XML. Write connectors receive XML data and convert it to a format that is adequate for the associated system. XML Schemas (XSD) will be used to help validate the information and check its completeness and integrity.

The Data Broker component is the central data processing module and controls how import and export data is managed. The module is isolated from the details of each external system, accepting only XML information.

It includes two sub-components: Data Validator and Data Transformer. Data Validator maps the information received by the broker to the corresponding XML Schema. XML Schemas define which structures are acceptable. Any validation errors cause the rejection of the underlying data. This feature helps to guarantee that any adapters that were incorrectly developed will not compromise system data integrity.

The Data Transformer module is responsible for making the imported information compatible with the structure the service broker expects to receive, using XSLT Style Sheets (XSL Transformation). These Style Sheets are applied to the previously validated XML data and generate standardized transformation results. These results are delivered to the local agent.

Main Functionalities Underlying the Proposed Framework. Figure 4 illustrates the main expected functionalities of the proposed framework for supporting the supply chain management and operations management for the considered automotive industry.

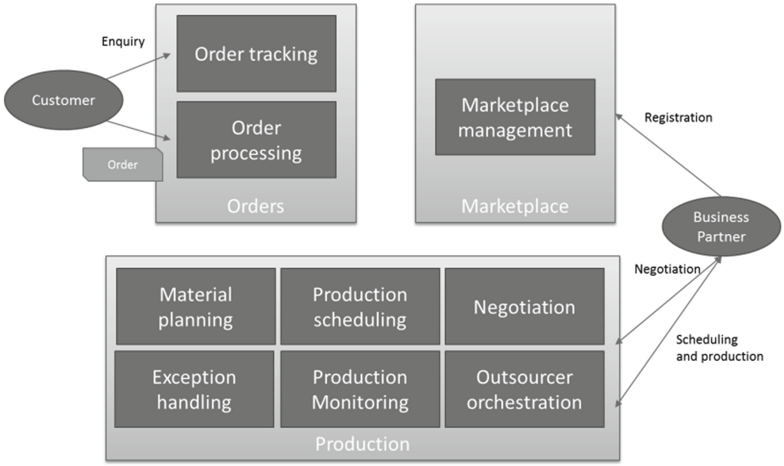

Fig. 4. Main functionalities underlying the proposed framework.

Customers will publish orders by submitting using available web services or server web pages. This paper assumes that order format and product description follow a base XML schema definition, mapped to a shared catalogue of valid product references.

Whenever an order is received by the system a new order agent is associated to it. The agent starts by analyzing the order and available data to identify the list of ordered products. Each product may have different production requirements. Once the products have been defined, the order agent performs material planning in order to identify how many finished goods or components have to be produced. It then builds an activity sequence made of (Component/Service, Start Date, Due Date, Qty) nodes, mapped to order delivery dates. The agent also identifies production dependencies and parallelism opportunities, then it instantiates one production agent for each component that must be produced. The order agent next enters a monitoring cycle, analyzing feedback from production agents, checking for completion and handling exceptions. When production completes, the agent performs the closing steps associated with shipping and invoicing procedures.

The production agents receive production assignments from the order agents. The agents perform a second phase of material planning, if needed, further decomposing components in production units. For each activity the agents define free slack (amount of time it may be delayed without affecting the next task) and total slack values (the amount of time the activity can be delayed without affecting the production deadline). Next they build a list of potential suppliers for each of the components or materials. For each of the components the agents initiate a bidding session, inviting registered business partners to place a bid in the system. The bid is made through local agents that are available on each of the registered business partners. These local agents are assigned to the business partners/suppliers when they register in the system. After receiving bid proposals from invited local agents, the production agents first evaluate production capacities. Each business partner that has enough production capacity is included in a list of qualified outsourcers for the associated component. If none of the business partners has enough capacity during the request period, the agent tries to coordinate the production order, checking dependencies and trying to change production schedule, trying to create compatibility with available capacities. If the coordination process is possible, the agent notifies business partners about proposed changes. If coordination is not possible, the agent tries to split production of the associated components between multiple producers, according to reported capacity availability from compatible partners. It then asks for updated bids according to proposed schedule and capacity allocation. If splitting is not successful, the agent triggers the reject order process. This process involves the order agent and, optionally, asks from further human approval to perform order rejection.

If there was enough capacity among bidders or production coordination was successful or even if production splitting occurred, the agent ends the process with a list of qualified outsourcers. For each entry on the list the agent evaluates and updates first level bidding factors (like cost, delivery, quality ratios and previous information). Next it evaluates transportation costs between suppliers that need to perform cumulative and sequential production. After that, the agent builds an ordered outsourcer short list based on first priority selection criteria. Next, it applies second and third level priority selection criteria, to decide between outsourcers with similar ratings. Finally, the agent selects one or more outsourcer(s) (in case of splitting or coordinated work), and notifies it or them about the final production schedule. Global production is saved locally along with associated data.

As soon as production scheduling is completed, the production agent enters a production monitoring cycle. The agent continuously checks information sent by local agents and sends them enquiries. Whenever a problem occurs, local agents may trigger an exception that is captured and handled by the production agents.

Whenever an exception signal is received, the production agent analyses it and evaluates the impact of the exception on the production plan. If there are no rescheduling requirements that may impact other outsourcers, the agent adjusts scheduling and notifies the local agent accordingly. If the changes affect other partners the agent starts a negotiation process with them. If the negotiation process is successful local data is updated and the monitoring cycle is resumed. If the negotiation was not successful and may compromise a final production deadline, the production agent interacts with the order agent, which will validate if the delay is acceptable. If it is not, the production may be cancelled. In this case, the production agent waits for formal production cancel approval, and informs local agents accordingly. During regular production monitoring cycle the production agent sends enquiries to local agents. In reply they send status reports and time estimates. If the production agent detects production delays it evaluates if they compromise production schedule, analyzing dependencies and total/free slack values. If scheduling is compromised, the agent checks with the order agent to see if the delay is acceptable, when matched with order delivery dates. If the delay is not acceptable, the agent starts the replace outsourcer process. After notifying the local agent from the outsourcer, the production agent starts a new bidding session for the work that was previously assigned to it.

6 Conclusion

Knowing that changing hardware systems is typically very costly, the notion of small tweaks to the same old system might bring almost the same efficiency as a newer one, but at a fraction of its cost. Making use of the existing hardware and software, we tried to super charge the existing framework in order to take full advantage of the different types of data systems in the context of an automotive industry. The issue here is the availability of on-time data information for supporting manufacturing decision making along the supply chain. This increase in data speed retrieval will influence almost every department in the supply chain by speeding up their decision making capabilities. Making use of a different methodology for data retrieval, the web services and multi-agents will allow communication, between the user and the actual system, in a much faster and automated way.

Moreover, collaboration along an integrated supply chain is a major concern of current manufacturing organizations that are worried about overcoming concurrency and surviving difficulties. Therefore, in this paper we make a contribution in terms of technological and organizational perspectives regarding these concerns, by putting forward a framework for supporting supply chain operations management and operation in an automotive industry, considering important requirements and trying to show how technology can serve the needs of an expanding and increasingly competitive organizational model. For this, it was assumed that business partners may have heterogeneous information systems and legacy systems.

Such an extended organizational model along an integrated supply chain environment is seen as a new and most advanced organizational paradigm, and is expected to serve as a vehicle towards a seamless perfect alignment of an enterprise within the global market context. Extended enterprises are addressed as a highly dynamic, reconfigurable agile network of independent enterprises sharing all resources, including knowledge, market, and customers; using specific organizational architectures that introduce the enterprises' true extended environments. The new organizational models are required for enabling a truly integrated and collaborative environment, with high adaptability and permanently aligned with businesses. Agility, scalability and evolutionary capability are the requirements for competitiveness that the new organizational models must address.

Future work includes the implementation of a mechanism to incorporate demand forecast in the suppliers' selection and order scheduling and negotiation processes. The adoption of a peer-to-peer architecture, without any central server mediation, will also be evaluated.

Moreover, implementation details, regarding the use of agent-based technology are expected to be published soon.

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Decision Making for a Risk-Averse Dual-Channel Supply Chain with Customer Returns

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Abstract. An optimal mathematic model is presented in consideration of customers' returns in a dual-channel supply chain consisting of a risk-averse manufacturer and a risk-averse retailer under the stochastic market requirement which supports the decision-making process for participants. Closed-form decisions are achieved in the centralized scenario. In the decentralized scenario, mean-variance analysis is used to conduct risk analysis. This study also delves into the influence of the degree of risk aversion, demand fluctuation and return rates on optimal decisions with the help of sensitivity analysis and numerical experimentation. Sensitivity analysis also indicates that the optimal solutions are robust. The model is a real expansion of the model library in the decision support system for dual-channel supply chains.

Keywords: Dual-channel supply chain · Risk-averse · Mean-variance · Pricing decision

1 Introduction

The Internet provides high-speed communication and close connection and serves as a new trading floor for enterprises, which can sell or purchase directly online through electronic marketplaces [1]. When e-commerce is used in a downside supply chain, the direct online channel and the traditional retail channel form a dual-channel supply chain. (A new retail channel and original direct online channel also form a dual-channel supply chain, such as Dell.) In this century, many well-known international enterprises have had dual channels, such as IBM, Dell, Cisco, Nike, Nestle and Estee Lauder. Reports from the Dell website [2] stated that the Dell retail presence amounted to more than 30,000 stores prior to 16 Jun 2009. According to IDC's worldwide quarterly tracking of PC sales statistics, in the first quarter of 2009, Dell's retail shipments rose by nearly 4 % compared with the same period last year. The total retail market share reached 7 %, which means that the dual-channel supply chain is now at the center stage of the business performance of manufacturing enterprises.

The decision-making process of a dual-channel supply chain is complicated because of its dynamic and large-scale nature, hierarchical decisions and random inputs. The decision-making process provides important technology support to the supply chain in terms of enterprise location, information integration, performance

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management, etc. Almost every enterprise (e.g., Nestle) has its own decision support system. A contract has been signed between Nestle and SAP to purchase $200 million worth of software to be accessed by all its employees. The applications, which are both internal and external, will be in the following areas: e-commerce, product life cycles, financial and cost management, marketing, customer relationships, and knowledge management. In addition, Nestle USA has signed a contract with IBM Corp to build its direct-to-customer B2B website, nestleezorder.com. Nestle is now one of the enterprises possessing a dual-channel supply chain.

Although dual-channel supply chains make profits for enterprises, problems also arise. Customer returns are so common that they become a very important factor influencing decision-making processes because the inherent characteristics of the direct online channel mean that customers cannot touch the physical commodities when the purchasing behavior occurs. In addition, profit is always accompanied with risk, and supply-chain participants have different attitudes toward risk. In fact, many factors should be considered in a dual-channel supply chain's decision-making process, and we want to make some contribution to this topic from the point of risk management. The principal contribution of this paper is the development of a model based on the consideration of participants' risk aversion attitude and costumer returns, which could support decision-making processes well.

2 Literature Review

The emergence of dual channels has caught the attention of academic circles, and conflict and coordination problems have been investigated by many scholars. In spite of the wide public concern and several academic research results on dual-channel supply chains, not much attention has been paid to dual-channel risk issues.

Currently, the study of supply chain risk issues focuses mainly on single traditional retail channels, and considering risk factor as a model parameter has gradually become the main method in supply chain research. Lau and Lau [3] used variance to measure retailers' risk and optimized the expected revenue of the manufacture and the retailer to obtain a counter-intuitive conclusion: it was not always good for the retailer to obtain return permission from the manufacturer. Gan et al. [4] proposed the coordinated study of risk-averse supply chains early. Recently, Choi et al. [5] and Choi and Chow [6] studied the return problem and fast response problem in supply chains using the mean-variance method. Chen et al. [7] analyzed the risk-averse newsvendor problem using an exponential utility function and found that the difference between the risk-averse case and risk-natural case was not very large. Chen et al. [8] took advantage of CVaR[1] to analyze the newsvendor problem and created an inventory model with additive stochastic demand and multiplicative stochastic demand. Wu et al. [9] adopted two

[1] VaR: Abbreviation for value at risk, which is a widely used risk measure of the risk of loss for a specific portfolio of financial assets in financial mathematics and financial risk management. CVaR: Abbreviation for conditional value at risk, also called Expected Shortfall (ES), which is an alternative to VaR that is more sensitive to the shape of the loss distribution in the tail of the distribution. —— Wikipedia. Both of them are also now used in supply chain risk management.

different risk measures, VaR (see Footnote 1) and CVaR, to studied the impact of uncertainty on the inventory strategy of a risk-averse newsvendor and found that different risk measures had a large effect on the inventory strategy. Chiu and Choi [10] reviewed the mean-variance model of supply chain risk issues, dividing the existing literatures into three types: single cycle problems, multiple cycle problems and information updating problems. All of these stated that the mean-variance model had become an important method for researching supply chain risk issues. The literatures above did not cover the optimal problem where both the supplier and the retailer are risk averse in dual-channel supply chains.

Today, market competition is becoming increasingly fierce, and accepting customer returns has proven to be an important means of enterprise marketing. Some scholars' research has suggested that customer returns are related to the price of the good and higher prices lead to more returns [11]. Anderson et al. [12] studied the online sales of women's fashion clothing and found that demand and customer returns were strongly positive correlated. Mostard and Teunter [13] studied the impact of customer returns on online retailer's strategies, but their research was restricted to the given price newsboy problem in a single cycle. Chen and Bell [14] studied pricing and ordering strategies in consideration of customer returns and presented the optimal retail price and order quantity under additive stochastic demand. Ghoreishi et al. [15] studied perishable goods' pricing and ordering strategies when there are currency inflation and customer returns. None of the literature refers to dual-channel supply chain strategies in which all of the supply chain participants are risk averse and customer returns exist.

Because of the inherent complexity of supply chains, especially dual-channel supply chains, modeling is not easy, and the management of supply chain systems requires not only rigid computer control but also human knowledge. A decision support system (DSS) can guarantee analysis. Decision making is easily understood with the help of a computer. Some research refers to DSS for Supply chain management (SCM). Audimoolam and Dutta [16] applied for a United States Patent for a DSS regarding SCM that collaborates forecasting, ordering, replenishment and inventory. Biswas and Narahari [17] disclosed a DSS called DESSCOM (decision support for supply chains through object modeling), the two major components of which are DESSCOM-MODEL (model library) and DESSCOM-WORKBENCH (decision workbench). Blackhurst et al. [18] proposed a decision support modeling methodology called a Product Chain Decision Model (PCDM), which can assist a manager in decision making by modeling both the operation of a supply chain design and the effects of product and process design decisions. Sarkis [19] discussed the decision framework for a green supply chain by exploring the applicability of a dynamic non-linear multi-attribute decision model. Few studies refer to decision support systems for dual-channel supply chains. This paper tries to build a decision-making model for a risk-averse dual-channel supply chain to support a better understanding of the system complexity and expand the model library.

In summary, few pieces of research refer to the decision-making process in a dual-channel supply chain in which both of the supply chain participants are risk averse. Although the customer returns problem has been studied many times, it mostly focuses on a single-channel supply chain. This paper analyzes the decision-making process in consideration of direct-channel consumers' returns under the stochastic market requirement and tries to provide references for practice in reality.

3 The Model

We consider a dual-channel supply chain in which a risk-averse manufacturer sells to a risk-averse retailer and to consumers directly. There is only one commodity. D_d, p_d, c_d, D_r, p_r and c_r indicate the demand, the price, and the production cost of the direct and retail channels, respectively. We assume that the manufacturer's wholesale price is w, and the unsold goods' salvage is zero. To obtain the demand functions (D_d and D_r), we adopt the customer utility function in Ingene and Parry [20]

$$U \equiv \sum_{i=d,r} (\alpha_i D_i - \frac{bD_i^2}{2}) - \theta D_d D_r - \sum_{i=d,r} p_i D_i. \tag{1}$$

α_i denotes the basic demand in channel i ($i = d, r$), b denotes the rate of change of marginal utility and is normalized to 1 in the sequel for brevity and θ ($0 \le \theta < 1$) denotes channel substitutability. The channels are demand interdependent (unless $\theta = 0$). Maximization of Eq. (1) yields the demand functions for each channel, as follows:

$$D_d = \frac{\alpha_d - \theta\alpha_r - p_d + \theta p_r}{1-\theta^2} \quad \text{and} \quad D_r = \frac{\alpha_r - \theta\alpha_d - p_r + \theta p_d}{1-\theta^2}. \tag{2}$$

The actual demand is often stochastic; we adopt the thought in Petruzzi and Dada [21], and assume that the stochastic demand in each channel is $X_i = D_i + \varepsilon$, $\varepsilon \sim N(0, \sigma^2)$, ($i = d, r$).

Based on the inherent characteristic that customers cannot touch the physical commodities when purchasing behavior occurs, we consider customer returns in the direct channel. We assume that customer returns can obtain full compensation. The returns function is $R_d = \beta_d X_d$ according to literature reviews, where β_d is the return rate in the direct channel. Manufacturers can always meet the needs of retailers in single cycle sales. The objective of the manufacturer and retailer is maximizing the expected revenue. We first discuss the optimal strategy under a centralized decision scenario and then discuss the optimal strategy under a decentralized decision scenario. After, we compare the results for each scenario.

3.1 Decision Making in Centralized Dual-Channel Supply Chain

In line with the model description, the stochastic demand in each channel is $X_d = D_d + \varepsilon$, $X_r = D_r + \varepsilon$, $\varepsilon \sim N(0,\sigma^2)$, and the customer return function in a single cycle is $R_d = \beta_d X_d$. Given the above, the manufacturer's revenue is $\Pi_d = (D_r + \varepsilon)w + (D_d + \varepsilon)(p_d - c_d) - p_d\beta_d(D_d + \varepsilon)$. Because we assume $E(\varepsilon) = 0$, the manufacturer's expected revenue is

$$E(\Pi_d) = D_r w + D_d(p_d(1-\beta_d) - c_d). \tag{3}$$

The retailer's revenue is $\Pi_r = (D_r + \varepsilon)(p_r - w - c_r)$, and its expected revenue is

$$E(\Pi_r) = D_r(p_r - w - c_r). \tag{4}$$

The dual-channel supply chain's revenue under a decentralized decision is

$$E(\Pi_{sc}) = D_r(p_r - c_r) + D_d(p_d(1-\beta_d) - c_d). \tag{5}$$

The first optimal conditions are as follows,

$$\frac{\partial E(\Pi_{sc})}{\partial p_d} = (-\frac{1}{1-\theta^2})(p_d(1-\beta_d) - c_d) + (1-\beta_d)D_d + \frac{\theta}{1-\theta^2}(p_r - c_r). \tag{6}$$

$$\frac{\partial E(\Pi_{sc})}{\partial p_r} = (-\frac{1}{1-\theta^2})(p_r - c_r) + D_r + \frac{\theta}{1-\theta^2}(p_d(1-\beta_d) - c_d). \tag{7}$$

Because the second optimal conditions are $\frac{\partial^2 E(\Pi_{sc})}{\partial p_d^2} = -\frac{2(1-\beta_d)}{1-\theta^2} < 0$, $\frac{\partial^2 E(\Pi_{sc})}{\partial p_r^2} = -\frac{2}{1-\theta^2} < 0$, the dual-channel supply chain's revenue is strictly a concave function with respect to p_d and p_r under a centralized decision. Combining Eqs. (6) and (7) gives proposition 1. Then, we can obtain the optimal expected revenue $E(\Pi_{sci}^*)$ according to Eq. (5).

Proposition 1. The optimal prices of the manufacturer and the retailer under a centralized decision are as follows:

$$p_{di}{}^* = \frac{2A_d + \theta(2-\beta_d)\cdot A_r}{B} \quad \text{and} \quad p_{ri}{}^* = \frac{2(1-\beta_d)\cdot A_r + \theta(2-\beta_d)\cdot A_d}{B},$$

where $A_d = c_d - \theta c_r + (1-\beta_d)(\alpha_d - \theta\alpha_r)$, $A_r = c_r - \theta c_d + \alpha_r - \theta\alpha_d$ and $B = 4(1-\beta_d) - \theta^2(2-\beta_d)^2$.

3.2 Decision Making in a Decentralized Dual-Channel Supply Chain

The stochastic fluctuation of market demand gives risk to supply chain participants. We use mean-variance analysis to evaluate the expected utility in consideration of the risk aversion of the manufacturer and the retailer. We assume that there is a Stackelberg game between the manufacturer, who is the leader, and the retailer, who is the follower. The expected utility function is $U(\Pi) = E(\Pi) - k\sqrt{Var(\Pi)}$, which is presented in Lau [22]. The following are the expected revenue and variance of the manufacturer and the retailer.

The revenue, expected revenue and revenue's variance of the manufacturer and retailer are as follows:

$$\Pi_d = (D_r + \varepsilon)w + (D_d + \varepsilon)(p_d(1-\beta_d) - c_d), \Pi_r = (D_r + \varepsilon)(p_r - w - c_r),$$

$$E(\Pi_d) = D_r w + D_d(p_d(1-\beta_d) - c_d), E(\Pi_r) = D_r(p_r - w - c_r),$$

$$Var(\Pi_d) = E[(\Pi_d - E(\Pi_d))^2] = [w + p_d(1-\beta_d) - c_d]^2\sigma^2 \text{ and}$$

$$Var(\Pi_r) = E[(\Pi_r - E(\Pi_r))^2] = [p_r - w - c_r]^2\sigma^2.$$

3.2.1 Decision Making of the Retailer

With the reverse recursive method, the retailer decides the retail price in the case of having known the wholesale price and direct channel price of the manufacturer in the second stage of the Stackelberg game. The expected utility function of the retailer is

$$U(\Pi_r) = E(\Pi_r) - k\sqrt{Var(\Pi_r)} = (p_r - w - c_r)(D_r - k_r\sigma). \tag{8}$$

k_r is the degree of risk aversion; $k_r > 0$ means the retailer is risk averse, and $k_r = 0$ means the retailer is risk neutral.

Taking the first and second derivatives of $U(\Pi_r)$ with respect of p_r yields the following:

$$\frac{\partial U(\Pi_r)}{\partial p_r} = D_r - k_r\sigma + (p_r - w - c_r)(-\frac{1}{1-\theta^2}), \frac{\partial^2 U(\Pi_r)}{\partial p_r^2} = -\frac{2}{1-\theta^2} < 0.$$

$U(\Pi_r)$ is concave function about p_r. Therefore, we can obtain the optimal retail price:

$${p_r}^* = \frac{1}{2}[\alpha_r - \theta\alpha_d + \theta p_d - k_r\sigma(1-\theta^2) + w + c_r]. \tag{9}$$

3.2.2 Decision Making of the Manufacturer

In the first stage of the game, the manufacturer decides the optimal wholesale price and direct channel price. The expected utility function of the manufacturer is

$$U(\Pi_d) = E(\Pi_d) - k_d\sqrt{Var(\Pi_d)} = (D_r - k_d\sigma)w + [p_d(1-\beta_d) - c_d](D_d - k_d\sigma). \tag{10}$$

The manufacturer will take into account the retailer's action in the first stage. Therefore, p_r^* is substituted into Eq. (10). Taking the first and second derivatives of $U(\Pi_d)$ with respect of p_d and w yields the following:

$$\frac{\partial U(\Pi_d)}{\partial p_d} = \frac{\theta}{2(1-\theta^2)}w + (1-\beta_d)(D_d - k_d\sigma) + \frac{\theta^2 - 2}{2(1-\theta^2)}[p_d(1-\beta_d) - c_d] \tag{11}$$

and

$$\frac{\partial U(\Pi_d)}{\partial w} = -\frac{w}{2(1-\theta^2)} + (D_r - k_d\sigma), \tag{12}$$

$\frac{\partial^2 U(\Pi_d)}{\partial p_d^2} = \frac{(1-\beta_d)(\theta^2-2)}{1-\theta^2} < 0, \quad \frac{\partial^2 U(\Pi_d)}{\partial p_d \partial w} = \frac{\theta(2-\beta_d)}{2(1-\theta^2)}, \quad \frac{\partial^2 U(\Pi_d)}{\partial w^2} = -\frac{1}{1-\theta^2} < 0, \quad \frac{\partial^2 U(\Pi_d)}{\partial w \partial p_d} = \frac{\theta}{2(1-\theta^2)}$.
The Hesse matrix of the manufacturer's expected utility function is as follows:

$$H(U(\Pi_d)) = \begin{bmatrix} \frac{(1-\beta_d)(\theta^2-2)}{1-\theta^2} & \frac{\theta(2-\beta_d)}{2(1-\theta^2)} \\ \frac{\theta}{2(1-\theta^2)} & -\frac{1}{1-\theta^2} \end{bmatrix}. \tag{13}$$

$|H(U(\Pi_d))| = \frac{(8-5\theta^2)(1-\beta_d)-\theta^2}{4(1-\theta^2)^2}$. When $(8-5\theta^2)(1-\beta_d) > \theta^2$ and $|H(U(\Pi_d))| > 0$, the objective function is at a minimum. Actually, the customer return rate that the supply chain participants can bear is less than 50 %, i.e., $\beta_d \leq 0.5$; thus, the inequality above is usually set up. Combining Eqs. (11) and (13), we obtain the optimal direct channel price and wholesale price.

Proposition 2. The optimal direct channel price and wholesale price of the manufacturer under a decentralized decision are

$$p_d^* = \frac{2(2-\beta_d)\theta \cdot M_1 + 4(2-\theta^2)(1-\beta_d) \cdot M_2}{N} \quad \text{and}$$

$$w^* = \frac{2(2-\theta^2)(1-\beta_d)(2M_1 + (2-\beta_d)\theta M_2)}{N}.$$

Here,

$$N = 4(2-\theta^2)(1-\beta_d) - \theta^2(2-\beta_d)^2$$

$$M_1 = \frac{1}{2}[-\theta c_d - c_r + \alpha_r - \theta\alpha_d - \sigma(1-\theta^2)(2k_d - k_r)]$$

$$M_2 = \frac{1}{2(2-\theta^2)}[\frac{(2-\theta^2)c_d}{1-\beta_d} + \theta c_r + (2-\theta^2)\alpha_d - \theta\alpha_r - \sigma(1-\theta^2)(\theta k_r + 2k_d)].$$

Substituting p_d^* and w^* into p_r^* results in the following proposition.

Proposition 3. The optimal retail price under a decentralized decision is

$$p_r^* = \frac{1}{2}[\alpha_r - \theta\alpha_d + \theta p_d^* - k_r\sigma(1-\theta^2) + w^* + c_r].$$

We analyze the impact of k_d, k_r and σ on the optimal decision variables and obtain the following propositions.

Proposition 4. The degree of risk aversion of the manufacturer is negatively correlated with the optimal decisions of the manufacturer and the retailer under the decentralized decision.

Proposition 5. The degree of risk aversion of the retailer is positively correlated with the optimal direct channel price and wholesale price of the manufacturer and is negatively correlated with the retail price under the decentralized decision.

Proposition 6. The stochastic fluctuation of market demand is negatively correlated with the optimal decisions of the manufacturer and the retailer under the decentralized decision.

The proofs of Proposition 4, 5 and 6 can be obtained by emailing the authors.

4 Numerical Experimentation

We assume $\alpha_d = 100$, $\alpha_r = 100$, $c_d = 2$, $c_r = 2$, and $\theta = 0.3$ under a centralized decision scenario. When $\beta_d = 0.2$, the optimal direct channel price and retail price are $p^*_{di} = 52.7286$ and $p^*_{ri} = 49.9367$. The maximum expected revenue is $\Pi^*_{sci} = 3314.3$.

Next, we discuss the decentralized decision scenario.

(1) The impact of the customer return rate and demand fluctuation on optimal decision variables. Assume $k_d = 0.5$, $k_r = 0.5$ and $\sigma \in [0, 20]$. The results obtained by MATLAB are presented in the following four figures.

Based on Figs. 1, 2, 3 and 4, as the return rate increases, the wholesale price and the retail price first decrease and then increase, the direct channel price increases and the retailer's expected revenue increases. However, the manufacturer's expected revenue and the whole supply chain's expected revenue decrease until the return rate approaches 1. Actually, the customer return rate that the supply chain participants can bear is less than 50 %. By plotting between 0 and 1, observing the variation trend of each variable becomes more intuitive. We define $\Delta z/\Delta x$ as the *rate of change* of z. For the retailer, let $\sigma = 5$. When β_d changes from 0 to 0.5, the rate of change of the wholesale price is $(47.3750 - 44.5862)/0.5 = 5.5776$, and the rate of change of the retail price is $(65.9562 - 65.1714)/0.5 = 1.5696$, which is smaller than the return rate's rate of change, i.e., the main reason the retailer's revenue increases. For the manufacturer, the wholesale price decreases, and goodwill is damaged, as evidenced by the return rate increasing and sales dropping in the direct channel, resulting in revenue decreasing, despite the wholesale price increasing. Eventually, the manufacturer accounts for most of the revenue in terms of the supply chain revenue distribution.

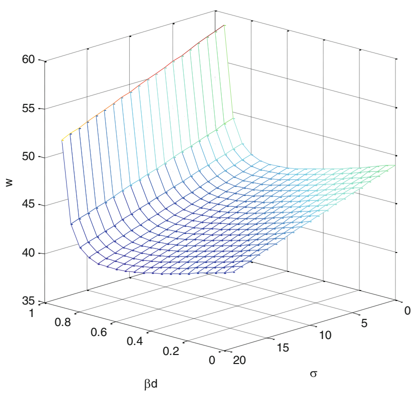

Fig. 1. Impact of β_d and σ on w

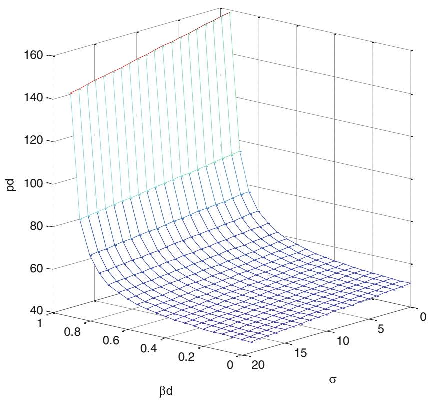

Fig. 2. Impact of β_d and σ on p_d

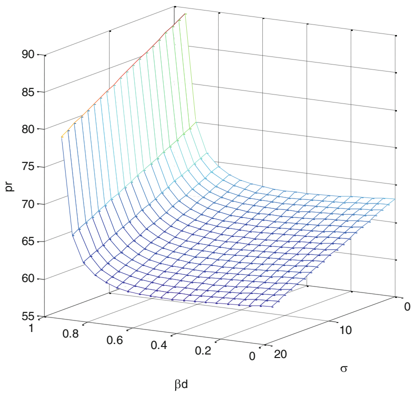

Fig. 3. Impact of β_d and σ on p_r

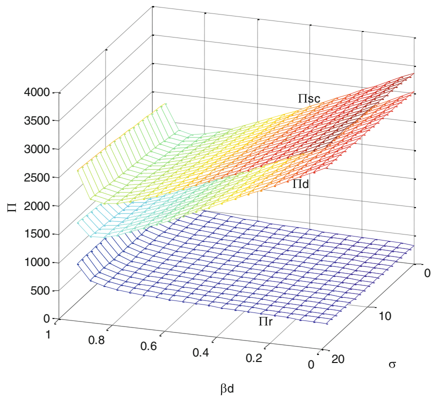

Fig. 4. Impact of β_d and σ on Π_d, Π_r and Π_{sc}

As demand fluctuation becomes more aggravated, the wholesale price, direct channel price and retail price decrease. Both of the channels' revenues increase.

When $k = 0$ and $\sigma = 0$ under decentralized decision, we obtain $p_d^*(\beta_d = 0.2) = 51.9889 < p_{di}^*$, $p_r^*(\beta_d = 0.2) = 67.6668 > p_{ri}^*$ and $\Pi_{sc}^*(\beta_d = 0.2) = 2960.6 < \Pi_{sci}^*$, indicating that the revenue under the decentralized decision is smaller than that under the centralized decision.

(2) The impact of the degree of risk aversion and demand fluctuation on optimal decision variables. Assume $k_d = k_r = k$, $k \in [0, 3]$ and $\sigma \in [0, 30]$. The results obtained by MATLAB are presented in Fig. 5.

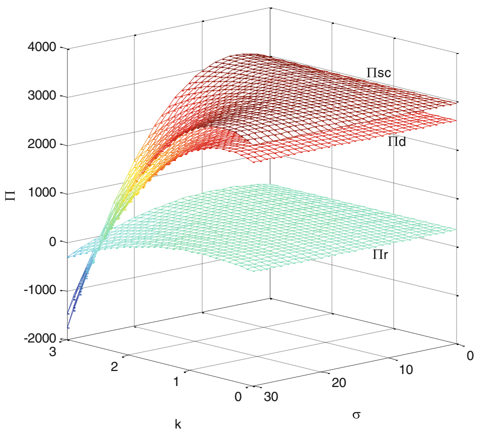

Fig. 5. Impact of k and σ on Π_d, Π_r, Π_{sc}

Based on Fig. 5, as the degree of risk aversion increases, the variation trends of the revenue of the manufacturer, the retailer and the whole supply chain change similarly, and all have close relations to the demand fluctuation. When demand fluctuation is small, revenue increases as the degree of risk aversion increases; as demand fluctuation becomes larger, revenue first increases and then decreases. The demand fluctuation directly depicts the risk that participants face. The above results suggest that participants' risk aversion favors high revenue when demand is relatively stable but may have a negative impact on revenue with demand volatility.

As the demand fluctuation becomes more aggravated, the variation trends of the revenue of the manufacturer, the retailer and the whole supply chain are closely related to the degree of risk aversion. When the degree of risk aversion is small, revenue increases as demand fluctuation increases; when the degree of risk aversion degree becomes larger, revenue first increases and then decreases.

Revenue under the decentralized decision is lower than that under the centralized decision when participants are risk neutral or demand is stable ($\Pi^*_{sc}(k = 0, \sigma = 0) = 2960.6 < \Pi^*_{sci}$). However, when participants are risk averse and demand is unstable, revenue under the decentralized decision could increase, but the maximum revenue is still lower (Π^*_{sc} $(k = 0.25, \sigma = 30) = 3161.4 < \Pi^*_{sci}$).

(3) Let us discuss the variation trends of the decision variables when the variance of the demand is confirmed and the degrees of risk aversion between the manufacturer and the retailer are different. Fixing $\beta_d = 0.2$ and $\sigma = 10$, the results are as follows:

Table 1. Optimal solutions when k_d is fixed and k_r changes

k_d	k_r	w^*	p_d^*	p_r^*	Π_d^*	Π_r^*	Π_{sc}^*	Π_{sci}^*
0.5	0	42.3	48.6	64.4	2587.0	446.4	3033.4	3314.3
0.5	1	46.9	48.7	62.2	2777.7	328.6	3106.3	3314.3
0.5	2	51.4	48.8	59.9	2991.2	176.7	3167.8	3314.3
0.5	3	56.0	48.9	57.7	3227.4	−9.4	3218.0	3314.3
0.5	4	60.6	49.0	55.4	3486.3	−229.6	3256.8	3314.3
0.5	5	65.2	49.1	53.2	3768.1	−483.9	3284.2	3314.3

Based on Table 1, when k_d is fixed and k_r increases, the optimal wholesale price and direct channel price increase, and the optimal retail price decreases. Meanwhile, the manufacturer's revenue increases, and the retailer's revenue decreases, which results in the whole supply chain's revenue increasing. This scenario is very bad for the retailer. The retailer decreases the retail price, but the manufacturer increases the wholesale price. The slight increase in the direct channel price has little impact on customers' transformation between the two channels. So, the retailer's revenue receives a large shock, but the manufacturer benefits.

Table 2. Optimal solutions when k_r is fixed and k_d changes

k_r	k_d	w^*	p_d^*	p_r^*	Π_d^*	Π_r^*	Π_{sc}^*	Π_{sci}^*
0.5	0	50.0	52.0	66.5	2699.9	304.2	3004.1	3314.3
0.5	1	39.1	45.3	60.1	2618.6	490.2	3108.7	3314.3
0.5	2	28.2	38.7	53.6	2374.7	719.7	3094.3	3314.3
0.5	3	17.3	32.0	47.2	1968.2	992.7	2960.9	3314.3
0.5	4	6.4	25.3	40.7	1399.1	1309.2	2708.3	3314.3
0.5	5	-4.5	18.6	34.3	667.3	1669.3	2336.6	3314.3

Based on Table 2, when k_r is fixed and k_d increases, the optimal wholesale price, direct channel price and optimal retail price decrease. Meanwhile, the manufacturer's revenue decreases, and the retailer's revenue increases, which results in the whole supply chain's revenue first increasing and then decreasing. The retail price decreases more slowly than the wholesale price and at the same rate as the direct channel price, which means that the price war has little impact on consumers' channel selection. Therefore, this scenario benefits the retailer, who obtains higher revenue.

5 Conclusions

The principal contribution of this paper is building a mathematic model that could support decision-making process in consideration of direct-channel consumers' returns under the stochastic market requirement. Optimum decisions are proposed in the centralized dual-channel supply chain. In terms of decentralized decisions, we use an analytical method and numerical simulation. The results show that a high direct channel return rate will reduce the revenue of the manufacturer and the whole supply chain, but it is beneficial for the retailer in obtaining high revenue, regardless of market demand fluctuations. The impact of the degree of risk aversion on revenue is closely related to demand fluctuation; when the market is stable, revenue increases with an increase in the degree of risk aversion, and when the market is unstable, revenue increases first and then decreases. When the manufacturer's risk aversion is fixed and the retailer's risk aversion increases, it is a nightmare for the retailer; however, when the retailer's risk aversion is fixed and the manufacturer's risk aversion increases, it is beneficial for the retailer. These conclusions could help supply chain participants adjust their risk aversion attitude to obtain maximum revenue through observing or predicting the market situation and other enterprises' risk attitude. The fact that the expected revenue under a decentralized decision is lower than that under a centralized decision shows that the decentralized decision will lead to double marginalization.

The model in this paper is not difficult to understand but is very useful for managers when making decisions. Parameters could be added or reduced or changed on the basis of our model, which means the model is flexible. As we know, the decision support system for a dual-channel supply chain is large scale and complex as a type of network information system that includes several modules, such as a problem analysis and information processing module, a decision analysis module, an electronic communication module, an electronic conference module, an information management module, a system management module and a human-computer interaction module. A little mistake may result in disastrous results in the complex system. The robust mathematic model in our paper could be used in the problem analysis and decision analysis module and will be good for the system. It is a real expansion of the model base in the decision support system for dual-channel supply chains.

There are some limitations in this paper. We did not consider the existence of substitute products in this paper. The contract problem of dual-channel supply chains in consideration of returns and risk aversion in both of the channels will be discussed in the future.

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Scaling Issues in Additive Multicriteria Portfolio Analysis

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Abstract. We discuss the effects of different utility scales on the results of multi-attribute portfolio problems. In particular, we analyze three effects: (i) the portfolio size effect, that the evaluation might be biased according to the number of items included in a portfolio, (ii) the baseline effect, which requires attention to the consequences of not including an item in a portfolio, and (iii) consistency across different aggregation sequences. We show that these three effects have similar causes related to the use of an interval utility scale, which allows for additive transformation of utilities. We discuss several ways to overcome these problems, and their consequences for utility and weight elicitation.

Keywords: Portfolio composition · Size effect · Baseline effect · Consistent aggregation · Utility scaling

1 Introduction

Most methods for multi-attribute decision making assume that the decision maker deals with a finite set of mutually exclusive alternatives, and has to choose one of them, or rank or sort these alternatives [19]. However, this assumption of exclusive alternatives is often not fulfilled in real life decision problems. Many problems are portfolio problems, in which the decision maker has to put together a portfolio of different actions, that will all be undertaken. The classical application of portfolio problems is in financial investments, where an investor can purchase different financial instruments and has to decide about how much to spend on each of them based on profit-risk considerations [14] or multiple criteria [23,24]. Problems with a portfolio structure also occur in many other fields. In particular, the selection of projects in many areas leads to portfolio problems, for example in the public sector [7,9,16], research and development [13,15,20], IT projects [18], introduction of new products etc. To abstract from the specific area of application, we will in this paper use the term "item" to denote the

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objects (projects, financial investments, products etc.) from which a portfolio is to be composed.

Multi-attribute portfolio problems add another level of complexity to multi-attribute decision problems. One not only has to perform an aggregation across attributes to evaluate alternatives. Portfolio problems also involve an aggregation across items to obtain the evaluation of the entire portfolio [13]. This higher level of complexity must also be reflected in DSS to support decision makers in such problems, which need to contain modules for both aggregation steps.

These two aggregation steps can be performed independently of each other, and in different sequences. One possibility is to first aggregate across items within each attribute and then perform a multi-attribute evaluation of entire portfolios. Alternatively, one can first perform a multi-attribute evaluation of each item, and then aggregate these (scalar) values for the entire portfolio. Both approaches have been discussed in literature. For portfolios of R & D projects, several methods following the first approach have been developed [10]. However, application of this approach is limited by the potentially large number of portfolios, which makes it difficult to determine the set of feasible and efficient portfolios. Special branch and bound methods [21] or metaheuristics [5,6] have been proposed for this task. Even if all efficient portfolios can be generated, the selection task among these many (then mutually exclusive) alternatives is very difficult and can present a challenge for the decision maker, which requires specific problem representations in DSS to make that task easier [8].

Other approaches try to determine an optimal portfolio based on evaluations of items, which result from the application of a multi-attribute decision method to individual items. These approaches then use mathematical programming techniques to construct the optimal portfolio. For the decision maker, this simplifies the multi-attribute evaluation task, which has to be performed only on individual items. The number of items is much smaller than the total number of (feasible and efficient) portfolios, and the consequences of individual items might be easier to evaluate. This makes this approach particularly suitable for DSS for portfolio problems. In the present paper, we therefore build on literature following this approach.

In principle, the evaluation of items can be performed using any method from multi-attribute decision making. Such portfolio models were proposed using for example multi-attribute value functions [3,12], Data Envelopment Analysis [4], or outranking methods like PROMETHEE [1,2,15]. In the present paper, we will focus on additive utility functions.

However, this approach requires the aggregation of scores of individual items to a portfolio score. In a mathematical programming formulation, this aggregation is usually performed as a summation of the values of items contained in the portfolio. However, this formulation imposes certain requirements on the measurement scales used for the items, which are often ignored in existing literature.

The purpose of the present paper is to explore the requirements on the scales used to measure item values, which are needed for a consistent aggregation of items to a portfolio. In Sect. 2, we review different aspects of these problems, and compare the proposed solutions found in literature. In Sect. 3, we discuss the consequences of these problems for elicitation of marginal utility functions and weights. Section 4 presents a small example and Sect. 5 concludes the paper with an outlook on future research topics.

2 Aspects of the Scaling Problem

We consider a problem in which n items A_i $(i = 1, ...n)$ are available for constructing portfolios. The A_i could, for example, be different R & D projects that can be undertaken. The decision maker can select several out of these projects, taking into account some resource constraints or other constraints that determine whether a portfolio is feasible.

Optimization models to determine the optimal portfolio typically maximize the objective function [12]

$$\sum_{i=1}^{n} z_i v(A_i) \tag{1}$$

subject to the feasibility constraints mentioned above. In (1), z_i is a binary variable indicating whether item A_i is included in the portfolio ($z_i = 1$ if it is included), and $v(A_i)$ is the value of item A_i obtained from the multi-attribute evaluation. In this paper, we assume that the evaluation results from an additive value function of the form

$$v(A_i) = \sum_{j=1}^{m} k_j v_j(x_{ij}) \tag{2}$$

where

x_{ij} is the outcome obtained by item A_i in attribute j;
v_j is the marginal value function of attribute j;
k_j is the weight (scaling constant) for attribute j.

For the purpose of this paper, it is not necessary to distinguish between value functions (defined on sure outcomes) and utility functions (which also represent risk preferences). We therefore will use the two terms interchangeably.

The weights are assumed to be normalized to

$$\sum_{j=1}^{m} k_j = 1 \tag{3}$$

As already pointed out by Almeida and Vetschera [1] for the PROMETHEE V method, a model of the form (1) is not invariant to a linear transformation of the value functions, although a transformation of scores is sometimes needed in order to avoid excluding portfolios with a negative net flow [15]. This can easily be shown by replacing the value function $v(.)$ by a function $w(.) = av(.) + b$:

$$\max \sum_{i=1}^{n} z_i w(A_i) = \sum_{i=1}^{n} z_i \left(av(A_i) + b\right) = a \sum_{i=1}^{n} z_i v(A_i) + bc \tag{4}$$

where $c = \sum z_i$ is the number of items contained in the portfolio. Depending on the sign of b, a linear transformation of the original value function will thus lead to a different objective function which favors either large portfolios (for $b > 0$) or small portfolios (for $b < 0$). We denote this effect as the *portfolio size effect*.

To overcome the portfolio size effect, Vetschera and Almeida [22] proposed the concept of c-optimal portfolios. By adding the constraint $\sum z_i = c$, problem (1) can be solved for portfolios of a given size c. By varying c, different portfolios are obtained, which then can be compared to each other at the portfolio level using any multi-attribute decision method.

A formally similar problem was identified by Clemen and Smith [3], which they referred to as the *baseline problem*. They noted that a model of the form (1) implies that the outcome of not performing a project has a utility of zero. In the usual scaling of marginal utility functions, this would mean it is identical to the worst possible outcome. This condition is obviously not always fulfilled, in particular if some attributes refer to negative effects of the items (e.g., environmental damages caused by construction projects). They argued that the utility scale should be chosen in a way that zero utility is assigned to the outcome of not doing a project, rather than the worst possible outcome. This implies that some projects have negative marginal utility values indicating that the project worsens outcomes in some attributes.

Both problems do not exist if $v(A_i)$ is measured on a ratio scale, which has a fixed zero point (which, to solve the baseline problem, should be identical to the outcome of not including an item in the portfolio). In some cases, portfolio evaluations are naturally measured on a ratio scale, for example if they are considered as certainty equivalents of monetary payoffs [13]. To solve the baseline problem, that would require that the outcome of not including an item in the portfolio is the same for all items. While this sounds like a natural condition, it is not necessarily always fulfilled. For example, the hydrological impact of not building a hydroelectric power station might be quite different depending on the river being considered. A more general formulation of model (1), which was also proposed by Clemen and Smith [3], could be used to solve this problem. Denote by $\overline{A_i}$ the value of not doing item A_i. By reformulating model (1) to explicitly consider the option of not including item A_i, we obtain

$$\sum_{i=1}^{n} z_i v(A_i) + (1 - z_i) v(\overline{A_i}) \tag{5}$$

Since $\sum v(\overline{A}_i)$ is a constant, maximizing (5) will lead to the same solution as maximizing

$$\sum_{i=1}^{n} z_i \left(v(A_i) - v(\overline{A}_i) \right) \tag{6}$$

Conceptually, (6) is very similar to measuring $v(.)$ on a ratio scale with a zero point at the outcome of not including an item, but it is more flexible because it allows for different "zero points" for different items. Morton [17] considered (1) and (5) as two different types of problems, called "project model" and "sector model", and also showed that for the project model, project outcomes must be measured on a ratio scale, while for the sector model, an interval scale is sufficient.

Scaling of the utility function also becomes important when one considers consistency across the different types of aggregations. As we have already discussed, multi-attribute portfolio problems involve both an aggregation across items, and an aggregation across criteria. These two aggregations can be done in different order. If aggregation across items is performed first, it can be done at two levels: at the level of outcomes, or at the level of marginal utilities. If aggregation across attributes is performed first, aggregation across items will always take place at the level of utilities.

Substituting (2) into (1), we can write the total utility of a portfolio as

$$\sum_i z_i \sum_j k_j v_j(x_{ij}) \tag{7}$$

This formulation represents a situation in which aggregation is first performed across attributes, and the comprehensive evaluations of items are then aggregated to obtain the utility of the entire portfolio. To model an approach in which aggregation across items is performed first (and at the level of marginal utilities), we can rewrite (7) as

$$\sum_j k_j \sum_i z_i v_j(x_{ij}) \tag{8}$$

which implies that the marginal value of a portfolio in attribute j is the sum of the marginal values of all items contained in the portfolio.

Most approaches which first aggregate across items actually do not aggregate items in terms of their marginal values, but in terms of outcomes in each attribute. For example, in creating a project portfolio of some public projects, one can add up the number of citizens who benefit from each project to obtain the total number of beneficiaries. This would imply that the portfolio is evaluated as

$$\sum_j k_j v_j \left(\sum_i z_i x_{ij} \right) \tag{9}$$

In general, the different representations of the total portfolio utility given in Eqs. (7) and (9) will lead to different results. Equivalence between these two values is only possible if certain conditions on the scales of marginal utility functions are fulfilled. Obviously, all $v_j(.)$ must be linear functions. However, this condition is not sufficient. For a general linear function of the form

$$v_j(x_{ij}) = a_j x_{ij} + b_j \tag{10}$$

(7) and (9) will still lead to different values of the entire portfolio, since in (9), the constant b_j is contained only once, while in (7) it occurs once for each item contained the portfolio. Thus, consistency of the different forms of aggregation

also leads to the requirement that the zero point of all marginal utility scales is fixed, and scales can not be transformed by adding a constant. Compared to the previous cases, consistency between different aggregation types further restricts the marginal utility functions to the case of multiplication by a positive scalar, i.e. to

$$v_j(x_{ij}) = a_j x_{ij} \tag{11}$$

while the other two effects also would allow other types of marginal utility functions.

3 Consequences for Utility and Weight Elicitation

For the remainder of the paper, we will, in accordance with [3], consider only linear marginal value functions. Usually, value functions are scaled so that a value of zero is assigned to the worst and a value of one is assigned to the best outcome. For a linear function, this implies that $v(.)$ is defined as follows

$$v_j(x_{ij}) = (x_{ij} - \underline{x_j})/(\overline{x_j} - \underline{x_j}) \tag{12}$$

where $\underline{x_j} = \min_i x_{ij}$ is the worst and $\overline{x_j} = \max_i x_{ij}$ is the best outcome in attribute j. Equation (12) is a linear transformation of the form (10) and thus will lead to the portfolio size effect. The baseline problem is also present, unless if $\underline{x_j}$ is also the outcome of not including an item in the portfolio (and this outcome is the same for all items). It can also lead to inconsistency between different types of aggregation.

For a ratio scale, an adequate transformation is

$$v_j(x_{ij}) = x_{ij}/\overline{x_j} \tag{13}$$

which avoids the constant term. This transformation has the structure of (11) and therefore provides consistency across different types of aggregation. It also avoids the portfolio size effect. It is adequate for the baseline problem if and only if the outcome of not including an item in the portfolio is actually zero, and this is the same for all items. This will be the case in many applications. For example, in considering portfolios of public facility projects, if a facility is not built, zero citizens will benefit from it, or zero area of land will be used if a construction project is not carried out. However, there might also be instances where this is not the case, for example erosion of a river bed will take place (at a non-zero level), if a hydroelectric dam is not built.

This scaling will also guarantee that all items have marginal utility values which are less than or equal to one in all attributes. However, the marginal utility value of the worst item (concerning this attribute) is not zero, and might even be negative (if that item has consequences which are worse than doing nothing).

The transformation (13) will map outcomes to a different utility scale than (12). This means that weights which were elicited using (12) can not directly be applied to a model using (13) (and vice versa), but have to be adjusted to the different scale. Denote by k_j the weights used in the original model using (12) and by q_j the weights to be used for (13). To obtain equivalent evaluations of alternatives, the weights must be rescaled as

$$q_j = k_j \cdot \frac{\overline{x_j}}{\overline{x_j} - \underline{x_j}} \tag{14}$$

or, to maintain the scaling that weights sum up to one

$$q_j = \frac{k_j \cdot \overline{x_j}/(\overline{x_j} - \underline{x_j})}{\sum_l k_l \cdot \overline{x_l}/(\overline{x_l} - \underline{x_l})} \tag{15}$$

This change in weights could be avoided by using the transformation

$$v_j(x_{ij}) = x_{ij}/(\overline{x}_j - \underline{x}_j) \tag{16}$$

which transforms x_{ij} by the same factor as (12), but does not include a constant term. In this scale, the best item might have a utility which is larger than one, and the worst item might have a negative utility. On the other hand, with this scaling, weights which were obtained using the standard scaling (12) can still be used without transformation.

4 Numerical Example

We present these ideas in an example, which is similar to the one used in [3]. We consider a portfolio of IT projects, which are evaluated according to four criteria (financial contribution, project success, contribution to the business image, strategic fit) as shown in Table 1. The last column lists the necessary resources for each project, in total there is a budget limit of 2600. The weights presented in the last line are related to an elicitation procedure based on an interval scale.

Applying the additive model, the results indicate a portfolio with projects P1, P3, P5, P6, P8, for the interval scale. Using the ratio scale with the appropriate new set of weights, leads to another portfolio, in which P6 is replaced by P7 and P10. This is the correct solution for this problem, based on a multicriteria portfolio analysis. That is, the interval scale favors a portfolio with size $c = 5$, while the ratio scale indicates a portfolio with $c = 6$. According to Table 1, projects P7 and P10 require additional resources of 50, available in the limit constraint, compared to project P6. On the other hand these two projects, compared to project P6, give additional outcomes for all criteria, as shown in Table 2. The interval scale distorts the results. In contrast, the ratio scale is consistent with the actual outcomes at the portfolio level, which matter to the DM. The interval scale favors portfolios with fewer alternatives, decreasing artificially the actual value of larger portfolios. This application is realistic and similar to any kind of portfolio related to real application, specifically in the domain of information systems and DSS Web. The criteria may represent quite well the needs for global environments: the success of the project, and both the strategic fit and image of the organization, when environmental concerns are taken into account.

Table 1. Data for example

Project	Financial contribution	Success	Image	Strategic fit	Resources
P1	7298	0.91	45	98	500
P2	5869	0.99	52	79	800
P3	6873	0.93	82	10	300
P4	4725	0.50	50	100	400
P5	8336	0.71	89	67	400
P6	6982	0.88	60	99	600
P7	7085	0.55	51	10	400
P8	9800	0.99	70	15	700
P9	9823	0.53	45	100	600
P10	5120	0.51	53	97	250
Weights	0.33	0.28	0.22	0.17	

Table 2. Results from example

Project	Financial contribution	Success	Image	Strategic fit
P6	6982	0.88	60	99
P7 + P10	12205	1.06	104	107

5 Conclusions

In this paper, we have discussed several scaling issues which can arise in the context of multi-attribute portfolio problems: The *portfolio size problem* that additive changes in the utility of items create a bias in portfolio evaluation which depends on the number of items in the portfolio; the *baseline problem*, which refers to the fact that not including an item does not necessarily have a utility of zero; and the problem of *consistency of aggregations* in which a different sequence of aggregations across items and attributes might lead to different results. We have shown that these three problems are very similar and are all caused by the impact of an additive utility transformation on the standard portfolio construction model (1).

Since all these problems have a common cause, the methods to alleviate them are also similar. If for all items the effect of not including an item in the portfolio is identical and is equal to zero, a ratio scale type transformation of the form (13) or (16) is sufficient to correct all of them. However, one needs to take care that attribute weights are elicited using the correct scaling, or alternatively adequately adjust weights to reflect the change in scale. In the more general case of unequal baselines for the different items, an optimization model of the type (6) should be used. To ensure consistency of aggregations, it is still necessary to use marginal utility functions of the form (13) or (16). Alternatively, one can focus only on portfolios of a given size, as suggested in the concept of c-optimal portfolios [22].

The present paper still refers to a rather specific setting which is based on an additive aggregation for both items and attributes, as well as linear marginal utility functions. Generalizations in all these directions are therefore possible and necessary. Concerning attributes, an additive utility function implies preferential independence between attributes [11]. If this assumption is violated, other forms of utility functions like multiplicative, bi- or multilinear functions must be used. This increases the complexity of one aggregation step, and this will have an impact on the relationship between the two steps, in particular the consistency problem. We also assumed an additive aggregation across items. While forming the sum is a natural aggregation in many contexts, this is not always the case. In some instances, for example the performance of the weakest item might determine the value of the entire portfolio, suggesting the use of a minimum operator to aggregate across items. Finally, the assumption of linear marginal utility functions is a strong one, and methods for nonlinear marginal utilities need to be developed. However, it should already be clear from the comparatively simple setting we have analyzed in this paper that the question of utility scaling in portfolio problems requires careful consideration in order to avoid possibly misleading results.

The phenomena we have discussed here have practical implications both for decision makers solving portfolio problems, and for the designers of DSS to support them. Decision makers need to be aware that data at the item level can not directly applied to the portfolio problem, and DSS designers have to include adequate methods for aggregation in their systems.

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A New Fuzzy Multi-criteria Decision Making Approach: Extended Hierarchical Fuzzy Axiomatic Design Approach with Risk Factors

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Abstract. In recent years, Axiomatic Design (AD) has been widely used as a multi criteria decision making approach. AD approach compares the design objects and system capabilities in a framework and then selects the best alternative based on these comparisons. Some researchers then include fuzziness in the AD approach which helps to evaluate alternatives in fuzzy environments. The main advantage of fuzzy AD approach is the ability to evaluate both crisp and fuzzy values at the same time during decision process. However, these approaches are not appropriate for hierarchical decision problems. Therefore, these are extended to solve the hierarchical decision problems and Hierarchical Fuzzy Axiomatic Design Approach (HFAD) is presented. In this study, HFAD is extended to include risk factors for the first time in literature and a new approach called RFAD is proposed. Moreover, the application of the new approach is shown on a real world supplier selection problem and the results are compared to the other widely used decision making approaches in literature.

Keywords: Multi criteria decision making · Hierarchical fuzzy axiomatic design · Risk factors · Axiomatic design · Fuzzy analytic hierarchy process · Supplier selection

1 Introduction

Decision making has an important effect on everyday life. Since decisions affect our lives, decision making has attracted the attention of the researchers and numerous methodologies such as Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) etc. have been proposed to solve these problems. In recent years, as an alternative to different multi criteria decision making (MCDM) approaches, Axiomatic Design (AD) has been proposed. AD principles can show how well the system capabilities fit the functional requirements (FRs). There are two axioms in the AD principles. The first one is the *Independence Axiom* and the second one is the *Information Axiom*. Information Axiom provides a new decision making tool when there is a number of alternatives. Different applications of AD such as product design [27, 32], system design [2, 28], manufacturing system design [29], office cells design [19], software design [23, 32] and

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decision making [1, 15, 17, 18] can be found in literature. Kulak et al. [20] present a recent review considering the applications of AD in different areas.

In most decision problems, it is not always possible to know all data exactly. Therefore, fuzzy sets theory, fuzzy numbers and linguistic terms are used in order to incorporate imprecise information. Using fuzzy values in pair-wise comparisons enables to get more accurate results [11]. When data are incomplete or fuzzy, fuzzy MCDM methods are used [5–7]. AD approach is also extended to deal with decision making problems in fuzzy environments by Kulak and Kahraman [17] and Fuzzy Axiomatic Design approach (FAD) is proposed by the authors. Although FAD approach is capable of solving both crisp and fuzzy values in the same model during the evaluation process [18], the literature on FAD as a decision making tool is rather limited. Kulak and Kahraman [17] uses FAD for the selection of a transportation company and comparison of advanced manufacturing systems. Kulak et al. [16] proposes an extended version of FAD including the weights and apply this new approach to the selection of punching machines. Kahraman and Çebi [13] modify the FAD and call it as the Hierarchical Fuzzy Axiomatic Design (HFAD). They illustrate the application of the approach in selecting the teaching assistant.

In addition to criteria and alternatives, decision problems might contain risk factors related to decision elements (i.e. criteria and alternatives) which make decision problems more complicated. Risk factors indicate the potential undesired situations that might occur in future and are useful in uncertain situations. Therefore, considering these risks help decision makers understand the decision elements extensively and make a better decision. However, most decision making approaches proposed so far have not taken into consideration these factors. To fill this gap in literature, a new multi criteria decision making approach considering risk factors is proposed in this study. Unlike other decision making approaches which treat risk factors as separate criteria in the hierarchy of the problem, the proposed approach integrates these factors into the structure of the methodology. Moreover, we illustrate the application of the new approach on a real world supplier selection problem in marble-travertine industry and compare the results with the other well known approaches in literature. Up to our knowledge, this study is the first study that proposes HFAD as a solution approach in supplier selection literature.

The rest of the paper is organized as follows. Detailed explanations of the approach used for supplier selection are described in Sect. 2 followed by the solutions given in Sect. 3. The last section of the paper presents the conclusion.

2 Axiomatic Design (AD)

The most important concept in axiomatic design (AD) is the existence of the design axioms. As stated before, there are two design axioms, namely, Independence Axiom which maintains the independence of *FR*s and Information Axiom which minimizes the information content.

The Independence Axiom states that the independence of functional requirements (*FR*s) must be maintained. *FR*s are the minimum set of independent requirements that characterizes the design goals [27].

The Information Axiom states that among the designs that satisfy the Independence Axiom, the design that has the minimum information content is the best design. The Information Axiom defines the information in terms of information content, I_i, which is the probability of satisfying the given *FR*s. For a given FR_i, I_i is defined as follows:

$$I_i = \log_2\left(\frac{1}{p_i}\right) \quad (1)$$

where p_i is the probability of achieving the functional requirement FR_i and log is the logarithm in base 2. For any design, design range shows what designer wishes to achieve in terms of tolerance and this is defined by the decision maker/ makers. System range shows the capabilities of the system itself and corresponds to the features of alternatives. The intersection of "Design Range" and "System Range" is called the "Common Range". Figure 1 shows the relationship between design, system and common ranges where x-axis shows the value of the functional requirement and y-axis shows the probability density function. The acceptable design solution should be within the common range as shown in Fig. 1. In the case of uniform probability distribution function, p_i can be calculated as in Eq. (2).

$$p_i = \left(\frac{Common\ range}{System\ range}\right) \quad (2)$$

and the information content, I_i is equal to

$$I_i = \log_2\left(\frac{System\ range}{Common\ range}\right) \quad (3)$$

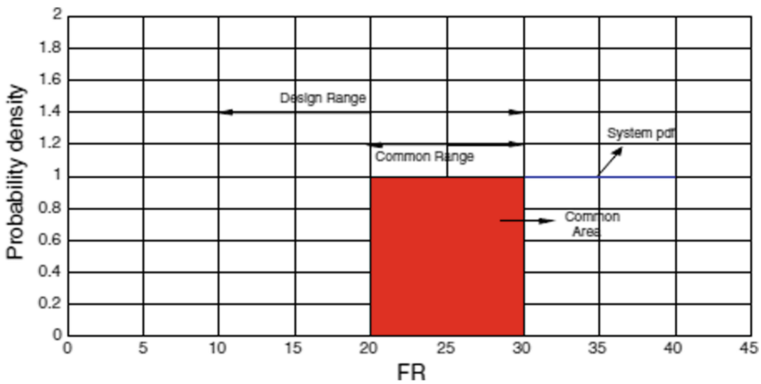

Fig. 1. Design range, system range, common range and probability density function of a *FR* [17, 18]

2.1 Fuzzy Axiomatic Design Approach (FAD) and Hierarchical Fuzzy Axiomatic Design (HFAD)

In fuzzy environments, there is incomplete information about the system and design ranges. The system and design ranges for a certain criterion can be expressed by using linguistic terms, fuzzy sets or fuzzy numbers. If linguistic variables are used, they are first transformed into fuzzy numbers and then converted to crisp scores. The common area is the intersection of triangular or trapezoidal fuzzy numbers of design and system ranges.

In real world decision problems, all criteria do not have the same effect on decision problem. Some of them might be more important than others and this importance should be integrated into the problem. In order to add the weights of criteria, FAD approach is modified and this new approach is called Weighted Fuzzy Axiomatic Design Approach (WFAD) [17]. The modified formulas for WFAD approach are stated in Eq. (4).

$$I_{ij} = \begin{cases} \left[\log_2\left(\frac{1}{p_{ij}}\right)\right]^{\frac{1}{w_j}} & 0 \leq I_{ij} < 1 \\ \left[\log_2\left(\frac{1}{p_{ij}}\right)\right]^{w_j} & I_{ij} > 1 \\ w_j, I_{ij} = 1 & \end{cases} \quad (4)$$

where w_j is the weight of the decision element, p_i is the probability of achieving the functional requirement FR_i, I_{ij} is the information content of the FR_i under the decision element j. The weights of decision elements can be obtained by decision maker via different MCDM approaches such as AHP, TOPSIS etc. However, the WFAD approach can not deal with hierarchical decision making problems. To solve hierarchical decision making problems, Kahraman and Çebi [13] extends the FAD method for solving the hierarchical decision making problems. Similar to FAD and WFAD, HFAD approach can deal with both crisp and fuzzy numbers. The main difference between WFAD and HFAD is that WFAD can not deal with the decision problems having more than one level however HFAD takes the weight of each criterion into account at each level of the hierarchy. For more information about HFAD, the reader can refer to Kahraman and Çebi [13].

2.2 The Proposed Approach: Extended Hierarchical Fuzzy Axiomatic Design with Risk Factors (RFAD)

Risks affect almost all decisions. It can be defined as the probability and severity of adverse effects [24]. Decision making process inherits risks associated with the alternatives and criteria. Therefore, in order to consider these risks in the decision process, the HFAD is extended to include the risk factors in this study and an application of the approach is shown on a supplier selection problem. The new approach is called the extended HFAD with risk factors (RFAD). The objective of the RFAD is to diminish the common range, i.e. the intersection area between the system and design ranges. Common range is the area in which the functional requirements are satisfied, so risk factors are considered in this area. If we can diminish the common range, it is possible to increase the information content. Increasing the information content of an alternative means that this alternative is not good enough to be selected since the AD approach forces the alternative with the minimum information content to be selected as the best alternative in the overall process.

Let *r* define the risk factor of a criterion. In order to diminish the common range, we should multiply it by (1-r), so the information content considering risk factor is calculated as follows.

$$I^m = \log_2\left(\frac{System\ range}{Common\ range\ (1-r)}\right) \tag{5}$$

There are two special situations that might occur when using this formula. The first one is the situation where the risk factor is 0 meaning that there is no risk related to this decision element. In this case, the value of the information content is same with the value of the information content obtained by Eq. (4). The second one is where the risk factor is 1. It means that there is a very high risk in decision element, we obtain 0 in the denominator of the Eq. (5) and the result goes to Infinity. "Infinity" means that the information content of this decision element can not be calculated which implies that this decision element can not be selected. This is expected under a very risky situation (i.e. r=1), and choosing this decision element is not a logical behaviour. Consider an example given in Fig. 2. The example shows the design, system and common ranges for a criterion. Note that all ranges are triangular fuzzy numbers.

Risk factors are defined between 0 and 1. The information contents with three different risk factors are calculated by using Eq. (5) as follows.

I. *r*=0 (no risk)

$$I^m = \log_2\left(\frac{3}{0.286}\right) = 3.39 \tag{6}$$

II. *r*=0.5

$$I^m = \log_2\left(\frac{3}{0.286(0.5)}\right) = 4.39 \tag{7}$$

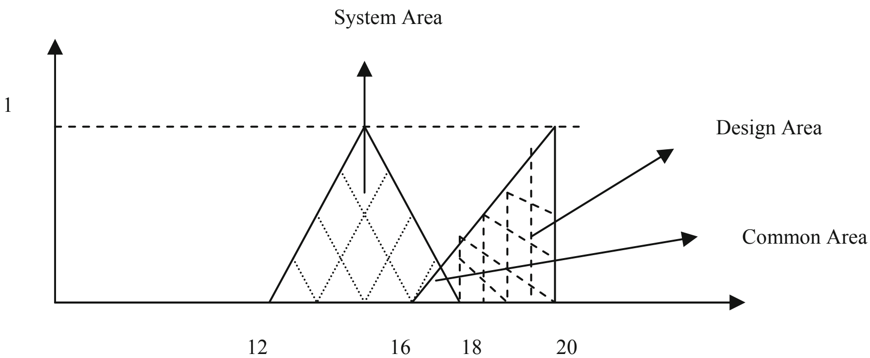

Fig. 2. System, design and common ranges for a criterion

III. *r*=1 (very high risk)

$$I^m = \log_2\left(\frac{3}{0.286(0)}\right) = Infinity \qquad (8)$$

The flowchart of the new approach is shown in Fig. 3.

The RFAD is also appropriate to be used in group decision making when negotiation is achieved. When group members agree on the design ranges, then RFAD can be applied easily to obtain the result.

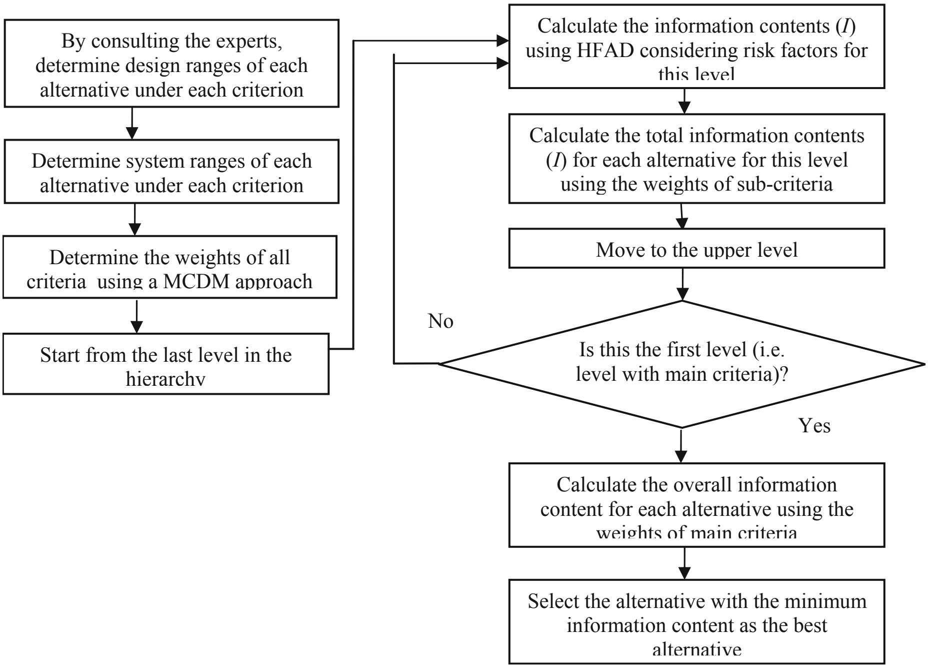

Fig. 3. The flowchart of the RFAD.

3 Application of the Approaches to a Real World Supplier Selection Problem

3.1 Supplier Selection Problem

The competition in the market forces companies to give much more important on the management of supply chain than ever. A good supply chain does not only enable companies gain a competitive advantage but also increases the market size. As a result of competition in the market, the life cycles of products have shortened and the demand for products having good quality with low prices have increased. As a result, the companies are forced to work with different suppliers in order to fulfill these requirements. Although working with different suppliers may provide advantages of high quality products, short production times and low costs, it may lead to the disadvantage of complex management. To gain the quality, speed and cost performance, suppliers should work in accordance with the companies' objectives. The purchasing objectives of most organizations are to reduce the costs of purchased materials and transportation, to keep inventories as low as possible, to assure on-time deliveries with good quality and to have good supplier relations. In order to satisfy these objectives, the suppliers should be selected carefully. The evaluation criteria to identify the suppliers settled which can be described as the *supplier selection problem*. The supplier selection problem can be simply defined as choosing right supplier(s) that can meet the companies' requirements for certain product or material groups. The objective of supplier selection is to determine appropriate suppliers which can meet the firm's needs and strategies at an acceptable cost and quality. Selection of suppliers is the most critical function of purchasing. A vast amount of literature has focused on the supplier selection problem using different approaches. The reader can refer to Ho et al. [12] for a recent up-to-date literature survey on supplier selection.

As a multi criteria decision problem, supplier selection process might include some risks considering features of suppliers, economy, etc. in itself and it is necessary to consider these risks in the decision process. In recent years, risk factors have been widely used in the supplier selection literature. A real world supplier selection example is presented in Levary [22] proposing AHP for decision process. In this study, a manufacturer evaluates and ranks its current foreign supplier against two other potential foreign suppliers based on several criteria of supply reliability such as supplier reliability, country risk, reliability of transportation companies and reliability of supplier's suppliers. Lee [21] proposes to use fuzzy AHP in selecting the supplier of backlight unit. The author considers benefits, opportunities, cost and risks in the hierarchy of the problem. A fuzzy multi-objective programming model is presented in Wu et al. [35] for supplier selection problem taking risk factors into consideration. Different kinds of risks such as quality of the product, service risk, supplier's profile risk and long-term cooperation risk are taken into account in Xiao et al. [36] and an integrated approach consisting of fuzzy cognitive map and fuzzy soft set model is proposed to deal with the supplier selection problem. However, in all these studies, risk factors are integrated in the hierarchy of the problem and treated as separate criteria in selection process. Different from these studies, we integrate the risk factors into the structure of the methodology and propose a new approach. The application of the new approach is shown in the following section.

3.2 Definition of the Real World Supplier Selection Problem

A travertine-marble company needs to determine the best supplier for the production of the product called Classical Travertine with the size of 45.7 × 45.7. The alternatives and criteria are determined by consulting an expert in the company via interviews. The criteria determined are grouped in three classes as cost, product and supplier. The product criterion has four sub-criteria and supplier criterion has three sub-criteria. The hierarchy of the problem is shown in Fig. 4.

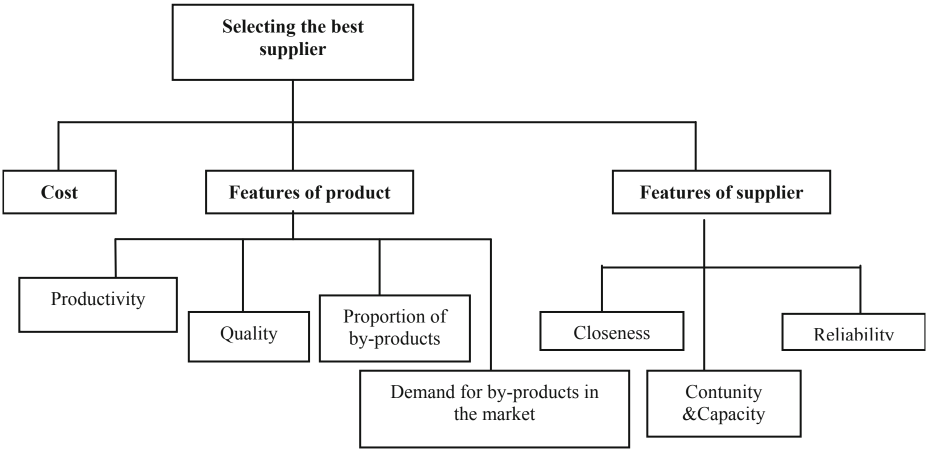

Fig. 4. The hierarchy of the problem.

As presented in the hierarchy, there are three main criteria: *cost*, *features of product* and *features of supplier*. Since the company wants to buy the product with the minimum price in order to decrease the total cost, cost is the first main criterion to be taken into consideration when comparing the suppliers. Total cost is the *purchasing cost* of travertine block.

The second main criterion is the *features of product* criterion which is related to the properties of the product purchased from suppliers such as quality of raw materials and finished products. This criterion consists of four sub-criteria: quality, productivity, proportion of by-products and demand for by-products. Quality is related to the amount of colour variation in the travertine block. So, there is always a risk that the purchased travertine block satisfies the company's requirements. Productivity is related to percentage of the product obtained from given amount of travertine block. This criterion also contains a risk in itself since travertine is a natural material and from some travertine blocks the company cannot get 100 % efficiency. The productivity of the travertine block depends on the site where it is extracted from (i.e. from the supplier). During the production process, travertine scrap is generated. The company can produce products with different sizes from this scrap. These are called by-products. Since there is a limited demand for these products in the market, the company wants to produce by-products as less as possible. Being a natural material, the proportion of by-products and demand for these products cannot be estimated during purchasing. Therefore, there is always a risk that the company cannot get rid of these by-products and the company wants to minimize this risk.

The *features of supplier* criterion are related to the properties of suppliers. This criterion includes three sub-criteria: continuity & capacity, closeness and reliability. The capacity criterion shows that the supplier should have the capacity in order to satisfy the company's need whereas the continuity criterion shows the relationship between supplier and company. This criterion consists of a risk factor that the supplier might not have enough capacity to satisfy the company's orders. In order to reduce transportation cost, supplier should be close to the company. The supplier must be reliable so that it should provide the right amount of materials at the right time from the price written on the contract. So, there is always a risk that the supplier might not satisfy the company's requirements at the right time from the price they have agreed.

3.3 A Numerical Application of HFAD Approach

The problem will be solved first using HFAD. Based on the interviews with the expert in the company, it is appropriate to define the cost, productivity and proportion of by-products as crisp values and the quality, continuity, reliability, closeness and demand for by-products as linguistic variables. Design ranges determine the levels of the properties that the supplier should have. The company's design ranges for the suppliers are as follows:

FR_C = Cost (*C*) must be in the range of $ 7. 41 to 9.63 per cubic meter.

FR_{PR} = Productivity (*PR*) must be in the range of 65 % to 95 %.

FR_Q = Quality (*Q*) must be Good.

FR_{CON} = Continuity & Capacity (*CON*) must be Good.

FR_{PRO} = The proportion of by-products (*PRO*) must be in the range of 0 % and 35 %.

FR_{DEM} = The demand for (*DEM*) byproducts must be Good.

FR_{CL} = Closeness of Supply (*CL*) must be Excellent.

FR_{REL} = Reliability (*REL*) of the supplier must be Excellent.

The decision maker uses the linguistic variables shown in Fig. 5 for comparing quality, continuity and closeness criteria of four suppliers. First, linguistic variables are defined for each supplier under these criteria and then these variables are transformed into triangular fuzzy numbers shown in Fig. 5. To calculate the information contents, fuzzy numbers are converted into crisp scores. For example, when the decision maker

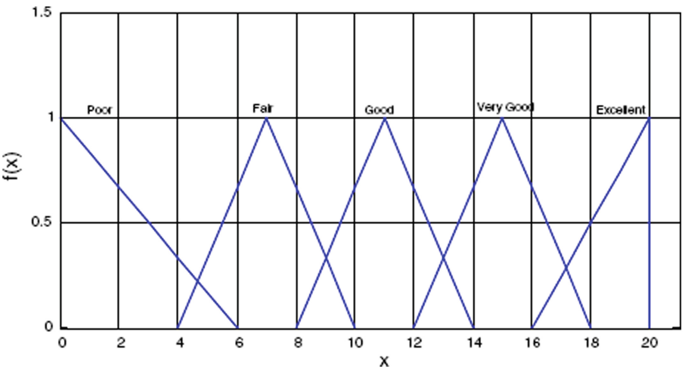

Fig. 5. Triangular fuzzy numbers for intangible factors [16, 17].

Table 1. The system range data for alternative suppliers.

Suppliers	Supplier selection criteria							
	Cost ($)	Product				Supplier		
		PR (%)	Q	PRO (%)	DEM	CON	CL	REL
Supplier 1	8,89–10,37	75–80	Fair	30–40	Good	Good	V. Good	V. Good
Supplier 2	8,89–10,37	70–75	Good	20–30	Good	Good	V. Good	V. Good
Supplier 3	7,41–8,89	65–75	Fair	30–40	Fair	V. good	V. good	Excellent
Supplier 4	9,63–11,11	75–90	V. good	20–30	V. good	Poor	Fair	Poor

uses the linguistic variable "Fair" for the "Quality" criterion of Supplier 1, the variable is transformed into triangular fuzzy number (4, 7, 10) (see Fig. 5). The same procedure is applied in defining the system ranges of suppliers as shown in Table 1.

System ranges showing the properties of the suppliers are given in Table 1 for each supplier.

The weights of the criteria are found using fuzzy AHP with extent analysis [4] and these weights are shown in parentheses in Table 2. Using these system and design ranges, the information contents for each *FR* for each supplier can be computed using Eq. (4). Calculating the information content of the reliability criterion for supplier 1 is given in the following as an example.

The system, design and common ranges for the reliability criterion for Supplier 1 are shown in Fig. 6.

The common area, system area and information content are calculated using Eq. (4) as follows.

$$\begin{aligned} Common\ Area &= (18-16)0.286/2 = 0.286, \\ System\ Area &= (18-12)0.5 = 3, \\ I &= \log_2\left(\frac{3}{0.286}\right) = 3.39. \end{aligned} \tag{9}$$

Table 2. Weights of the criteria and information contents of the sub-criteria.

Selecting the best supplier								
	COST (0.457)	Product (0.457)				Supplier (0.086)		
		PR. (0.275)	Q. (0.371)	PRO. (0.075)	DEM. (0.279)	CON. (0.614)	CL. (0.229)	REL. (0.157)
S1		0	3.17	1	0	0	3.39	3.39
S2		0	3.17	0	0	0	3.39	3.39
S3		0	0	1	3.17	3.17	3.39	0
S4		0	3.17	0	3.17	∞	∞	∞

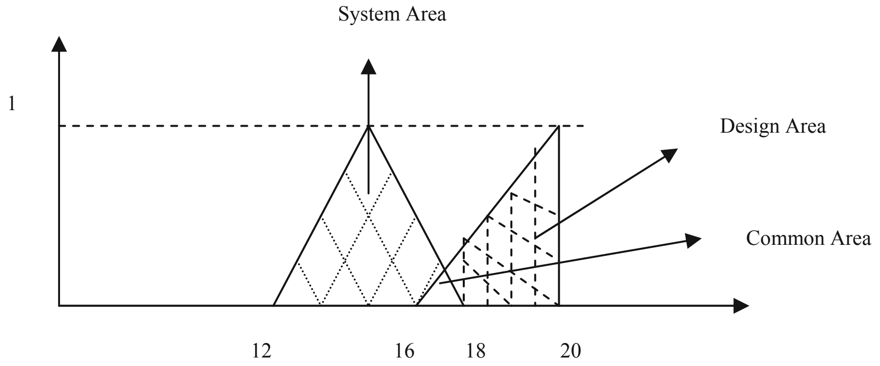

Fig. 6. System, design and common ranges for Supplier 1 with respect to Reliability criterion.

The calculations of the information contents for product criterion with respect to the alternatives are given in the following.

$$\begin{aligned}
&Supplier \quad 1 = 0.275 * 0 + 0.371 * 3.17 + 0.075 * 3.17 + 0.279 * 0 = 1.25, \\
&Supplier \quad 2 = 0.275 * 0 + 0.371 * 0 + 0.075 * 0 + 0.279 * 0 = 0, \\
&Supplier \quad 3 = 0.275 * 0 + 0.371 * 3.17 + 0.075 * 1 + 0.279 * 3.17 = 2.14, \\
&Supplier \quad 4 = 0.275 * 0 + 0.371 * 3.17 + 0.075 * 0 + 0.279 * 3.17 = 2.06.
\end{aligned} \tag{10}$$

The final combination of the information contents are given as follows. Here, infinity (∞) means that the supplier does not meet the requirements of the company therefore; the information content can not be calculated.

$$\begin{aligned}
I_{S1} &= 0.457 * 1 + 0.457 * 1.25 + 0.086 * 1.31 = 1.14, \\
I_{S2} &= 0.457 * 1 + 0.457 * 0 + 0.086 * 1.31 = 0.57, \\
I_{S3} &= 0.457 * 0 + 0.457 * 2.14 + 0.086 * 2.72 = 1.21, \\
I_{S4} &= 0.457 * \infty + 0.457 * 2.06 + 0.086 * \infty = \infty.
\end{aligned} \tag{11}$$

According to the final combinations, the second supplier with the least information content is selected as the best supplier.

3.4 A Numerical Application of Extended HFAD Approach with Risk Factors

The same problem will be solved by using the RFAD approach considering risk factors. The risk factors are determined via the interviews with the expert in the company. The expert defines the risk factors between 0 and 1 (i.e. 0 shows no risk) for the sub-criteria except the closeness sub-criterion. Since the definition of cost and closeness criteria do not include any risk factors, there are no risks defined for these criteria. The risk factors determined by the expert are given in Table 3.

Table 3. Risk factors of each supplier for sub-criteria

	PR	Q	PRO	DEM	CON	REL	CL
Supplier 1	0.10	0.2	0.3	0.05	0.01	0.2	0
Supplier 2	0.15	0.1	0.1	0.05	0.01	0.25	0
Supplier 3	0.2	0.2	0.3	0.1	0.05	0	0
Supplier 4	0.05	0.05	0.1	0.01	0.5	0.4	0

An example is given here to show how to calculate the information content considering risk factors for the productivity sub-criterion of Supplier 1. The system and design ranges for Supplier 1 under the productivity sub-criterion is shown in Fig. 7.

$$\text{System range} = (80 - 75) * 1 = 5$$

$$\text{Common range} = (80 - 75) * 1 = 5$$

$$I^m = \log_2\left(\frac{5}{5(1 - 0.10)}\right) = \log_2\left(\frac{1}{0.90}\right) = 0.151 \tag{12}$$

The information contents calculated using Eq. (5) belonging to the second level of the hierarchy are given in Table 4.

The overall information contents for each supplier are obtained as follows. It should be noted that the information contents of each supplier under each main criteria without any risk factors are same with the information contents obtained in Sect. 3.3.

$$\begin{aligned} I_{S1} &= 1 * 0.457 + 1.471 * 0.457 + 1.332 * 0.086 = 1.244 \\ I_{S2} &= 1 * 0.457 + 0.153 * 0.457 + 1.347 * 0.086 = 0.643 \\ I_{S3} &= 0 * 0.457 + 2.423 * 0.457 + 2.766 * 0.086 = 1.35 \\ I_{S4} &= \infty * 0.457 + 2.122 * 0.457 + \infty * 0.086 = \infty \end{aligned} \tag{13}$$

Based on the information contents calculated, the second supplier with the least information content is the best supplier. This result is same with the HFAD.

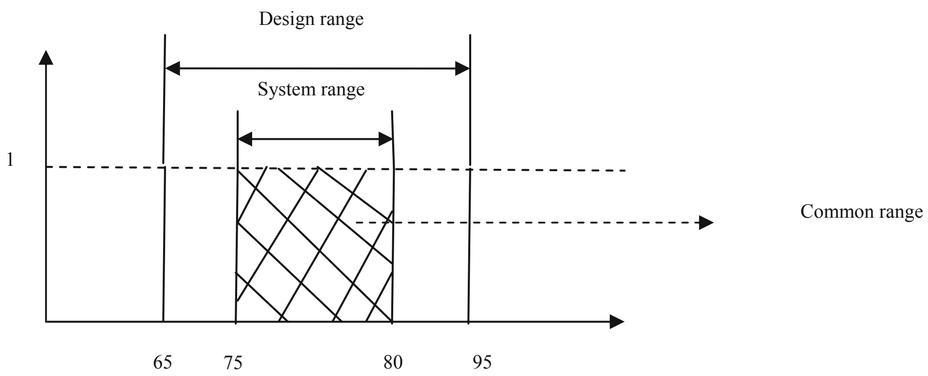

Fig. 7. Design and system ranges for supplier 1 under productivity sub-criterion.

Table 4. Modified information contents considering risk factors for the second level in the hierarchy.

	PR	Q	PRO	DEM	CON	REL	CL
Supplier 1	0.151	3.49	1.52	0.075	0.014	3.49	3.39
Supplier 2	0.234	0.152	0.151	0.075	0.014	3.58	3.39
Supplier 3	0.32	3.49	1.52	3.32	3.24	0	3.39
Supplier 4	0.075	3.24	0.151	3.184	Infinity	Infinity	Infinity

As expected, the information contents obtained by RFAD are greater than the information contents obtained by HFAD since risk factors decrease the chance of being selected.

The results of the new approach are compared to the widely used multi criteria decision making approaches in literature. Table 5 presents the rankings of the suppliers obtained by AHP with weighted average [26] and fuzzy AHP [4], HFAD and the RFAD. The main difficulty with using AHP is the pairwise comparisons. The decision maker finds it difficult to express his opinions using Saaty's scale for comparisons. The result of this difficulty can be seen in comparisons of approaches stated in Table 5. Different from AHP, other approaches (Fuzzy AHP, HFAD and RFAD) determine the second supplier as the best supplier. This could be attributed to the use of linguistic variables which can reflect human preferences more precisely than crisp values. Although using linguistic variables in pairwise comparisons is easier than Saaty's scale, fuzzy AHP requires too many calculations. On the other hand, HFAD and RFAD do not require pair-wise comparisons in decision process. Another advantage of these approaches is that if an alternative does not meet the system requirements, it cannot be selected by using HFAD and RFAD. This property does not exist in any other MCDM approach in literature and is useful in preventing the problems that might occur in the future.

3.5 Sensitivity Analysis

This section examines the impact of different risk factors on the overall solution. To show the effect of different risk factors, we carried out a sensitivity analysis. Sensitivity analysis helps us to understand the problem and different effects of the problem elements comprehensively.

Suppose the risk factors of suppliers are given as in Table 6.

Table 5. Comparison with conventional and fuzzy AHP.

Rank	AHP	Fuzzy AHP	HFAD	RFAD
1	3	2	2	2
2	2	3	1	1
3	4	4	3	3
4	1	1	4	4

Table 6. Revised risk factors of each supplier for sub-criteria.

	PR	Q	PRO	DEM	CON	REL	CL
Supplier 1	0.10	0.5	0.8	0.05	0.01	0.2	0
Supplier 2	0.15	0.1	0.1	0.5	0.1	0.25	0
Supplier 3	0.2	0.2	0.3	0.1	0.05	0	0
Supplier 4	0.05	0.05	0.1	0.01	0.5	0.4	0

Table 7. Information contents for the second level.

	PR	Q	PRO	DEM	CON	REL	CL
Supplier 1	0.151	4.17	2.32	0.075	0.014	3.49	3.39
Supplier 2	0.234	0.152	0.151	1	0.151	3.58	3.39
Supplier 3	0.32	3.49	1.52	3.32	3.24	0.234	3.39
Supplier 4	0.52	3.24	0.151	3.184	Infinity	Infinity	Infinity

According to these risk factors stated in Table 6, the information contents for the second level computed using Eq. (5) are given in Table 7. It should be noted that the information contents increase as the risk factors increase.

$$
\begin{aligned}
I_{S1} &= 1 * 0.457 + 1.724 * 0.457 + 1.31 * 0.086 = 1.35 \\
I_{S2} &= 1 * 0.457 + 1.46 * 0.457 + 1.46 * 0.086 = 1.29 \\
I_{S3} &= 0 * 0.457 + 0.96 * 0.457 + 2.767 * 0.086 = 0.68 \\
I_{S4} &= \infty * 0.457 + 2.199 * 0.457 + \infty * 0.086 = \infty
\end{aligned} \tag{14}
$$

When there are high risk factors, the proposed approach selects the third supplier having the least information content as the best supplier. It is expected since the risk factors of this supplier are smaller compared to the risk factors of other suppliers. However, if risk factors are ignored, the second supplier will be again selected as the best supplier although it has relatively high risk factors when compared to the other suppliers.

4 Conclusion

Decision problems are affected by risk factors. Every alternative has its own risks and these should be integrated into the decision hierarchy in order to select the best alternative. As a multi-criteria decision problem, the supplier selection is one of the most important problems which companies face up to in marble-travertine industry. Since the raw material is natural, the quality of purchased raw material cannot be known before starting production. Moreover, there are a number of different suppliers from which companies can choose. Therefore, these issues make the problem more complex and difficult to deal with. However, to choose the most appropriate supplier, nearly all companies in this industry make their supplier decisions based on experiences and intuitions which might lead to some wrong decisions and problems. In order to solve the supplier selection problem with a systematic approach, different MCDM approaches have been proposed so far. However, most of the approaches do not integrate risk factors into the structure of the methodology. Risk factors in supplier selection problem are important and should be taken into account. To fill this gap, a new multi criteria decision making approach is proposed and the application of the new approach is shown on a real-world supplier selection problem for a company in marble-travertine industry. Furthermore, considering the risk factors in the selection process is important since it makes the solution approach more realistic. Future research direction for this study can be to analysis of RFAD performance in solving other decision problems or develop a group decision support system based on these approaches.

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A DSS for Resolving Evaluation of Criteria by Interactive Flexible Elicitation Procedure

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Abstract. This paper describes the implementation of a Decision Support System (DSS) with a flexible elicitation procedure to support a decision maker (DM) to establish weights for a multi criteria choice decision problem, based on the concept of a flexible procedure. The DSS not only presents an elicitation interface to establish weights, but computes the performance of alternatives in an additive model, thus enabling the DM to reduce the set of non-dominated alternatives since partial information about preferences is given. When the flexible elicitation procedure implemented in this DSS is performed less information is required from the DM, which implies that less cognitive effort is required. The DSS contributes by providing a user friendly interface which enables the elicitation protocol to be performed using graphics and by computing alternatives performance quickly so that the elicitation process can be finished quickly with the minimum number of questions needed to solve the choice problem. The flexible elicitation procedure proposed is illustrated with a numerical application.

Keywords: Decision support system · Flexible elicitation · Eliciting weights · Additive model

1 Introduction

Most of multi criteria decision methods require inter-criteria information, but eliciting such information for a particular decision model is one of the most important and difficult tasks in multi criteria decision making [1] and this has been for many years a subject of academic discussion [2].

Depending on the multi criteria model, the inter-criteria information, usually called weights, can have different meanings. Some authors argue that in many situations the concepts of trade-off and criteria weight are not distinguished [3].

When the weight represents the relative importance of the criteria, which is not unusual, a direct assessment is usually performed. For these cases, the term importance is then defined as the level of contribution of one criterion amongst others.

For situations when weights are scale constants or tradeoffs, instead of assigning importance, the DM is interviewed to determine which committed relationship he/she is willing to establish between two criteria [4].

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In both cases, the elicitation of weights requires a level of precision that, in many cases, a DM is not able or is not comfortable about doing so. There are several papers in the literature which propose alternatives so as to avoid specific preference values, yet which can fulfill decision purposes by having the DM provide as little information as possible [3]. Due to the difficulty that a DM has in providing exact values for these weights another approach is to look not for the exact values of weights, but rather to use partial information regarding these exact values, this being an easier way which minimizes this difficulty. There is much in the literature regarding the use of intervals to represent DM weights [2, 5–7], however in many approaches [8–11] there is a compromise between theoretical aspects regarding scale constants and the process for eliciting them, and simplifications on preference modelling to provide a recommendation.

In this context and with a similar objective to previous studies, this paper presents a DSS (Decision Support System) built to elicit the scale constant for a multi criteria additive model, based on a flexible elicitation procedure [12] that seeks to reduce the amount of information that is required from DM while preserving theoretical aspects related to tradeoff relations in the scale constants of additive models. The next item presents the flexible elicitation procedure and the DSS.

2 The Proposed Approach for the Flexible Elicitation of Weights

Additive models are widely used to model a DM's preferences in multi criteria decision problems [2, 4, 8, 13–15] and important pieces of information in this context are the weights or more precisely, the scale constant.

In classical decision analysis [4], a decision analyst interviews a DM about what criteria or attributes of the decision shall be considered in the decision context and the DM's preferences as to consequences. As mentioned in [16], this evaluation usually requires a DM to think carefully about the boundaries of each attribute, to consider the DM's attitude regarding the range of consequences (min to max values), and to establish which attributes are value independent from other attributes.

This classical analysis represents a complete decision model. However, this demands a considerable effort from the DM, who has to think carefully about issues involving the definition of tradeoff comprehending the importance of criteria and the evaluating the alternatives over criteria, which in many situations are not easy to conduct.

In the case of using an additive model in a multi criteria problem, when using the classical model [4] to establish the scale constant, the DM is asked to answer questions in situations of indifference. Indifference means that the value of *A* is the same as *B*, and this is a procedure which is more difficult to answer than situations of preference, such as the value of *A* is at least the same as the value of *B* ($v(A) \geq v(B)$) which represents less cognitive information from the DM, since indifference means that the value of *A* is at least the same as the value of *B* and that the value of *B* is at least the same as the value of *A* ($v(A) \geq v(B)$ and $v(B) \geq v(A)$).

This means that even if a partial information elicitation process requires more questions, it does not necessary mean that this elicitation process requires more cognitive effort from the DM.

The flexible elicitation procedure proposed in this paper is an alternative procedure which seeks to minimize the effort required from the DM on eliciting scale constants for additive models, thus preserving theoretical aspects of tradeoff relations in additive model scale constants. The flexible elicitation procedure proposed is based on a preference elicitation protocol built over consequences.

From the classical elicitation procedure [4], consequence C has the result x_i for criterion i, and the worst result for the other criteria. The DM is asked to report results for x_i that make the consequences C and A indifferent, and so on, when all i criteria are considered and the scale constants are set.

An alternative procedure can be defined using results around x_i, assuming that the criteria are ordered, for $k_1 \geq k_2 \geq \ldots k_i \ldots \geq k_{n-1} \geq k_n$, and for a criterion i, assuming that $x_i' \geq x_i \geq x_i''$. Then using x_i' as a consequence related to criterion i would be preferable to the result related to criterion $_{i+1}$ and so on.

Unlike classic model of elicitation, the flexible elicitation procedure proposed, seeks to obtain x_i' and x_i'', based on the DM's preference relation judgments. In this alternative procedure it is assumed that:

- It is easier for the DM to specify x_i' and x_i'' than to specify x_i or
- It may not be reliable to assume that this information can be obtained in a consistent way from the DM.

The following assumptions and information are required for the flexible elicitation procedure:

- The weights are normalized;
- It is assumed that a ranking of weights can be obtained from the DM;
- It is assumed that the DM can specify x_i' and x_i'', so that $v_i(x_i') \geq k_{i+1}/k_i$ and $v_i(x_i'') \leq k_{i+1}/k_i$. Where v is the value of the consequence over criterion i and k_i are scale constants.

To implement the flexible elicitation procedure a DSS was built, thus it is easier for the DM to cope with consequence values such as x_i' and x_i'' when a DSS is used to calculate $v_i\,(x_i')$ and $v_i\,(x_i'')$. During the flexible elicitation procedure partial information is obtained about the scale constants (1) and the performance of the alternatives is computed by the DSS based on the additive value function (2) using the partial information from (1).

$$\begin{cases} k_i x_i'' < k_{i+1} \\ k_{i+1} < k_i x_i' \end{cases} \cdots \begin{cases} k_{n-1} x_{n-1}'' < k_n \\ k_n < k_{n-1} x_{n-1}' \end{cases} \cdots \begin{cases} \sum_{i=1}^{n} k_i = 1 \end{cases} \tag{1}$$

$$v(x) = \sum_{i=1}^{n} k_i v_i(x_i) \tag{2}$$

The DSS combines questions regarding (1) and computational tests on (2) thus seeking a flexible elicitation procedure that seeks DM's minimum cognitive effort from the DM to enable a choice to be made without needing to define specific values for scale constants.

Thus the DSS seeks to evaluate the maximum value of each alternative x_j in (2) with the objective of reducing the set the non-dominated alternatives using the partial information acquired on the DM's preferences (1) instead of defining specific values for the scale constants.

To allow the DSS to perform the elicitation process in a flexible way, the DM is requested to state a preference relation that specifies x_i' and x_i'', this being sufficient to obtain a unique solution for a linear programming problem (LPP). In order to do this, the following LPP (3) is solved for each alternative j:

$$\begin{aligned}
&\text{Max} \quad v(x_j) \\
&\text{s.t.} \\
&k_{i+1} \leq k_i && \text{for } i = 1 \text{ to } n-1 \\
&k_{i+1} \leq x_i' \times k_i && \text{for } i = 1 \text{ to } n-1 \\
&k_{i+1} \geq x_i'' \times k_i && \text{for } i = 1 \text{ to } n-1 \\
&\sum_{i=1}^{n} k_i = 1 \\
&k_i \geq 0
\end{aligned} \tag{3}$$

The linear programming problem presented in (3) is used to explore the weights vector space and show whether there is a subset of the space in which alternative j has maximum value to allow the comparison with the maximum value of all alternatives by solving the LPP for each alternative j. This model includes explicitly, the constraint for the weight space, obtained from the information collected in the flexible elicitation process. A constraint of the dominance condition should also be introduced.

The DSS architecture and interface is explained in the following item.

3 Overall System Architecture of DSS

The first version of the DSS was developed and implemented in a Matlab environment, with a good performance in speed. However, a new version of the DSS is being developed to allow a web platform besides the standalone version. The DSS allows input and output to be imported and exported using MS Excel spreadsheets, thus reducing effort and typing time. Information about the preference relations are obtained directly from the DM throughout the flexible elicitation procedure proposed in Almeida [12].

Figures 1 and 2 provide an overview of the DSS user interface. The user interface has a dialogue based on a combination of menu, questions and answers, since the DMs are generally not experts in applying multi criteria decision methods and in eliciting the parameters for these methods.

Fig. 1. User interface – preference relation eliciting based on consequences.

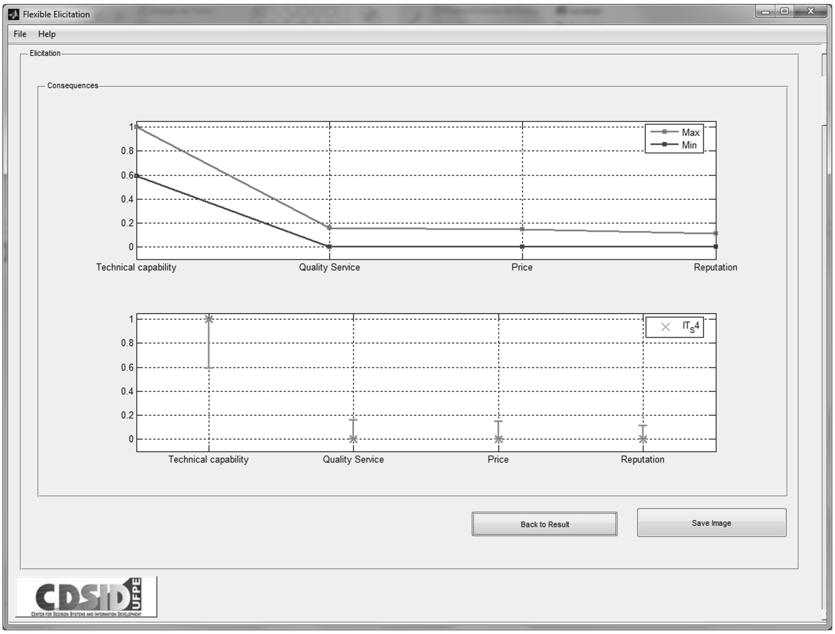

Fig. 2. User interface – scale constants or "weights" space when a non-dominated alternative was found.

3.1 Data Input

Initially the user or DM is required to provide information on the problem, such as: the decision context, alternatives, criteria, the preference direction for criteria (max or min) and the evaluation scale for each criterion. Once all data entries have been provided, the next step is to begin asking the DM about preference relations in order to provide partial information regarding the scale constants.

3.2 Elicitation Procedure

In the first phase, the elicitation process consists of a sequence of questions about the DM's preferences. The DM must choose from between the performance of two alternatives plotted for each criterion on the DSS screen as presented in Fig. 1. For this question, the DM is requested in a user-friendly way to express his/her preferences so as to gather information that will establish the ranking of the scale constants. The graphical visualization of the performance of a criterion makes it easier for the DM to understand the cognitive processes involved in evaluating preference relations.

In Fig. 1, b_i states the best value found among the alternatives for criterion i and w_i states the worst value found among the alternatives for criterion i, thus enabling the ranking of scale constants to be obtained with regard to theoretical aspects of tradeoff relations in additive model scale constants.

In the second phase, the procedure seeks to gather inequality relations which will be useful for evaluating the performance of alternatives as per (2) and to establish dominance relations by asking the DM as much as needed so that the number of non-dominated alternatives is minimized using the partial information on preferences defined in (1) to satisfy a choice problem.

On the DSS screens, the DM is always is permitted not to answer a specific question (if he/she is not cognitively comfortable about it) and/or is always permitted to check results for the amount of partial information (that he/she has already provided) in the flexible elicitation process. Sometimes partial results may be a small number of non-dominated alternatives (two or three, for example), which is fair enough for the partial information which the DM was confident about giving. However, whenever only one non-dominated alternative is indicated, there is a DSS dialog that informs the DM that a single non-dominated alternative was found based on the partial information that he/she has provided.

The dominance test is performed whenever the DM provides new preferential partial information during the flexible elicitation process, given that the main objective of this procedure is to minimize the DM's cognitive effort. This dominance test is performed considering the solution obtained for (3) and, after several tests, it was found that time needed for computation did not rise to this becoming a concern.

3.3 Data Output

After all data have been entered, and the DM has defined preference relations, all the possible scale constant values subjected to (1) are considered and the DSS presents a graphical representation of the scale constant space. The additive value function for each alternative is evaluated to establish a dominance relation between alternatives using the DM's preferences which were revealed by applying the flexible procedure using partial information.

The following item presents an illustrative choice problem so that results obtained from the proposed procedure using the DSS can be observed and the decision process evaluated with this new approach. The choice problem considered is related to an Information Technology Outsourcing (ITO) context and the graphic interface used during the elicitation process was presented in Figs. 1 and 2.

4 DSS Applied to Supplier Selection in ITO

In order to show how the DSS may be used to support a decision process and to minimize the level of information required from the DM, let us consider a numerical application based on a problem found in the literature related to evaluation process for selecting ITO suppliers [17].

Lacity et al. [17] presented a review of studies regarding ITO practice based on 191 ITO articles and by September 2013 this had been cited 102 times in the Scopus database, their review being on the list of articles most cited in the Journal of Strategic Information Systems.

Lacity et al. [17] provided substantial evidence that amongst common risks, the one which decreases the likelihood that a client's outsourcing decision will be successful is to do with cultural differences between client and supplier. To evaluate an outsourcing decision and to make a successful choice, several aspects of the performance of a supplier may observed such as: the supplier's capability, quality service, financial stability, reputation and cultural fit, among others.

According to Lacity et al. [17], the supplier evaluation process seems to be decisive for contract pricing, outsourcing decision, expected cost reduction and for outsourcing in general to achieve success.

Thus, ITO supplier selection is a relevant topic and is influenced by multiple criteria which will be evaluated by the DM when considering an ITO selection problem. However, establishing scale constants for this problem is not an easy task, thus if the decision process can be performed without having to fix specific values for scale constants, the recommendation provided by the decision model will be more reliable since the DM has no doubt whatsoever about whether a specific weight should be, for example, 0.68 or 0.79. Usually the analyst will conduct a sensitivity analysis to explore this matter in an ex-post-evaluation perspective. However, if the flexible elicitation procedure proposed is used, all these sensitivity analysis is built into the process.

The selection problem considered in this numerical application is summarized in Table 1, represented by the choice amongst six non-dominated alternatives and four criteria with their respective consequence values ($v_i(x_i)$).

The first elicitation dialog for this problem was presented in Fig. 1 and after a further two elicitation dialogs, there were only three non-dominated alternatives to be considered. Thus after a total number of five elicitation dialogs using the DSS, the decision process was finished when there was only one non-dominated alternative for this ITO selection problem.

Table 1. Evaluation matrix

IT supplier	Technical capability	Quality service	Price	Reputation
IT_S1	0.780356	0.839432	0.870277	0.224728
IT_S2	0.064347	0.519343	0.834165	0.636921
IT_S3	0.930625	0.734279	0.583251	0.105254
IT_S4	0.995166	0.66834	0.424364	0.716088
IT_S5	0.934539	0.798078	0.343789	0.639647
IT_S6	0.848783	0.952457	0.288657	0.468626

Figure 2 presents the scale constants space defined through the flexible elicitation process in dialogs such as those presented in Fig. 1, after the DM answered five questions in the DSS dialogs. The range of the weights obtained for each criterion defines the value of the alternatives in (3) and this solution is used to establish the dominance relation of alternatives in order to give a final recommendation for the selection problem.

For the "weights" space presented in Fig. 2 and defined during the elicitation process, the single non-dominated alternative found was "IT_S4" or Information Technology Supplier number 4.

From Fig. 2 the DM can observe the space of weights obtained after the iterations of the proposed procedure have been performed. The initial space of weights was reduced after the DM's preference statements over attribute consequences have been considered. The ranges presented in Fig. 2 were obtained through LP as a result of the proposed procedure iterations and for this space of weights no other alternative dominates "IT_S4" and "IT_S4" dominates all other alternatives.

5 Conclusions

This paper presented a DSS built to drive the process for the flexible elicitation of scale constants in a multi criteria additive model. Using the DSS led to less cognitive effort and information being required from the DM, thus reducing the chance of errors and making elicitation procedure more reliable. The use of graphical information during the elicitation process contributes to giving the DM a better understanding of the decision process when using the system.

The flexibility incorporated into the elicitation procedure allows the DM to skip and avoid elicitation questions when he/she is not comfortable (confident) about providing an answer while the simplicity of the DSS dialogue enables complex calculations to be made quickly. It is impossible to do so, in a real time basis, unless there is a DSS for the elicitation process.

Another aspect to be highlighted is the importance of considering the DM's cognitive processes when using a DSS [18, 19]. The proposed procedure implemented in a DSS enables some of the biases of the DM's cognitive processes to be reduced, such as those caused by confusion and overload.

Unlike the classical elicitation procedure, the flexible elicitation procedure presented in this paper requires that the DM provides partial information based on preference relations, since indifference relations are more difficult to express and more easily lead to confusing a DM.

There are several approaches in the literature regarding eliciting weights for additive functions using partial information [2, 6–9, 11, 20–23]. These studies explored dominance relations and optimality aspects by considering interval weights, partial/ incomplete information on weights and unknown weights. Thus the main differences between these and the proposed procedure are with regard to the adaptation incorporated during the decision process which is carried out without compromising theoretical aspects related to scale constants and to the process for eliciting them which minimizes the amount and level of information required.

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Robustness Analysis in Multicriteria Disaggregation – Aggregation Approaches for Group Decision Making

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Abstract. Multicriteria Disaggregation - Aggregation (D-A) approaches results to the estimation of Decision Makers' preference models (usually of additive value) through interactive procedures, where the global preferences of DMs are analysed. The low robustness of preference models, presented in many cases, can be the result of the ill-structured problem formulation or can reflect the real thoughts of DMs. The case of collaborative decision making presents more complicated situations. This research work describes the use of visual techniques based on 3d graphs and a set of indices, which can be used for picturing and comprehension of the low robustness in collaborative decision making problems. Also, the frame of feedbacks which can be utilised for the reducing and the exploitation of the low robustness is described and illustrated through a case study.

Keywords: Multicriteria decision aid · Collaborative decision making · Robustness analysis

1 Introduction

The cases of collective decision making is more complex than to the individual ones, given that, the different perspectives increase the ill-structured nature into decision problems of the real world. Multicriteria Disaggregation Aggregation (D-A) approaches for discrete alternative actions aim to the estimation of preference models (usually of additive value) based on Decision Makers (DMs) global preferences [7, 11].

The additive value model is described in the following formulae:

$U(\mathbf{g}) = \sum_{i=1}^{n} p_i u_i(g_i)$ subject to normalization constraints:

$$u(g_{i^*}) = 0,\ u(g_i^*) = 1,\ \forall i = 1, 2, \ldots, n \ \text{ and } \ \sum_{i=1}^{n} p_i = 1, \forall i = 1, 2, \ldots, n$$

where: $\mathbf{g} = (g_1, g_2, \ldots, g_n)$ is the evaluation vector of an alternative action on the n criteria, g_{i*} and g_i^* are the least and most preferable levels of the criterion g_i respectively and $u_i(g_i)$, p_i are the value function and the relative weight of the i-th criterion.

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DM's global preferences are expressed by rank-ordering (pre-ranking) of a representative and familiar to the DMs subset of the alternative actions, called reference set. Special Linear Programming (LP) techniques are utilised in order to estimate an additive value model, which produces a ranking of the reference actions as consistent as possible with the pre-ranking given by the DM. The alternative actions of the reference set are rearranged in such a way that a_1 is the head and a_k is the tail of the ranking and for every pair of consecutive actions (α_m, a_{m+1}) holds, either $\alpha_m \mathbf{P} \alpha_{m+1}$ (preference) either $\alpha_m \mathbf{I} \alpha_{m+1}$ (indifference). For the estimation of the additive value model, UTA methods solve the following LP problem:

$$[\min] F = \sum_{m=1}^{k} \left(\sigma^{+}(a_m) + \sigma^{-}(a_m)\right) \text{ subject to:}$$

$$\left.\begin{array}{l} \sum_{i=1}^{n} p_i u_i[g_i(a_m)] - \sigma^{+}(a_m) + \sigma^{-}(a_m) - \sum_{i=1}^{n} p_i u_i[g_i(a_{m+1})] - \sigma^{+}(a_{m+1}) + \sigma^{-}(a_{m+1}) \geq \delta \text{ if } a_m \mathrm{P} a_{m+1} \\ \sum_{i=1}^{n} p_i u_i[g_i(a_m)] - \sigma^{+}(a_m) + \sigma^{-}(a_m) - \sum_{i=1}^{n} p_i u_i[g_i(a_{m+1})] - \sigma^{+}(a_{m+1}) + \sigma^{-}(a_{m+1}) = 0 \text{ if } a_m \mathrm{I} a_{m+1} \end{array}\right\} \forall m$$

$$\sum_{i=1}^{n} p_i = 1, \text{ for } i = 1, 2, \ldots, n, \; p_i \geq 0, \sigma^{+}(a_m) \geq 0, \; \sigma^{-}(a_m) \geq 0 \, \forall i \text{ and } m$$

where δ being a small positive number; $g_i(\alpha_m)$ the evaluation of the α_m action on the i-th criterion and $u_i[g_i(\alpha_m)]$ the corresponding marginal value; and σ^+, σ^- the overestimation and the underestimation error, respectively.

The results of the LP could be the estimation of:

1. A unique optimal solution indicating a robust preference model.
2. Infinite multiple optimal solutions which are bordered into a hyper-polyhedron (low robustness). In this case the beaten track is to undertake a post-optimal analysis in order to estimate a mean solution of the LP's multiple optimal solutions corresponding to the vertices of the hyper-polyhedron. Such a post-optimal analysis approach, is used in MINORA [13] and MIIDAS [12] systems, which is oriented to the approximation of a barycentre solution by maximizing the weight of each criterion at a time [11]. This barycentre solution is used as the working preference model for the next steps of D-A approach.
3. No solution, in the case where the DM's preferences cannot lead to the estimation of a curved hyper-polyhedron.

The case of low robustness is the most frequently observed. Many recent research studies [5] focus on how to tackle low robustness issues, by intervening into the initial preferences of the DMs so as to increase robustness a priori. Low robustness can be the result of moderately or ill structured problems (due to absence of one or more criteria, non-rational evaluation of the alternative actions on the criteria, no effective selection of the reference set etc.). In many cases, low robustness can be a real representation of DM's thoughts and preferences. The study of low robustness, through an in depth analysis and investigation of the estimated preference model and the post-optimal analysis of the results, could reveal very useful information about DM's preference structure.

The Disaggregation - Aggregation (D-A) approaches and especially UTA methods can be applied in collective decision making situations, either by the construction of a collective additive value preference model, incorporating techniques of the Social Choice Theory (a priori aggregation of individual preferences) or by the estimation and composition of several individual preference models [15, 16] followed by an a- posteriori aggregation of individual preference models). Tackling low robustness issues by using the appropriate tools helps the analysis of DMs preferences' structure and supports the negotiation processes and the approximation of areas of convergence in sensitive points of the decision space.

There are a lot of cases where D-A approaches were utilised in order to support collaborative decision making, mainly in cases of small group of DMs. Spyridakos et al. [14] applied UTA II and Cook and Seiford model [4] in order to assess a common accepted value function, evaluating all the executive positions in a large organization. Beuthe and Scanella [1] undertook an exhaustive analysis showing the relation between the "quality" of results and the value of the parameters involved in the different UTA methods. Kadziński et al. [8] proposed the concept of a representative value function applied in robust multicriteria problems and solved with the aid of an extension of UTAGMS and GRIP methods. Kersten et al. [9] develop geometric representations of the mean-variance-skewness (MVS) portfolio frontier using the shortage function and related approaches. Spyridakos and Yannacopoulos [15] proposed the RACES software, incorporating the social choice functions for aggregating individual rankings with MINORA [13] and MIIDAS [12] systems, in order to assess value function(s), as compatible as possible with a collective ranking.

This research work is oriented on the robustness analysis of the estimated preference models of collaborative decision making for small group of DMs. The main aim of this study is to exploit the results of robustness analysis, in order to support a deeper analysis of the different preference structures of the DMs and to identify points or areas of differentiation and convergence. Furthermore, a set of new tools for the measurement and visualization of the preference models robustness is proposed, in order to explain and analyse the different attitudes of the participating stakeholders. Through this process a comparison among the stakeholders' preferences structures can be achieved. In addition, new interactive feedbacks, triggered by the robustness analysis results, are designed and proposed aiming to achieve a better convergence among the participating DMs.

The paper comprises an introduction and four sections. The robustness analysis of the additive value models is presented in the second section along with the way through which knowledge can be extracted concerning the DMs' preferences models during collaborative decision making processes. The third section proposes a set of indices and 3-D visual techniques that support the implementation of robustness analysis of the estimated by UTA methods preference models. The whole process is illustrated in the next section through a real world case study, which demonstrates the novel interactive capabilities of the proposed approach for small group decision aid. Finally, conclusions and further suggestions are outlined in the last section.

2 Robustness Analysis of Collective and Individual Preference Models

Spyridakos and Yannacopoulos [15] presented a methodological frame and a software (RACES) for small group collaborative decision making, utilising the UTASTAR Method [11]. The proposed process was consisted of two alternative paths. The first one concerns an "a priori" aggregation of the individual global preferences to a collective pre-ranking of the alternative actions by exploiting one of the social choice functions [2, 3, 6]. Following that, the estimation of a collective preference additive value models is triggered, taking advantages from the collective pre-ranking. The second one concerns an "a posteriori" aggregation of individual preferences functions. Individual additive value models are estimated for each one of the individual pre-rankings and then they were synthesised to a collective one. The main aim of this approach was to provide mechanisms for the support of the analysis of the individual and collective preference models and to enrich the knowledge of the decision problem and the structure of DM's preferences.

The estimated additive value models (Collective and Individual) present (in most of the cases) low robustness. The post optimal techniques of MINORA and MIIDAS systems are activated in cases of low robustness, aiming to calculate an approximation of the convex hyper-polyhedron of the LP solutions by applying one of the following algorithms:

- Maximisation of each criterion weight which leads to the estimation of a hyper-polyhedron with at most n vertices (n the number of criteria).
- Maximisation and minimisation of criteria weights which leads to the estimation of a hyper-polyhedron with at most 2n vertices.
- Manas-Nedoma [10] Algorithm which estimates all the vertices of the hyper-polyhedron through a set of relating steps implementing a Hamiltonian path.

The mean solution (barycentre, in Fig. 1) is selected as a representative solution for further exploitation.

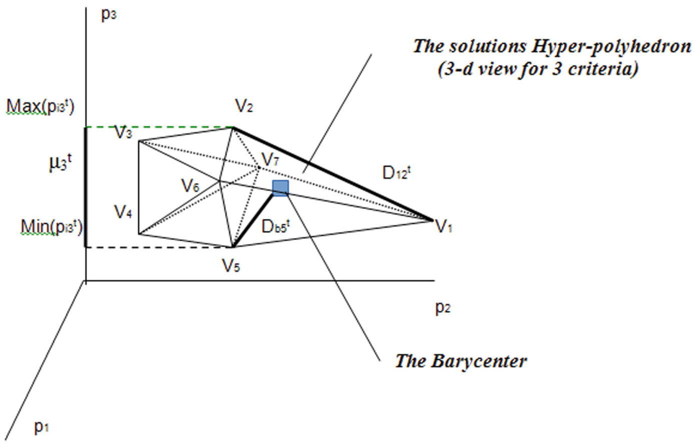

Fig. 1. Geometric representation of solutions hyper-polyhedron for 3 criteria

Let $\mathbf{V}_i^t$ be the i-th vertex of the hyper-polyhedron of the preference model of individual t, where $\mathbf{V}_i{}^t = \{p_{i1}{}^t, p_{i2}{}^t, \ldots, p_{ij}{}^t, \ldots, p_{in}{}^t\}$, with:

$j = 1, \ldots, n$ (n the number of criteria),
$i = 1, \ldots, k$ (k the number of vertices) and
$t = 1, \ldots, m$ (m the number of DMs).

Let also $\mathbf{V}_i^c$ be the i-th vertex of the hyper-polyhedron of the Collective Preference Model where $\mathbf{V}_i{}^c = \left\{p_{i1}{}^c, p_{i2}{}^c, \ldots, p_{ij}{}^c, \ldots, p_{in}{}^c\right\}$.

The barycentre solutions are denoted for each criterion j and each DM t as:

$\mathbf{V}_b{}^t = \left(p_{b1}{}^t, p_{b2}{}^t, \ldots, p_{bj}{}^t, \ldots, p_{bn}{}^t\right)$ where $p_{bj}{}^t = \left(\sum_{i=1}^{k} p_{ij}{}^t\right)/k \;\; \forall i = 1, 2, \ldots, k$ for the individual preference models, and

$\mathbf{V}_b{}^c = \left(p_{b1}{}^c, p_{b2}{}^c, \ldots, p_{bj}{}^c, \ldots, p_{bn}{}^c\right)$ where $p_{bj}{}^c = \left(\sum_{i=1}^{k} p_{ij}{}^c\right)/k \;\; \forall i = 1, 2, \ldots, k$ for the collective preference model.

The robustness analysis and feedbacks proposed in this work target in two directions:

- to analyse the robustness in the individuals and collective preference models
- to determine significant factors of the preferences models among the DMs which differentiate them or common points that may be a starting point, for triggering convergences in a compromising process.

For the purposes of the analysis, a set of five indices are used measuring the degree of robustness of the preference models:

A. The range between minimum and maximum values of the j-th criterion weight, as these values are estimated at each vertex of the hyper-polyhedron during post optimality analysis. For the j-th criterion and t individual preference model the index is estimated as:

$$\mu_j{}^t = \max_i(p_{ij}{}^t) - \min_i(p_{ij}{}^t) \;\; \forall i = 1, 2, \ldots, k$$

Index μ_j^t is used in order to identify variations in the ranges of criteria weights as a major measure for evaluating robustness.

B. The normalized Euclidean distance of a vertex i from some other vertex r of the high dimensional hyper-polyhedron for the t individual preference model is estimated as:

$$D_{ir}{}^t = \sqrt{\sum_{j=1}^{n} \left(p_{ij}{}^t - p_{rj}{}^t\right)^2 / n} \;\; \forall j = 1, 2, \ldots, n \text{ with } i \neq r$$

This index is used in order to identify vertices which are far away from each other.

C. The normalized Euclidean distance between the barycentre of the hyper-polyhedron and a vertex i is estimated as:

$$D_{bi}{}^{t} = \sqrt{\sum_{j=1}^{n} (p_{bj}{}^{t} - p_{ij}{}^{t})^2 / n} \quad \forall j = 1, 2, \ldots, n$$

It is used for the estimation of the volume of the hyper-polyhedron.

D. Euclidean distance between barycentres $\mathbf{V}_b^t$ and $\mathbf{V}_b^z$ of t and z individual preference models respectively is estimated as:

$$DV_b^{tz} = \sqrt{\sum_{j=1}^{n} (p_{bj}{}^{t} - p_{bj}{}^{z})^2 / n} \quad \forall j = 1, 2, \ldots, n$$

E. Euclidean Distance among the barycentre $\mathbf{V}_b^c$ of the collective preference model and the barycentre $\mathbf{V}_b^t$ of an individual preference model is estimated as (Fig. 2):

$$DV_b^{ct} = \sqrt{\sum_{j=1}^{n} (p_{bj}{}^{c} - p_{bj}{}^{t})^2 / n} \quad \forall j = 1, 2, \ldots, n.$$

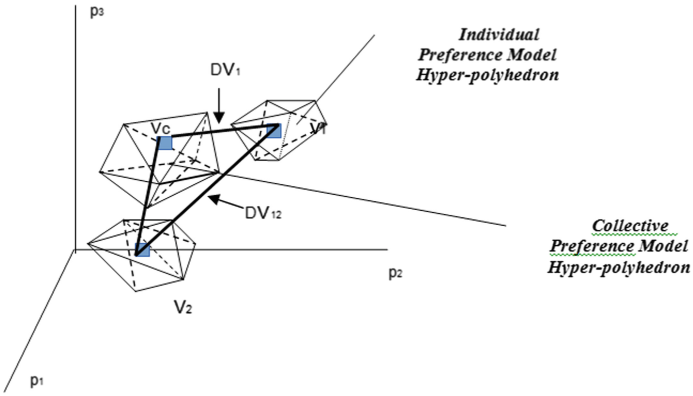

Fig. 2. Individuals and collective hyper-polyhedra for three criteria

3 Robust Analysis Through Visual and Interactive (RAVI) Approaches

RAVI approaches are proposed as a set of tool for further supporting of the interactive nature of D-A methods by analysing the assessed additive value preference models. This kind of robustness analysis operates in a synergistic manner with the existing functions of MINORA and MIIDAS systems and enriches the feedbacks and the interactivity of the construction procedure of the preference models'. The aim of these feedbacks is to estimate more robust preference models. This can be achieved through processes that reduce the volumes of the hyper-polyhedra (increase the robustness) by exploiting new preference information which can be derived from the DMs.

A crucial point of this process is to examine how the following questions can be answered:

- How robust are the assessed individual preference models?
- Which criteria make DMs more or less sensitive to changes?
- How far away from each other lay the individual preference models into the decision space and which are their major differences?
- Which criteria present higher or lower differentiations among the DMs.
- Which are the criteria with common levels of weights for all or the majority of DMs.

A set of interactive processes aimed to assess preference models could provide valid answers to the above mentioned questions. The estimation of the indices described in previous section as well as the production of visual 3-d graphics of the RAVI system (new software developed for the needs of this research work) can provide a frame to work on, by exploiting the results of robustness analysis. Such kind of interactive processes are found in MINORA and MIIDAS systems, namely:

- The adaptation of problem formulation such as the criteria modelling, the alternatives' evaluation on the criteria and the selection of the reference set.
- The reformulation of DMs preferences as they were expressed in the pre-ranking or in the evaluation of the alternatives on the criteria.

In addition, interactions can be implemented aiming to reduce the low robustness of individuals and collective preference models in order to achieve a better convergence. This includes two kind of interactive processes. During the first one, through the analysis of the indices and the 3-d visualisation of the hyper-polyhedra, common ranges of the criteria weights among the DMs can be identified. Lower ranges of the criteria weights could be obtained by exploiting focused dialogues with the DMs expressing their attitudes. Through these dialogues new conditions are produced for one or more criteria. For example for the j-th criterion of t individual preference model this conditions are taking the form of:

$$p_j{}^t < Q_j{}^t,\ \text{where } Q_j{}^t \leq \max_i(p_{ij}{}^t) \text{ and } \mathrm{p}_\mathrm{j}^\mathrm{t} > \mathrm{q}_\mathrm{j}^\mathrm{t},\ \text{where } \mathrm{q}_\mathrm{j}^\mathrm{t} \geq \min_i(p_{ij}{}^t)\ \forall i = 1, 2, \ldots, k',$$

$[\mathrm{Q}_\mathrm{j}^\mathrm{t}, \mathrm{q}_\mathrm{j}^\mathrm{t}]$ are now the new ranges of the criteria weights. These conditions are inserted into UTA LP programme, which will lead to the estimation of new preference models for both individuals and collective models. Therefore higher robustness and a better convergence among the DMs will be achieved.

The second interactive process concerns the estimation of inter-priorities of the criteria weights either for a couple of criteria, for a subset or even for all of them. This is easily achieved by utilizing a small set of virtual or real alternative actions, very carefully selected in order to efficiently determine preferences concerning the importance of the criteria by each individual DM. The additional preference information acquired by the DMs can support the identification of priorities between two or more criteria and enrich the UTA linear programmes with one or more conditions in the form:

$p_y > p_j$, with y, j ϵ {1,2,…,n} and y≠j, in preference models where the intersection of the criteria weights ranges is not null.

The estimation of the new preference models is expected to be more robust, leading to a shrinking of the hyper-polyhedra.

The above described interactive feedbacks can be implemented for these preference models that exhibit low robustness and high range of the criteria weights. The main target of this process is to shrink the hyper-polyhedra through a refining process in the cases where the global preferences of the DMs cannot be changed.

The system RAVI provides a set of graphical representations which facilitates the picturing of the robustness of the estimated preference models. Specifically it supports:

- Presentations in three-dimensional form of the hyper-polyhedra for any given three criteria, which are selected by the user in an interactive manner.
- Rotation of the hyper-polyhedra both horizontally and vertically, so as the DM can have full view of their shape, using polar coordinates and a set of scroll bars which allow the change of the view position.
- Calculation and presentation of robustness indices in tables along with the graphic representations,

In Fig. 3 the four steps of the proposed process are presented. In the first stage we estimate the preference models (individuals and collective) and in the second one the we present and analyse the results to the DMs, in a similar way as in MINORA and MIIDAS systems. Provided that the results are clear and understandable to the DMs we can move forward in the robustness analysis. The next two steps involve the robustness analysis of the estimated preference models and the identification and implementation of feedbacks, as described above, for the assessment of new individual and collective preference models. Through the new preference models we intend to achieve higher robustness and possible better convergence among DMs preference models.

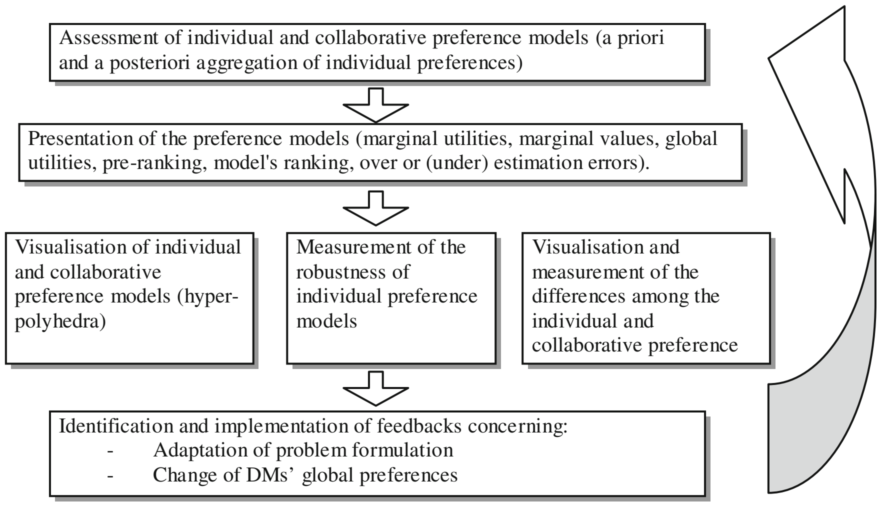

Fig. 3. Steps of the preference models robustness analysis and feedbacks

4 Illustration Example

The proposed methodological approach will be presented through an example concerning the job evaluation (positions of authority). The evaluation was commissioned by four experts (Decision Makers) and their duty was to evaluate 25 jobs (p - 1, p - 2, . . ., p - 25). For the evaluation of the jobs the committee used 6 criteria (qualifications required by the position holder, the staff, decisions taken, multiplicity of the tasks, responsibility of the position and budget handling). From a set of 25 positions, 13 were selected as a reference set and the DMs rank-order them separately, expressing their global preferences. Also, a collective ranking was calculated using the Borda function, a simple and credible method for the purposes of this illustration (Table 1).

Table 1. DMs' pre-rankings (global preferences) and collective ranking (Borda social choice function)

Jobs	DM1	DM2	DM3	DM4	Collective
P3	1	2	4	6	3
P13	2	1	2	1	1
P7	3	3	1	2	2
P17	4	4	3	3	4
P4	5	6	5	7	5
P22	6	5	7	5	5
P16	7	7	8	9	7
P10	8	8	6	4	6
P6	9	9	10	8	8
P18	10	10	11	10	9
P23	11	11	12	11	10
P9	12	12	9	13	11
P19	13	13	13	12	12

The four individual additive value models were estimated as well as the collective utilising the DMs' pre-rankings and the collective one. Table 2 presents the weights of the assessed individuals and collective preference models (minimum, maximum and average weights) as well as an index μ indicating the robustness measurement. Fig. 3 presents in 3-d graph, views of the hyper-polyhedra where M is the Kersten-centre of the collective preference model and M1, M2, M3, M4 the barycentres of the individuals' ones.

The analysis of the robustness brings to the fore some interesting results. DM4 preference model is totally robust, while all the others present a high level of low robustness. The higher low robustness presented in DM 1 followed by DM 2. The preference structures of DM1 and DM2 are quite close to each other which is pictured in the 3-d graph and the distance among their barycentres is small. Opposite, DM3 and DM4 seem to be differentiated from the first two DMs. For the needs of the presentation of the proposed approach, the focus will centre on DM3 given that: The assessed

Table 2. Criteria weights (after post optimal analysis) for individuals and collective preference models

Criteria	DM1 (weights)				DM2(weights)				DM3 (weights)			
	min	Mean	max	μ_i^1	min	mean	max	μ_i^2	min	mean	max	μ_i^3
Cr 1	0	0.036	0.211	0.121	0	0.023	0.121	0.054	0.398	0.426	0.452	0.054
Cr 2	0	0.12	0.282	0.279	0	0.135	0.279	0.016	0.144	0.152	0.16	0.016
Cr 3	0.211	0.257	0.333	0.115	0.112	0.189	0.227	0.052	0.162	0.198	0.214	0.052
Cr 4	0.198	0.266	0.336	0.093	0.217	0.244	0.31	0.032	0.058	0.074	0.09	0.032
Cr 5	0.158	0.189	0.264	0.096	0.167	0.223	0.263	0.044	0.105	0.127	0.149	0.044
Cr 6	0	0.131	0.199	0.171	0.14	0.187	0.311	0.002	0.032	0.033	0.034	0.002

Criteria	DM4 (weights)			Collective (Borda)			
	min	mean	max	min	mean	max	μ_i^{Ψ}
Cr 1	0.058	0.058	0.058	0.051	0.061	0.165	0.114
Cr 2	0.275	0.275	0.275	0.03	0.185	0.279	0.249
Cr 3	0.081	0.081	0.081	0.115	0.184	0.231	0.116
Cr 4	0.102	0.102	0.102	0.165	0.191	0.22	0.055
Cr 5	0.227	0.227	0.227	0.178	0.204	0.235	0.057
Cr 6	0.257	0.257	0.257	0.114	0.173	0.23	0.116

preference model of DM3 has some inconsistencies with the pre-ranking since alternatives P-6 and P-16 are ranked in other positions in relation to what DM ranked them (Fig. 5).

The hyper-polyhedron of DM3 is far away from the hyper-polyhedra of the other DMs (Fig. 4) and the collective one. Moreover, the distance of the barycentre of DM3 is higher from the collective preference model (0.17004) as well as from all the other DMs preference models (0.20613, 0.21308 and 0.22312 correspondingly) (Table 3). On the other hand DM3 seems to have a level of convergence with DM1 and DM2 in criterion 2, since the intersection of the weights ranges is [0.144, 0.16]. The same is presented into other criteria but in a pair-wise manner. The above lead us to re-examine the case of DM 3.

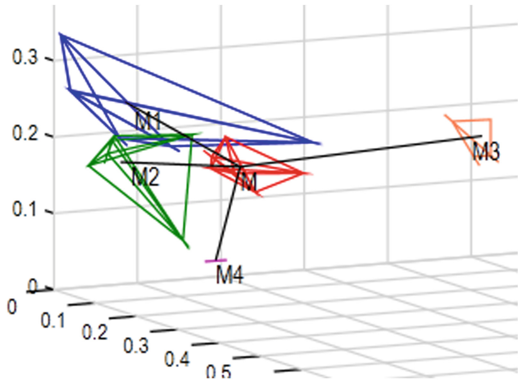

Fig. 4. 3-D views of individuals and collective hyper-polyhedra before the post analysis feedbacks (color lines (Blue - DM 1, Green - DM 2, Orange - DM3, Coral DM 4, Red - Collective)) (Color figure online).

Table 3. Euclidean distances of the barycentres

Barycenters	Euclidean distance (before feedback)	Euclidean distance (after feedbacks)
M1 - M	0.0546	0,0436
M2 - M	0.03353	0,03517
M3-M	0.17004	0,13662
M4-M	0.07561	0,076
M1-M2	0.00987	0,00456
M1-M3	0.20613	0,10703
M1- M4	0.0999	0,08348
M2-M3	0.21308	0,13863
M2-M4	0.05674	0,06275
M3-M4	0.22312	0,20535

An extensive dialogue was initiated with the DM3 trying to explain the inconsistencies of the estimated individual preference model, the low robustness and the high differentiation from the other DMs. The dialogue led to an alternation of DM3 global preferences, which resulted in the estimation of a new collective ranking (Table 4) and a new preference model of DM3, impacting also the new collective model (Fig. 5). Also, another dialogue took place with DM1, DM2 in order to check the acceptance of the extreme (min, max) weights of Criterion 2. The dialogues point out to more strict ranges of the criteria weights for these two DMs. In our illustration example the new ranges of the weight for criterion 2 are [0.12, 0.2] and [0.1, 019] for DM1 and DM2 correspondingly. These conditions were inserted into the LP of UTA method and new preference models were estimated. These interventions bring out the estimation of new ranges of criteria weights, without affecting the final ranking of alternative actions. This constitutes a tool to bring closer the DMs preferences structures without changing their essential global preferences and the calculated ranking by the preference models. The new results presented in Fig. 6 and Table 4 provide a better robustness of the preference models as well as convergence of the individual preference models.

Table 4. Criteria weights for individuals DM1, DM2 and DM3 after feedbacks

Criteria	DM1 (weights)				DM2(weights)				DM3 (weights)			
	min	mean	max	μ_i^1	min	mean	max	μ_i^2	min	mean	max	μ_i^3
Cr 1	0	0.034	0,2	0.2	0	0.0271	0.117	0.117	0.262	0.2767	0.321	0.059
Cr 2	0.12	0.15	0.2	0.08	0,1	0.1452	0,19	0.09	0.123	0.156	0.195	0.072
Cr 3	0,22	0.239	0,3	0.08	0.12	0.189	0.214	0.094	0.3106	0.328	0.343	0.0324
Cr 4	0.211	0.256	0.321	0.11	0.23	0.254	0.301	0.071	0.143	0.158	0.169	0.026
Cr 5	0.158	0.195	0.264	0.106	0.175	0.226	0.251	0.076	0	0.0221	0.053	0.053
Cr 6	0	0.126	0.167	0.167	0.14	0.158	0.289	0.149	0.032	0.056	0.091	0.059

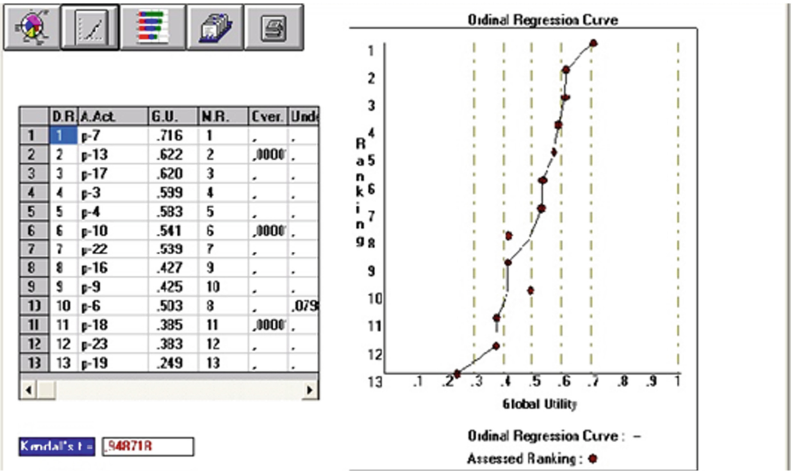

Fig. 5. Additive value model and ordinal regression curve for DM3 (Initial)

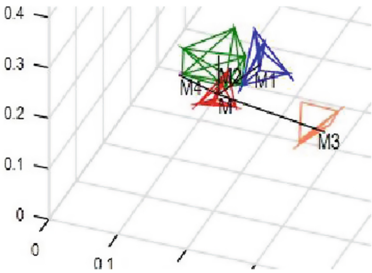

Fig. 6. 3-D views of individuals & collective hyper-polyhedra, after the post analysis feedbacks (color lines (Blue - DM 1, Green - DM 2, Orange - DM3, Coral DM 4, Red – Collective)) (Color figure online).

5 Conclusions

The proposed approaches for handling preference models with low robustness provide new capabilities for the DMs' profiling in collaborative decision making. The interactivity in the processes for the estimation of the individual and collective preference models can be more efficiently supported, provided that the knowledge of the preference structures is improved. In the case of collective decision-making, finding a better level of convergence among participants is often requested in order to avoid unpleasant situations, delays and cost increases. The visualization of the robustness and the comparison of the individual preference models with the collective one can provide an easy way to picture and contrast profiles of preference. The new feedbacks are included in the systems MINORA and MIIDAS for increasing the robustness of individual preferences models and convergence among them, as well as for improving the interactive nature of D-A approach to collective decision-making environment. There is a lot of work that remains to be done yet, since robustness analysis of the preference models opens new promising directions for further development of the interactive nature of D-A approaches. Furthermore, a lot of opportunities emerge from the exploitation of robustness in collective decision making and particularly in situations where conflicts among the stakeholders must be resolved. We will address these unresolved in our future research undertakings.

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