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Dynamics in Logistics

Proceedings of the 6th International Conference LDIC 2018, Bremen, Germany

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Preface

For more than a decade, the International Conferences on Dynamics in Logistics (LDIC) brings together researchers and practitioners from logistics, operations research, production, industrial and electrical engineering as well as from computer science. LDIC 2018 was the sixth event in this series to be held in Bremen (Germany) from February 20 to 22, 2018. This time, LDIC 2018 featured satellite events such as the Internet of Things (IoT) Workshop, the Interdisciplinary Research Colloquium of the International Graduate School for Dynamics and Logistics as well as tours through the Bremen Ambient Assistant Living Lab (BAALL) and the Robot Soccer Team (B-Human) at the Deutsches Forschungszentrum für Künstliche Intelligenz GmbH (DFKI). Similar to its five predecessors, the Bremen Research Cluster for Dynamics in Logistics (LogDynamics) of the University of Bremen organized this conference in cooperation with the Bremer Institut für Produktion und Logistik (BIBA).

The topic of the conference was the integration of dynamics within the modeling, planning, and control of logistic processes and networks, which has shown to contribute massively to the improvement of the latter. Moreover, diversification of markets and demand has increased both the complexity and the dynamic changes of problems within the area of logistics. To cope with these challenges, it must become possible to identify, describe, and analyze such process changes. Moreover, logistic processes and networks must be revised to be rapidly and flexibly adaptable to continuously changing conditions. This proceedings book summaries the contributions to LDIC 2018 and primarily addresses researchers and practitioners from the field of industrial engineering and logistics and presents new ideas to solve such problems.

The LDIC 2018 proceedings consist of 57 papers selected by a double-blind reviewing process. The volume is organized into the main areas

- Supply Chain Management and Coordination,
- Maritime Logistics,
- Cyber-physical Production and Logistic Systems,

- Robotics in Logistics,
- Advanced Modeling Techniques.

There are many people whom we have to thank for their help in one or the other way. For pleasant and fruitful collaboration, we are grateful to the members of the program and organization committee:

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February 2018

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Contents

Supply Chain Management and Coordination

Digitalization Elements for Collaborative Planning and Control in Supply Chains

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Abstract. Due to the increasing digitalization and networking along supply chains (SCs), the topic of Industry 4.0 (I4.0) is particularly important for collaborative planning and control. Considering new paradigms and a higher use of technologies, existing processes in value-added networks will fundamentally change. The Digitalization Elements (DEs) presented in this paper describe the future changes of planning and control processes with focus on production and distribution. Based on DEs, a concept allowing to design I4.0-oriented collaborative planning and control processes in SCs will be developed in future work.

Keywords: Collaborative planning and control · Digitalization Element Industry 4.0 · Supply Chain Management

1 Introduction

Increasing individualization of products leads to a growing complexity in planning and control of supply chain networks. To achieve a high efficiency and transparency in SCs, digitalization of business processes is an important trend and a necessary requirement (Kersten et al. 2016). Using technologies like Cyber-Physical Systems (CPSs) an increased data availability and quality can be achieved, allowing new opportunities for collaboration between SC partners and areas (Schuh et al. 2014). In particular at the interface of production and distribution, high potentials for improvement are well known since years caused by a better coordination of the production and transport plannings (e.g., Jung and Jeong 2005). Within these plannings, hierarchical approaches are used going along with less flexibility, responsiveness and adaptability (Dudek 2009). New paradigms and the increased use of I4.0 technologies allow to solve these deficits but also lead to fundamental changes in planning and control processes (ten Hompel and Henke 2017).

Currently in literature, there is no scientific approach that accompanies the transformation of collaborative planning and control processes in the context of I4.0. Existing papers only describe general changes in supply chains and not at the interface of production and distribution. As a first step of a I4.0-oriented concept for process

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design, the objective of this paper is to develop DEs in the area of production and distribution with the focus on transport. The DEs characterize the changes of these processes in the context of I4.0 to allow a further analysis of individual planning and control task in a next step of the concept.

2 Development of Digitalization Elements

To develop the DEs, a structured literature analysis consisting of a literature search and text analysis is conducted. According to literature search method of vom Brocke et al. (2015), literature that addresses the changes of planning and control in production and distribution in the context of I4.0 is selected (step 1–3). In step 4 and 5, the identified papers are analyzed to determine the DEs using open coding and selective coding method (Holton 2010; Corbin and Strauss 2015). The proceeding is presented in the following.

Step (1) – Definition of search scope: The literature search focusses on journal and conference papers because they present the largest trends and new issues in a research field (vom Brocke et al. 2015). A keyword search complemented with a backward search is conducted to identify the most relevant literature for the research topic. Due to Google Scholar covers the most common databases (Kilubi and Haasis 2016), it is chosen for the literature search and following test runs.

Step (2) – Definition of parameters: Based on the research field, objective and scope, three parameter classes with different search parameters are set up: *Process* (planning process, control process), *application field* (production, distribution, SC) and *innovative concepts* (I4.0, internet of things, digitalization, digital factory, smart factory). The search period has been selected from 2011 to present because the concept of I4.0 came up for the first time in this year (Kagermann et al. 2013). In the first test runs, most search hits were achieved with the combinations of the parameters “internet of things”, “planning process” and “SC”. Therefore, they were selected for the first run of literature search. In the test runs, many papers with irrelevant terms were discovered, which introduces a fourth parameter class: *Excluded terms* (e.g. city, electro mobility, agriculture, hospital, traffic).

Step (3) – Literature search: The literature search was conducted in single runs in May and August 2017 (see Table 1), so that the decision for the parameters could be validated. After each run, the identified literature was screened and reduced by non-scientific as well as inaccessible papers. Furthermore, the parameter class *excluded terms* was extended by terms, which are not relevant. German translations were added to integrate more papers in the analysis because the concept of I4.0 arose in Germany first. At the end of literature search, in total 355 literature sources were identified in 12 search runs.

Table 1. Results of the literature search

Number of search run	Process	Innovative concept	Application field	New identified papers
1	planning process	internet of things	production, distribution, SC	105
2	planning process	I4.0	production, distribution, SC	23
3	planning process	digital factory	production, distribution, SC	85
4	planning process	smart factory	production, distribution, SC	9
5	planning process	digitalization	production, distribution, SC	10
6	control process	internet of things	production, distribution, SC	107
7	control process	I4.0	production, distribution, SC	5
8	control process	digital factory	production, distribution, SC	1
9	control process	smart factory	production, distribution, SC	0
10	control process	digitalization	production, distribution, SC	5
11	Planungsprozess	Industrie 4.0	production, distribution, SC	4
12	Steuerungsprozess	Industrie 4.0	production, distribution, SC	1

All titles and abstracts of the identified papers were scanned with regard to the fourth parameter class to exclude all the remaining irrelevant papers. Finally, 143 papers are used for the text analysis.

Step (4) – Definition of categories: Open coding is a common method to analyze and understand text content with describing it in single words (codes) (Holton 2010). This method emerge to classify raw data into conceptual categories (Corbin and Strauss 2015). In this paper, codes represent identified changes of planning and control processes in production and transport in the context of I4.0. By conducting the method, sources with most promising titles and abstracts regarding future changes of planning and control in SCs are analyzed first. Relevant text passages are labeled by an individual code for describing the meaning of data (Corbin and Strauss 2015) and afterwards combined with similar codes of previously analyzed papers. Labeling stops when too many old codes arise. Created codes are summarized into general categories considering their differentiation (Corbin and Strauss 2015). Five categories are determined: *Data collection and data storage, data processing/analysis, data provision and decision-making, information system* and *organization*. Finally, remaining literature sources are reviewed and relevant passages are assigned to the five categories. Non-relevant sources are excluded reducing the number of used literature sources to 61.

Step (5) – Identification of patterns: The objective of selective coding is to identify codes with similar core content and summarize them into patterns (Holton 2010). With this method, the codes (identified changes) with similar meaning are summarized to a pattern within a category. DEs represent the patterns in the following. In result, 12 DEs in the five different categories are developed and briefly described in Table 2.

Table 2. Digitalization Elements with regard to the five categories

Category	Digitalization Element
Data collection and data storage	Real-time collection and storage of production and transport data Real-time collection and storage of production and logistics data for a high transparency. Status information of nodes and edges within the network, e.g. the transport status of products and current operating data of machines, are collected in short-term and stored in long-term.
Data processing/analysis	Machine learning in production and transport sector Machine learning as a subarea of artificial intelligence includes analytics that are applied to large data volumes, enable the identification of patterns and discover unknown relationships in complex systems, e.g. SC networks. The patterns can serve as input data for planning and control. As a result, forecasts regarding operational disruptions in production and transport sectors can be improved.
Data provision and decision-making	Model-based decision-making A digital model of the real world representing objects and their cause-effect relationships in a virtual environment. The model allows an assessment of the current system status and its future development (simulation and heuristics). Planning models can be improved by real-time information and used in the operational area, e.g. ad-hoc rescheduling of production and transport processes in case of operational disruptions.
	Smart products along the entire value-added chain Smart products have their own identities (product agents), collect their data along the entire value-added chain, store them in product data models that can be used decentral by process participants. Smart products are able to save the "history" of their value-added process and can guide themselves through production and transport systems.
	Control of production and transport resources via cloud Operation of several resources via cloud allows controlling production and transport facilities from outside of a company. This enables flexible, multi-resource control by location-independent operating personnel.
	Autonomous control of production and transport processes by CPS CPSs have the possibility to organize and optimize themselves. Thus, decentralized process coordination by CPSs allow autonomous process handling in the operational area of production and transport. They also enable autonomous process monitoring and punctual troubleshooting. Deviations are identified and analyzed in real-time using key performance indicators and valuation models. CPSs are able to initiate countermeasures.
Information system	Universal networking between planning and control Integrated communication architecture and infrastructure with standardized interfaces between planning and control to reduce media discontinuities, reaction times and latencies. Due to the universal networking of business systems and areas (vertical

(*continued*)

Table 2. (*continued*)

Category	Digitalization Element
	integration), real-time information can be transmitted faster, so that planning periods are shortened and planning quality is increased.
	Universal networking via virtual SC cloud Virtual SC cloud as a dynamic communication platform for SC partners to support networking (horizontal integration) and information exchange for the common goal achievement. Plan and feedback data are shared as well as flexibility of task assignment is increased.
	Market platform for negotiation of manufacturing and transport services for CPS Market platform for CPS to offer and inquire production and transport services (e.g. planning and executive activities) that allow a flexible utilization of production and transport capacities. This enables a dynamic and self-regulating SC.
Organization	Central production and transport planning Superordinate planning level that defines the master plan for production and transport considering all necessary parameters. Hierarchical planning limits will be resolved and tactical planning tasks will be integrated into the strategic and operational level in the context of I4.0.
	Decentralization in short-term planning and control In the operational area, decentralized structures and autonomous decision units in terms of CPSs are used increasingly. Due to the complete information transparency of the CPSs, decentralized decisions are made, so that a distributed planning is created. Thus, the degree of freedom in planning as well as the autonomy in the operational production and transport area will rise.
	Collaboration at all planning levels Increasing collaboration at all planning levels to manage complexity. Both internal and external company collaborations are strengthened. Particularly in the operational area, new collaboration forms result due to a stronger network of SC partners and a permanent provision of real-time information.

The determined DEs clarify that the future changes of planning and control processes in production and transport mainly deal with organizational and technological aspects. The elements address different I4.0 maturity levels from the networking of individual planning and control systems within a company to the autonomous planning and control of CPSs in production and transport along a SC. The results form the basis for a further analysis regarding changes of individual planning and control task in the context of I4.0.

3 Conclusion and Further Research

The paper presents the future changes of collaborative planning and control processes in production and distribution with the focus on transport. Based on a structured literature search and usage of open and selective coding method, 12 DEs were determined.

The used methods are well suited to conduct a literature analysis in a structured way. Nevertheless, the method involves a great effort. The procedure could be improved by directly assigning the codes to scientifically developed categories, e.g. stages of the I4.0 maturity model according to Schuh et al. (2017).

Future work will focus on specification and verification of the elements by extending the literature search to other databases. To develop a concept for the design of I4.0-oriented collaborative planning and control processes in SCs, an allocation of the elements to planning levels and to I4.0 technologies will be carried out. For further research, the refined DEs will be related to individual planning and control tasks at the interface of production and distribution in SCs. Subsequently, the accompanying transformation of hierarchical planning procedure will be analyzed.

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Mapping Research on Logistics and Supply Chain Coordination, Cooperation and Collaboration

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Abstract. There is more than 25 years of research done in the field of logistics and supply chain coordination, cooperation and collaboration. With the means of citation and co-citation analysis by using the software tools HistCite and VOSviewer we present a bibliometric mapping in order to characterise the intellectual foundation of this body of research. Our results show a dominance of logistics/supply chain coordination research with an emphasis on formal-analytical analysis of supply chain inventory management, contracting and pricing. Independently from this, there is an empirical, theory-driven stream on logistics/supply chain cooperation and collaboration.

Keywords: Coordination · Cooperation · Collaboration · Logistics · Supply chain Bibliometric analysis · HistCite · VOSviewer

1 Introduction

Supply chains are defined as long, complex and interwoven sequences of order-connected firms (see Kotzab and Otto 2004) and their management is concerned with the identification of optimal strategies for a complete chain. This induces the integration of business processes amongst a number of companies (Ryu et al. 2013). Integration is based on different levels of interaction amongst the involved firms ranging from harmonizing or synchronising activities (=coordination) to working together as equal partners (=cooperation) and even acting as one single entity (=collaboration). Consequently it is no surprise that the constructs of ‘coordination’, ‘cooperation’ and ‘collaboration’ (CCC) seem to be important ingredients for supply chain management (SCM) as Frankel et al. (2008) or Mentzer et al.(2008) argue for. Even though the CCC terms may be used interchangeably (Kaur et al. 2011), there is a certain difference between the individual parts of CCC which mainly refers to the degree of liaising with actors in a supply chain.

Kaur et al. (2008) see coordination as a goal-oriented process of harmonising interdependent activities between logistics and supply chain partners. Cooperation in a supply chain setting is given, when logistics and supply chain partners start to work

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together in order to achieve common goals (El Omri 2009). Collaboration in a supply chain context means that supply chain or logistics actors appear as one single entity. As such they start to share responsibility by exchanging common supply chain management measures which makes them achieve higher profitability as compared to acting alone (Cao et al. 2010; Min et al. 2005).

While researchers have so far examined the state-of-the-art of logistics and supply chain coordination, cooperation and/or collaboration research (see e.g. Cao et al. 2010; Ding et al. 2011; Kaur et al. 2008), thus our goal is to determine the roots, or ‘intellectual foundation’, of CCC in supply chain and logistics research.

By studying the intellectual foundation of CCC research, we want to recognise the most influential publications, display their interrelationships and reveal thematic trends in publications including extra-disciplinary works which researchers regularly draw upon (e.g. White and McCain 1998).

2 Methodology

We use the software tools HistCite (Garfield 2009) and VOSviewer (Van Eck and Waltman 2010) for our bibliometric analyses (citation as well as co-citation analysis). Both tools are analytical and visualisation software packages that help to recognise the most important work on a topic and their evolution. We collected and analysed data from the Web of Science Core Collection and gathered all academic journal articles that were published between 1991 and 2016 and contained the search terms ‘supply chain’, ‘logistic*’, ‘collabo*’, ‘coordi*’ and/or ‘cooper*’ in any of the title, abstract, or author-supplied keyword fields (=TOPIC). We limited our sample on papers that were published in English language as well as in a journal being listed in 2015 ABS journal rating list. Our search resulted in 3,359 records from 44 journals. The sample represents more than 5,500 authors and over 74,000 citations with over 14,000 citation links.

3 Results and Discussion

In Fig. 1 we can see the historiography of the citation relations of the 30 most cited papers of our sample based on the local citation score (LCS) as identified by the HistCite software (see also Appendix 1).

The publication date of these papers spans from 1999 to 2011. The citation relations refer to 30 nodes and 31 links and the citation strength ranges from a minimum LCS of 48 to a maximum LCS of 310. Looking at the pattern of the citation relations as outlined in Fig. 1, we see seven isolated papers, one small citation cluster (3 papers) and one large citation network (20 papers). Out of these 30 papers, the majority refers to supply chain coordination issues while only a small share deals with cooperation and/or collaboration. Especially in the large citation network, exclusively deals with coordination issues, especially with supply chain contracts and pricing. The citation relation of the small cluster of three papers seems to be justified by the publication outlet as all three papers were published in the Journal of Operations Management.

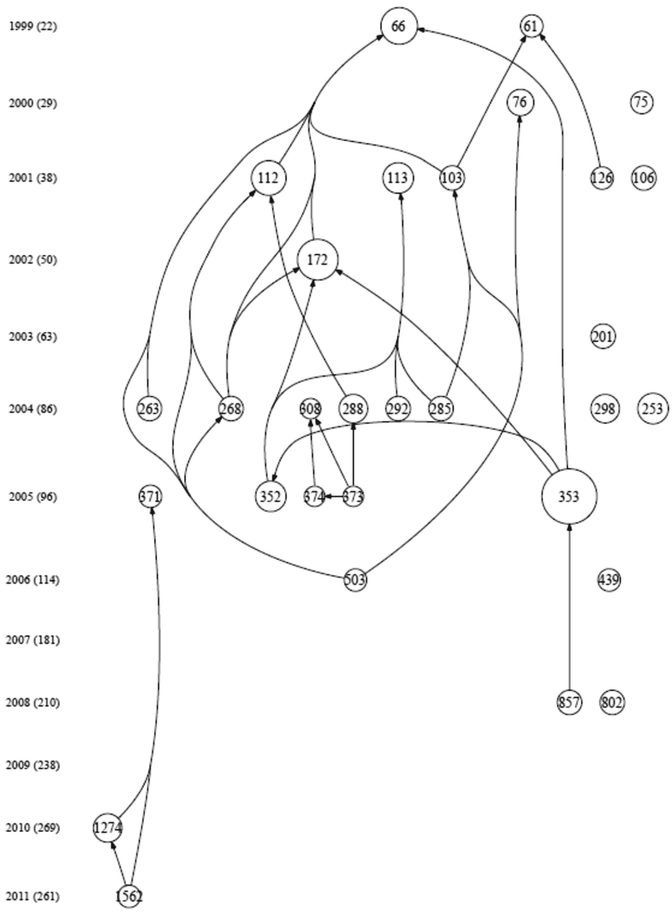

Fig. 1. Citation relations of the 30 most cited CCC papers as indicated by HistCite (for the circle number see Appendix 1 and 2)

Table 1 (as well as Appendix 1, 3a and 3b) shows the results for our co-citation analyses for articles as well as for journals.

The two journal-based co-citation clusters represent the outlets of different scientific communities within the field of CCC-research. One cluster includes journals of the OR-related research community characterizing a formal-analytical understanding of CCC-research while the other cluster contains journals of the empirical SCM-related research community. The co-citation density within each cluster is high and the co-citation relations between these two clusters are limited which means that the exchange of thoughts is rather exclusive within the groups than between the groups.

The three article-based co-citation clusters can be described as follows. Cluster 1 'Integration/Collaboration – empirical analysis' includes theoretical, methodological as well as supply chain integration/collaboration papers. All papers represent the empirical management oriented supply chain and logistics research community. Theoretical

Table 1. Description of identified co-citation results based on VOSViewer

30 most co-cited journals (alphabetical order)	
'Management Science oriented' journal cluster	Computers & Industrial Engineering; Computers & Operations Research; European Journal of Operational Research; IIE Transactions; International Journal of Production Economics; International Journal of Production Research; Management Science; Marketing Science; Naval Research Logistics; Omega; Operations Research; Production & Operations Management; Production Planning & Control; Transportation Research Part E
'Logistics/SCM-oriented' journal cluster	Academy of Management Journal; Academy of Management Review; Decision Sciences; Harvard Business Review; Industrial Marketing Management; International Journal of Logistics Management; International Journal of Operations Management; International Journal of Physical Distribution & Logistics Management; Journal of Business Logistics; Journal of Marketing Research; Journal of Operations Management; Journal of Supply Chain Management; Strategic Management Journal; Supply Chain Management: An International Journal
30 most co-cited papers (alphabetical order)	
Cluster 1: 'Collaboration/Coordination - empirical analysis'	Anderson and Gerbing 1988, Armstrong and Overton 1977, Barney 1991, Dyer and Singh 1998, Eisenhardt 1989, Fisher 1997, Fornell and Larcker 1981 , Frohlich and Westbrook 2001, Barratt 2004, Mentzer et al. 2001, Morgan and Hunt 1994, Podsakoff et al. 2003
Cluster 2: 'Value of sharing information in SCM'	Cachon and Fisher 2000, Cachon and Lariviere 2001, Gavirneni et al. 1999, Lee et al. 2000, 1997
Cluster 3: 'Coordination - formal analysis'	Banerjee 1986, Bernstein and Federgruen 2005, Cachon 2003, Cachon and Lariviere 2005, Emmons and Gilbert 1998, Jeuland and Shugan 1983, Lariviere and Porteus 2001, Pasternack 1985, Spengler 1950, Taylor 2002, Thomas and Griffin 1996, Tsay 1999, Weng 1995

papers deal with commitment-trust theory, resource based and relational view. Methodological papers refer to the use of case study research, structural equation modeling and non-response bias. The small cluster 'Value of Information Sharing in SCM' includes papers dealing with the value of information sharing in supply chain as well as in the field of inventory management. The third cluster ‘Coordination - formal analysis’ represents the foundation for supply chain coordination (especially contracting and pricing) from a formal-analytical point-of view. The co-citation density between these three clusters is also limited while between the clusters very high.

Even though it seems obvious that coordination, cooperation and collaborations are fundamental building blocks of the supply chain management and logistics domain our findings present noteworthy contradictions. The use of specific literature seems to depend on the particular research domain. There is no overall common understanding on the fundamentals of the three constructs.

4 Conclusions

The results of the citation analysis have shown that coordination is a dominating theme especially in the more management science oriented research community. Our co-citation networks show that there are research streams that are either related to empirical supply chain collaboration/cooperation problems or to formal-analytical supply chain coordination issues. This particular pattern leads to an isolated use of literature that is also documented by the results of the co-citation journal network. A similar result is shown by Georgi et al. (2013).

For future research in the field several questions emerge: why are these research streams disjunctive from each other? Do researchers perceive coordination of a supply chain as a research problem that can be solved by a mathematical formula, hence with a formal analysis only? Are supply chain cooperation and collaboration empirical research objects only? Are there any learning opportunities in crossing the lines to other research streams? Why not going the next step and including research approaches from other research streams?

For a practitioner, the clear cut of the research streams is a challenge, as supply chain management in the corporate world is always relying on both: having a clear formal analysis as well as having the managerial tools available to implement the results along the supply chain. Neither side can achieve any benefit without the other. Hence, the scholars are not supporting the real world situation with the artificial division of work among them.

For future research we suggest to look at the development of CCC research over time as well as to include other databases for the analysis in order to consider different type of literature. This might help to find the underlying patterns and answering some of the above-mentioned questions.

Appendix 1. References for Citation and Co-citation (Fig. 1 and Appendices 1 and 3a, 3b)

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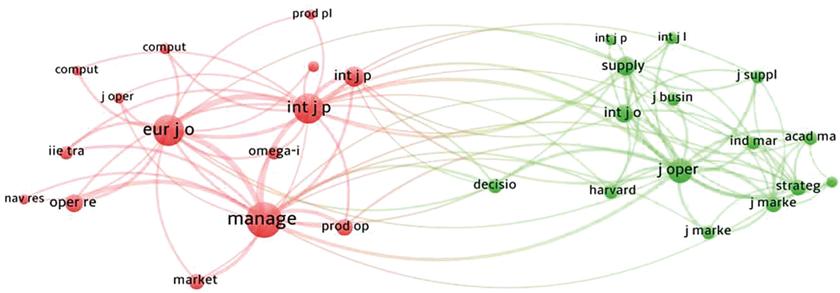
Appendix 2. Top 30 Citations as Identified by HistCite[1]

Nodes: 30, Links: 31
LCS, top 30; Min: 48, Max: 310 (LCS scaled)

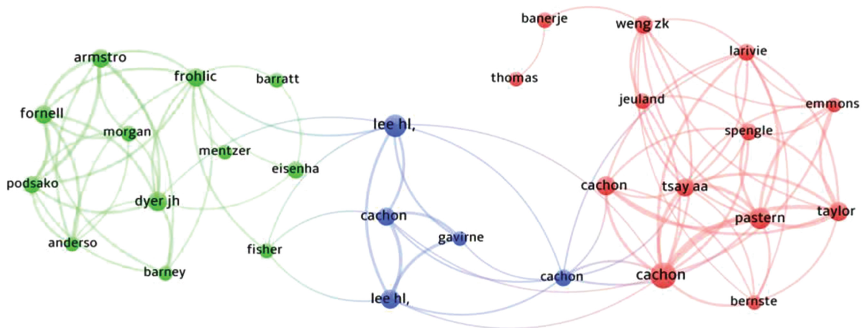
			LCS	GCS
1.	61	Cachon GP, 1999, MANAGE SCI, V45, P936	52	228
2.	66	Tsay AA, 1999, MANAGE SCI, V45, P1339	148	380
3.	75	Cetinkaya S, 2000, MANAGE SCI, V46, P217	53	245
4.	76	Corbett CJ, 2000, MANAGE SCI, V46, P444	80	245
5.	103	Ha AY, 2001, NAV RES LOG, V48, P41	61	162
6.	106	Viswanathan S, 2001, EUR J OPER RES, V129, P277	59	145
7.	112	Cachon GP, 2001, MANAGE SCI, V47, P629	127	367
8.	113	Chen FR, 2001, MANAGE SCI, V47, P693	93	230
9.	126	Aviv Y, 2001, MANAGE SCI, V47, P1326	57	215
10.	172	Taylor TA, 2002, MANAGE SCI, V48, P992	171	371
11.	201	Chiang WYK, 2003, MANAGE SCI, V49, P1	66	351
12.	253	Barratt M, 2004, SUPPLY CHAIN MANAG, V9, P30	105	321
13.	263	Krishnan H, 2004, MANAGE SCI, V50, P48	62	174
14.	268	Cachon GP, 2004, MANAGE SCI, V50, P222	64	234
15.	285	Corbett CJ, 2004, MANAGE SCI, V50, P550	68	181
16.	288	Gerchak Y, 2004, PROD OPER MANAG, V13, P23	86	193
17.	292	Tsay AA, 2004, PROD OPER MANAG, V13, P93	63	234
18.	298	Giannoccaro I, 2004, INT J PROD ECON, V89, P131	89	276
19.	308	Gan XH, 2004, PROD OPER MANAG, V13, P135	49	135
20.	352	Bernstein F, 2005, MANAGE SCI, V51, P18	95	240
21.	353	Cachon GP, 2005, MANAGE SCI, V51, P30	310	794
22.	371	Petersen KJ, 2005, J OPER MANAG, V23, P371	52	368
23.	373	Kleindorfer PR, 2005, PROD OPER MANAG, V14, P53	48	511
24.	374	Gan XH, 2005, PROD OPER MANAG, V14, P80	49	144
25.	439	Vachon S, 2006, INT J OPER PROD MAN, V26, P795	58	349
26.	503	Ozer O, 2006, MANAGE SCI, V52, P1238	50	131
27.	802	Vachon S, 2008, INT J PROD ECON, V111, P299	68	364
28.	857	Nagarajan M, 2008, EUR J OPER RES, V187, P719	61	207
29.	1274	Flynn BB, 2010, J OPER MANAG, V28, P58	82	461
30.	1562	Cao M, 2011, J OPER MANAG, V29, P163	52	263

[1] Underlined numbers indicate circle numbers in Fig. 1; LCS = Local citation score; GCS = Global citation score.

Appendix 3a. Visualisation of Identified Co-citation-Journal-Cluster



Appendix 3b. Visualisation of Identified Co-citation-Article-Cluster



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A System Dynamics Approach for SMEs Internationalization Networking Process

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Abstract. This paper presents the analysis of the relationship among small and medium-sized enterprises (SMEs) internationalization, logistics capabilities, and supply chain flexibility (SCF) from an integrative perspective to address this gap in the literature. We analyzed the networking process of SMEs internationalization using a system dynamics approach in order to determine the behavior of the relationship between internationalization, SCF, logistics capabilities, trust and commitment. The analysis of these relationships provides a better understanding of the role of trust and commitment as enablers of SCF through the development of logistics capabilities in the networking process of SMEs internationalization. This work constitutes the basis to prove further hypothesis and empirical research in order to develop strategies regarding SCF as a sustainable competitive advantage for SMEs internationalization.

Keywords: Internationalization · Logistics capabilities · Supply chain flexibility
System dynamics

1 Introduction

The phenomenon of small and medium-sized enterprises (SMEs) internationalization has received significant attention by policymakers, practitioners, and researchers due to the role of this group of enterprises in the economic health and growth of many countries (Love and Roper 2015). Nevertheless, SMEs lack resources and have limited capabilities (e.g. innovativeness) thus these firms require to develop a sustainable competitive advantage based on their main capabilities (e.g. flexibility) in order to compete in complex, dynamic, and uncertain environments (Gelinas and Bigras 2004; Singh et al. 2008; Ismail et al. 2011; Zhang et al. 2014). During the last decades, this complexity has increased as the competitive scenario regards a supply chain context (Christopher 2011). With this in view, the firm has to coordinate its core strategies, capabilities, resources and actions with its supply chain partners to provide an adequate response to customers' demand. To enhance this coordination across the supply chain, firms have to build up, synchronize and integrate their logistics capabilities (Gligor and Holcomb 2012; Gligor 2014). Consequently, this will lead to higher levels of flexibility within the supply chain (Gligor 2014).

Johanson and Vahlne (2009) presented a network approach for internationalization, and they stated that "relationships offer the potential for learning and building trust and

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commitment", where the last two are considered as "preconditions for internationalization". Furthermore, Mandal (2016) conducted an empirical study where he found a direct and positive influence of trust and commitment on logistics capabilities. He also identified a positive impact of integrated logistics capabilities on supply chain flexibility (SCF) as well as on the overall supply chain performance.

To the best knowledge of the authors, the relationships between SMEs internationalization, logistics capabilities and SCF have not been analyzed from an integrative perspective. Therefore, this work has two purposes: (1) to identify the behavior of logistics capabilities, SCF, and internationalization regarding trust and commitment as enablers of the networking process; and (2) to identify the behavior of the relationship between commitment and SCF regarding SMEs internationalization. The second section gives a brief definition of each component that is analyzed (i.e. internationalization, SCF, logistics capabilities, trust, and commitment). The third section presents a system dynamics approach to describe the behavior of the relationships of these components in the networking process of internationalization. The last section presents the theoretical and managerial conclusions of this paper.

2 Components of the Networking Process for SMEs Internationalization

Johanson and Vahlne (2009) stated that firm's internationalization depends on the firm's network relationships and its networking capabilities (i.e. the ability to communicate, cooperate, share market orientation, trust, networking efforts through information and knowledge exchange (Pihkala et al. 1999)). Therefore, the networking process takes the marked knowledge of the organization to reinforce the relationship between the network partners and as a result, this stimulates the internationalization of the firm (Fig. 1).

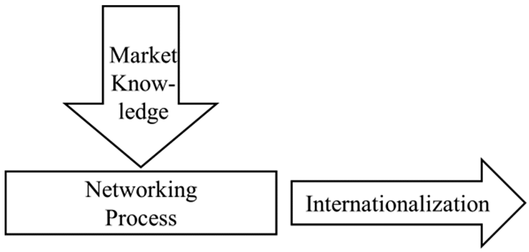

Fig. 1. Internationalization networking process

Leonidou (2004) defined firms' internationalization as "the ability to initiate, to develop, or to sustain business operations in overseas markets". Market knowledge refers to the body of knowledge based on the experiences and information gained overseas (Johanson and Vahlne 2009).

Supply chain flexibility (SCF) is the supply chain capability to reorganize partners' operations, align their strategies, and share efforts to give a quick response to customers' demand or any other fluctuation in the supply chain or its environment with a little penalty in the performance (Stevenson and Spring 2007; Tiwari et al. 2015). Logistics capabilities are the result of combining dynamic routines to align and restructure core skills, competences and resources in order to enhance the overall performance (Gligor and Holcomb 2012). These logistics capabilities can be categorized into four groups i.e. information exchange capabilities, integration capabilities, supply-management capabilities, and demand-management capabilities (Mentzer et al. 2004; Gligor and Holcomb 2012). Both, SCF and logistics capabilities constitute a competitive advantage for firms (Gligor and Holcomb 2012; Tiwari et al. 2015).

Trust is a key element for relationship development and business networking; then trust implies the ability to rely on the behavior and actions of another firm. This motivates information exchange and cooperative efforts between the parts involved in the relationship. Hence, trust may lead to commitment if the parts are willing to establish a more permanent relationship (Johanson and Vahlne 2009; Gligor and Holcomb 2012; Mandal 2016). Commitment is the willingness of exchanging efforts reflected as an investment in the relationship; hence as the commitment increases the relationship dependency also increases (Johanson and Vahlne 2009; Mandal 2016).

3 System Dynamics Approach

A system perspective has been used to have a better understanding of the interaction between the components of interest (Morecroft 2015). Figure 2 presents the system dynamics approach to identify the interaction of each component in the internationalization networking process.

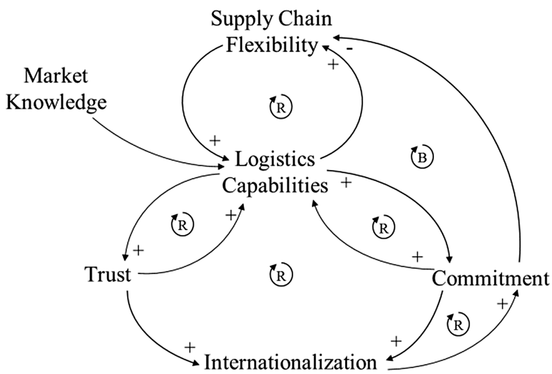

Fig. 2. Relationship analysis of the components of internationalization networking process

The market knowledge enters to the system through logistics capabilities (e.g. information exchange capabilities) acting as enablers of trust (Johanson and Vahlne 2009). Trust is reinforced by the logistics capabilities among the network partners. As trust increases through the logistics capabilities (e.g. supply-management capabilities and demand-management capabilities), the relationship commitment also increases. Furthermore, both trust and commitment also reinforce the effect on logistics capabilities across the network e.g. information exchange capabilities and integration capabilities have to increase as trust and relationship commitment increase. These two reinforcing loops have a direct positive effect of logistics capabilities on the internationalization of the firm. Moreover, the alignment of logistics capabilities across the supply chain partners reinforce SCF (Gligor and Holcomb 2012; Mandal 2016), and this in return stimulates the development of logistics capabilities e.g. to improve the time of response to customers' demand it will require to enhance demand-management capabilities and integration capabilities.

As the SMEs internationalization increases the commitment with certain markets, providers, and distributers increases as well. This increase in the commitment generates has an opposite relationship with SCF. As the commitment increases, the flexibility of the relationship will decrease e.g. the investment that a firm does in a specific relationship with a supplier limited the firm to invest those resources in other supplier and this creates dependency to that supplier.

4 Conclusions

This paper presented the first phase of a system dynamics approach to analyze the relationships between the components of the networking process of SMEs internationalization. As part of the theoretical contribution, this paper has described this networking process and identified its key components (i.e. internationalization, SCF, logistics capabilities, trust, and commitment). The analysis of the behavior between these components has not been addressed from an integrative perspective in the literature nor as a dynamic process (Novillo and Haasis 2017). This paper also contributes to the body of knowledge regarding the role of trust and commitment in moderating SCF as part of the internationalization strategy of SMEs. From the analysis, it is identified the enabler role that play by trust and commitment in the networking process. This role is reinforced by the positive relationship between logistics capabilities and SCF. Consequently, the reinforcing behavior between logistics capabilities and SCF has a positive impact on SMEs internationalization.

Although in general terms trust and commitment enable SCF through the enhancement of logistics capabilities (Mandal 2016), as internationalization increases the relation commitment also does, which leads to an opposite relationship between commitment and SCF. It has been established that increasing commitment results in a reduction of flexibility in the relationship among the supply chain partners, and hence commitment plays a moderate role on SCF, which also results in a limitation of SMEs flexibility.

Additional to the theoretical contributions, this work also presents managerial implications. SMEs decision makers, mainly in developing countries, have to be aware of the reinforced relationship between trust, commitment and logistics capabilities in order to enhance SCF. Decision makers have to integrate into their internationalization strategies the accurate development of logistics capabilities and the balance of the firm's commitment to a certain supply chain to remain flexible enough as a sustainable competitive advantage. This paper presents the theoretical foundation of a system dynamic approach to prove further hypothesis and empirical studies.

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Theory Landscape and Research Perspectives in Current Supply Chain Resilience Research

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Abstract. In an era of turbulence and increased volatility, the concept of Supply Chain Resilience is increasingly gaining attention within supply chain and logistics management research. However, both practitioners and scholars are still facing inconsistencies in the describing terminology, and thus anticipate a comprehensive understanding of the nature of Supply Chain Resilience. By conducting a systematic review of existing literature, and applying the conceptual lens of borrowing theories from related scientific disciplines, this research identifies 56 different theories and ten different perspectives within existing Supply Chain Resilience literature. This paper contributes to a better understanding of current Supply Chain Resilience research perspectives, based on theories applied within the field, and helps scholars to better investigate supply chain research activities within the proposed landscape of Supply Chain Resilience.

Keywords: Supply Chain Resilience · Systematic review
Theory development

1 Introduction

Within complex global supply chain networks, companies increase their supply chain disaster preparedness and reduce their supply chain vulnerability. Therefore, the development of know-how, methods, processes and tools is mandatory for global enterprises that are required for implementing mitigating strategies and improving competitiveness (Christopher and Peck 2004). In this context, the concept of Supply Chain Resilience (SCRES) has become increasingly popular in current supply chain management (SCM) and supply chain risk management (SCRM) research areas (Mandal 2014; Carvalho et al. 2012). However, Supply Chain Resilience still faces a lack of common understanding and inconsistency in its describing terminology (Hohenstein et al. 2015; Scholten et al. 2014; Blackhurst et al. 2011; Ponomarov and Holcomb 2009). As part of the evolutionary growth, in interdisciplinary SCM research (Klaus 2009), Supply Chain Resilience literature shows a lack of theoretical foundation (Kamalahmadi and Parast 2016). So far, only Tukamuhabwa et al. (2015) have analyzed theories within a sample of 91 Supply Chain Resilience research papers. Since then, the number of publications from both practitioners and theorists has increased. Thus we can anticipate a

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more comprehensive and up-to-date analysis of underlying theories and differentiation of existing perspectives within Supply Chain Resilience research.

The purpose of this paper is twofold. First, this research offers a comprehensive overview of theories applied within Supply Chain Resilience research. Second, this paper identifies specific perspectives within Supply Chain Resilience research and links those with theories applied. This research advances the discussion of Ponomarov and Holcomb (2009), Pettit et al. (2013) and other authors regarding different perspectives within Supply Chain Resilience research. Considering Light and Pillemer (1984), this paper aims to contribute to the process of building Supply Chain Resilience theory by answering the following research questions:

RQ1: What is the theoretical foundation of existing Supply Chain Resilience research based on the literature?

RQ2: Which research perspectives can be identified within Supply Chain Resilience research?

Overall, this paper contributes to a better understanding of current Supply Chain Resilience research perspectives, based on theories applied within the field. It also helps scholars to better investigate supply chain research activities within the proposed landscape of Supply Chain Resilience and thus to have an effect of *sensegiving* – “the process of shaping other academics’ and practitioners’ understanding of the phenomena” (Maitlis and Lawrence 2007). Concerning managerial implications, this paper contributes by providing insights into latest approaches to improve operational performance under increasingly severe global market conditions.

2 Methodology

Following Rousseau et al. (2008) this research uses a transparent, comprehensive analysis approach. Thereby we conducted a systematic review of existing literature based on the five-step approach of Denyer and Tranfield (2009) (Fig. 1). Because of its broader and more interdisciplinary search strategy, our systematic review differs from existing literature reviews such as Annarelli and Nonino (2016), Kamalahmadi and Parast (2016), and Hohenstein et al. (2015). The time frame of our literature search includes articles published between January 2003 and December 2016, as the year 2003 can be seen as a turning point in SCRM research (Kamalahmadi and Parast 2016; Ghadge et al.

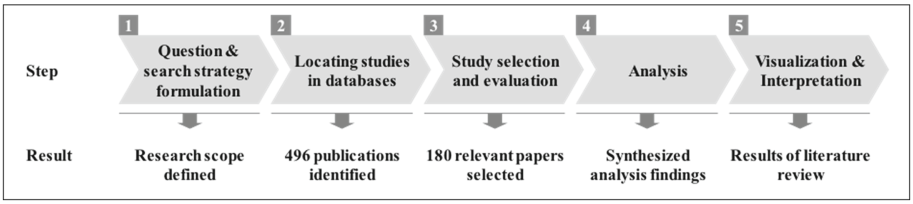

Fig. 1. Methodology of systematic review.

2012; Tang and Musa 2011). To locate existing studies, the search terms "supply chain" and "resilien*" were entered in publication titles and abstracts of the database entries.

We used the search engines sciencedirect.com, emeraldinsight.com, en.bookfi.org, tandfonline.com, wiso-net.de, link.springer.com, and ieeexplore.ieee.org. This led to 496 findings. After eliminating redundant articles, we substantively assessed the remaining articles on their relevance based on the procedure of Tukamuhabwa et al. (2015), according to which the reintroduction of the keywords identified in the selected abstracts is a proven way to identify definitions, strategies, properties and other aspects with direct reference to Supply Chain Resilience. Therefore, we reduced our database to a total of 180 publications. Finally, we visualized the results and interpreted them in order to answer our research questions.

3 Results and Contributions

3.1 Quantitative Overview and Methodological Research Approaches

Analysis shows that nearly 40% (n = 69) of the sample publications were published in 2015 and 2016, which highlights the gaining currency of the topic (Fig. 2). An overall increase in numbers from 2011 suggests that the global financial crisis - which reached its peak in 2009/2010 - triggered the research interest in Supply Chain Resilience (see also Jüttner and Maklan 2011). Based on the proposed differentiation criteria by Pilbeam et al. (2012), two-thirds of the sample articles (n = 121) are considered to apply a causal analytical research approach. The remaining third follows empirical research approaches.

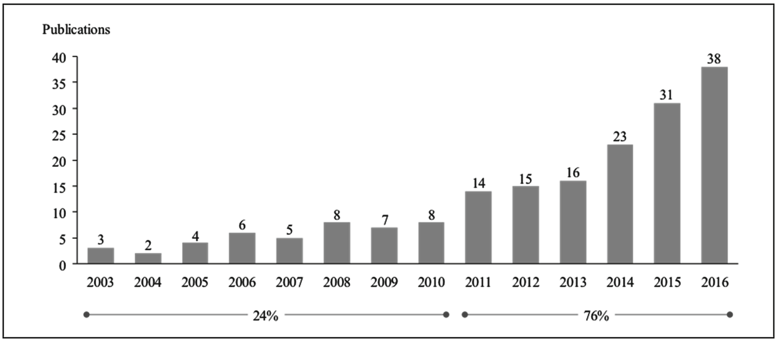

Fig. 2. Selected Supply Chain Resilience publications per year from 2003 to 2016

3.2 Theories Within Supply Chain Resilience Research

Our content-critical analysis shows that half of our sample articles (n = 93) refer to one or more theories, adding up in a total of 56 different theories used to analyze Supply Chain Resilience problems and issues. As the total number of Supply Chain Resilience research publications increases over time, so does the number of theoretical references (Fig. 2).

Out of the identified theories, system theory stands out as 21 articles (12%) refer to it, the most of any theory. This leading position can be substantiated by adding the three applications of the complex system theory: network theory follows with a total of 16 entries (9%), 11 applications (6%) were observed for complexity theory and ten (6%) for decision theory.

Eight publications (4%) demonstrated graph theoretical approaches. Game theory was referred to in a total of seven publications (4%). Grey theory finds five applications (3%) while the content-similar fuzzy theory counts four (2%), and control theory counts five use cases (3%). Normal accident theory is cited four times (2%).

Theories from the area of Lean Management are found four times (2%), with two more publications (1%) that apply Lean Six Sigma in the range of Supply Chain Resilience. The remaining 44 theories are applied one to three times amongst our sample articles. Considering the classification of theories by Halldórsson et al. (2007), we classified all theories either as *grand theories*, *middle-range theories* or *small-scale theories*.

Figure 3 shows the heat map of cited theories within Supply Chain Resilience research from 2003 to 2016.

3.3 Specific Supply Chain Resilience Research Perspectives

Ponomarov and Holcomb (2009) identify seven general perspectives on resilience: ecological, psychological, economical, organizational, emergency management, sustainable development, and supply chain risk management perspective. However, our findings show that these seven perspectives are not precise enough to sufficiently describe and differentiate actual theoretical lenses applied within Supply Chain Resilience research today.

For example, research approaches based on system theory, organization theory or network theory need to be considered separately, since underlying research paradigms as well as the applied concepts and research approaches differ fundamentally. If underlying theories are used as distinguishing features, a total of ten different perspectives towards the phenomena of Supply Chain Resilience can be differentiated. The allocation of theories to specific Supply Chain Resilience perspectives is based on the information provided by the respective authors as well as on the coding of Chicksand et al. (2012) and Tang (2006).

Figure 4 summarizes our results, where the darker the blue color, the more theory applications have been counted.

Theory Level	Theory	2003 - 2009	2010	2011	2012	2013	2014	2015	2016	Σ	Total
Grand Theories (14)	system theory	4		3		3	3	4	4	21	**69**
	network theory	2	1			2	5	5	1	16	
	decision theory	3			1	1	1	3	1	10	
	lean management			1			1		2	4	
	complex system theory	1						2		3	
	social theory								3	3	
	(macro-) economic theory	2								2	
	management theory							1	1	2	
	organizational behavior theory	1				1				2	
	organizational theory						1		1	2	
	coordination theory								1	1	
	disaster theory						1			1	
	marxist theory					1				1	
	weberian theory					1				1	
Middle-range Theories (20)	complexity theory		1				4	3	3	11	**61**
	graph theory				2		4	2		8	
	game theory	3				1		1	2	7	
	grounded theory	1	1			1	1	1		5	
	normal accident theory		1	1	1	1				4	
	design theory				1			2		3	
	dynamic capability theory					1	2			3	
	social capital theory					1	2			3	
	bayesian network theory								2	2	
	chaos theory				1	1				2	
	contingency theory							1	1	2	
	principal agent theory	1					1			2	
	relational view					1		1		2	
	cell theory						1			1	
	collaborative control theory							1		1	
	emergency mgmt theory					1				1	
	resource-based view							1		1	
	signalling theory							1		1	
	social network theory								1	1	
	system dynamics							1		1	
Small-scale Theories (22)	control theory				1		1	2	1	5	**38**
	grey theory							3	2	5	
	fuzzy theory	1			1				2	4	
	inventory theory	1			1			1		3	
	high reliability theory				1	1				2	
	lean six sigma	1					1			2	
	marginal gain/revenue theory								2	2	
	autonomous agency theory			1						1	
	back-up placement				1					1	
	bargaining theory	1								1	
	biological cell elasticity theory			1						1	
	extreme value theory								1	1	
	fitness landscape theory			1						1	
	organizational ambidexterity								1	1	
	possibility theory							1		1	
	probability theory							1		1	
	rational choice theory						1			1	
	resilience theory								1	1	
	ripple effect							1		1	
	risk communication theory					1				1	
	risk perception theory					1				1	
	social constructionist theory					1				1	
	Total (citations)	**22**	**4**	**8**	**11**	**21**	**30**	**39**	**33**	**168**	
	Number of different theories	13	4	6	10	18	16	22	20	56	

Fig. 3. Theories within Supply Chain Resilience research between January 2003 and December 2016

10 Specific Perspectives on Supply Chain Resilience	Related Theories: Grand Theories	Middle Range Theories	Small-Scale Theories
System Approach	▪ System Theory (incl. Coordination Theory) ▪ Complex System Theory	▪ Complexity Theory ▪ System Dynamics ▪ Chaos Theory	▪ Grey Relational Analysis ▪ Control Theory ▪ Autonomous Agency Theory
Logistic-, Transport- & Network Management	▪ Network Theory ▪ Approaches of System Theory	▪ Graph Theory ▪ Collaborative Control Theory ▪ Design Theory	▪ Extreme Value Theory ▪ Inventory Theory (incl. Back-up placement)
Relational Governance	▪ Social Theory ▪ Decision Theory ▪ Weberian Theory	▪ Social Capital Theory ▪ Grounded Theory ▪ Relational View	▪ Approaches of Network Theory
Strategy & Organization	▪ Organizational Theory ▪ (Organizational) Behavior Theory ▪ Management Theory	▪ Dynamic Capability Theory ▪ Contingency Theory ▪ Resource Based View (RBV)	▪ Organizational Ambidexterity
Operations Management	▪ Lean Philosophy ▪ (Macro-) Economic Theories ▪ Approaches of Decision Theory	▪ Principal-Agent Theory	▪ Lean-Six-Sigma ▪ Marginal Gain/Revenue Theory
Emergency Management	▪ Emergency/ Disaster Theory ▪ Approaches of System Theory	▪ Emergency-Mgmt. Theory ▪ Normal Accident Theory	▪ Rational Choice Theory ▪ Resilience Theory ▪ High Reliability Theory
Multi-Disciplinary	▪ Approaches of System-, Decision- & Network Theories ▪ Marxist Theory	▪ Game Theory	▪ Ripple Effect ▪ Bargaining Theory
Supplier Selection & Management	▪ Approaches of System Theory	▪ Approaches of Network Theory (e.g. Bayesian Network Theory)	▪ Fuzzy Logic ▪ Probability Theory ▪ Possibility Theory
Ecology	▪ Cell Theory ▪ Approaches of System Theory	▪ Behavioral Biology (Signaling Theory)	▪ Biological Cell Elasticity Theory ▪ Fitness Landscape Theory
Psychology	▪ Approaches of Organizational Theory	▪ Social Network Theory	▪ Risk Communication Theory ▪ Risk Perception Theory ▪ Social Constructionist Theory

Fig. 4. Supply Chain Resilience research landscape by specific perspectives based on theories applied

4 Discussion and Recommendations for Future Research

Our findings show that both number and variety of theories applied within Supply Chain Resilience research are increasing, especially during the last few years. Based on our content-theoretical evaluation, this research comes to the conclusion that three main research areas can be identified. These include the *system approach* with the system theory, complexity theory and chaos theory; the *logistical, transport and network management driven research approach* based on the network theory, graph theory and collaborative control theory; as well as the social science-driven *relational governance approach* based on decision theory, social capital theory, grounded theory, and relational view (Fig. 4). Surprisingly, in today's Supply Chain Resilience research, strategic-organizational aspects as well as operations management research approaches like Lean Management seem to play a secondary role. Moreover, scientific contributions driven by disaster management, supplier selection and management, ecology and psychology approaches can be regarded as little represented in the current theory-building process.

Overall, our findings help scholars to review current research approaches and to channel their activities within the proposed landscape of Supply Chain Resilience research. Future research is required in order to evaluate our deductive findings by means of empirical or inductive approaches. From a managerial perspective, questions regarding future success factors as well as implementation steps for the expansion of resilient supply chains are arising.

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Simulation Vs. Optimization Approaches to Ripple Effect Modelling in the Supply Chain

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Abstract. As a result of supply chain structural dynamics, the ripple effect occurs whereby disruption propagates downstream or upstream from the initial disturbance point in the network. Since ripple effect analysis includes both dynamic and static parametrical sets, the research objective of this study is to identify recommendations on the preferable applications of simulation and optimization methods. We identify some problem classes and datasets for which optimization, simulation, and hybrid optimization-simulation methods can be recommended.

1 Introduction

The *ripple effect* (RE) describes the cascading impact of a disruption on supply chain (SC) performance, disruption propagation, and the disruption-based scope of changes in SC structural design and planning parameters. In other words, SC structural dynamics is encountered (Ivanov et al. 2010; Liberatore et al. 2012; Ivanov et al. 2014a, b; 2017a, b, c; Scheibe and Blackhurts 2017). Examples include but are not limited to fires at distribution centres, tsunami, and floods leading to production facility disruptions, legal conflicts between suppliers, and strikes at airlines and railway companies (Tang 2006; Ho et al. 2015). The RE deals with low-frequency-high-impact disruption or exceptional risks which differentiates it from the bullwhip effect, which considers for low-frequency-high-impact risks, which are operational and recurrent (Ivanov 2018; Dolgui et al. 2018).

Modeling methodologies differ across publications on SC disruption management, but most consider a disruption (or a set of disruptions), impact of the disruption on operational and strategic economic performance, and stabilization and recovery policies. Within this data set, most studies on SC disruption consider how changes to some parameters ripple downstream or even upstream from the disturbance point in the SC and affect SC performance in terms of annual sales, profits, service level, or market share. Optimization and simulation approaches are most popular in SC RE analysis

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(Klibi and Martel 2012; Ho et al. 2015; Snyder et al. 2016; Ivanov et al. 2017c). The RE is a relatively new phenomenon in SC literature that requires the development of substantial theoretical taxonomy and the respective terminology. The novelty of this research is to identify some problem classes and datasets and derive recommendations on the preferable applications of simulation and optimization methods for RE analysis.

2 Literature Analysis

This section provides a brief overview of recent optimization and simulation studies. We refer to the works by Snyder et al. (2016), Ivanov (2017), Ivanov et al. (2017c), and Dolgui et al. (2018) for more comprehensive state-of-the art reviews.

Optimization studies on RE analysis apply linear or non-linear mathematical programming approaches using mixed-integer programs. By parametric variations, these models allow analysis of the impact of disruptions on SC performance. The model by Snyder and Daskin (2005) aims at finding optimal SC design by assigning customers to locations with the objective of minimizing total SC costs. The authors assume known disruption probabilities of different SC sites. Lim et al. (2010) analyze the impact of having reliable backup supplier included in recovery costs, which can be used if a primary supplier is destroyed. The optimization problem statements with multiple products and many periods consider inventory, backordering, available capacity levels in settings with such *redundancies* as backup suppliers, reserved capacity, and risk mitigation inventory that satisfy demands at higher prices without the disrupted facility. Correlated disruption consideration has been included in the study by Hasani and Khosrojerdi (2016).

Non-linear optimization models have been applied to develop a resilient topology of a SC that is able to recover from and react quickly to disruptions. Rezapour et al. (2017) analyze three policies to find the most profitable network and mitigation policies: keeping emergency stock at the retailers, reserving back-up capacity at the suppliers, and using multiple sourcing.

A specific research domain in optimization is represented by stochastic programming. Sawik (2013) developed a stochastic programming model for integrated supplier selection, order quantity allocation, and customer order scheduling in the presence of SC disruption risks. Torabi et al. (2015) developed a bi-objective, mixed, two-stage stochastic programming model for supplier selection and order allocation problem under operational and disruption risks. They consider reactive strategies such as suppliers' business continuity plans and using backup suppliers. Recently, Sawik (2017) conceptualized a portfolio approach to SC disruption management.

Finally, hybrid optimal control and mathematical programming studies can be encountered in literature. The combination of linear programming and optimal program control allows the inclusion of transportation reconfiguration into the SC design in a multi-period model in the event of SC disruptions (Ivanov et al. 2014b). Ivanov et al. (2016) use a hybrid optimization-control model for simulation of SC recovery policies for multiple disruptions in different periods in a multistage SC. The performance impact assessment and SC plan reconfiguration is also possible with consideration of the duration of disruptions and the costs of recovery (Ivanov et al. 2017b).

Simulation studies on the RE naturally play important roles in research communities since they are able to handle time-dependent and gradual disruption duration, duration of recovery measures, capacity degradation, and recovery. For complex problem settings with situational system behavior changes in time, simulation can be even more powerful than analytical closed form analysis (Frazzon et al. 2017). Carvalho et al. (2012) analyze how different recovery strategies influence SC performance in the event of disruptions. The simulated scenarios differ in terms of presence or absence of a disturbance and presence or absence of a mitigation strategy. The performance impact was analyzed in terms of lead-time ratio and total SC costs. Schmitt and Singh (2012) analyze time-to-recovery as an amplification of the disruption. The modeled proactive and recovery strategies include satisfying demand from an alternate location in the network, procuring material or transportation from an alternative source or route, and holding strategic inventory reserves throughout the SC. Ivanov (2017) analyzed the SC RE using anyLogistix software and derived some implications on the values of simulation modelling of the RE. Schmitt et al. (2017) revealed that accelerating the ordering policy in the case of disruptions can even worsen the SC performance. Using simulation, they derived an efficient adaptive ordering mechanism. Ivanov and Rozhkov (2017) used AnyLogic simulation model and revealed an "effect of postponed redundancy" that is related to the impact of disruptions even in the post-disruption period after a capacity restoration.

3 Analysis and Classifications

Analysis of literature allows identification of several problem classes and datasets; it is recommended to analyse these using optimization, simulation, or hybrid simulation-optimization techniques. The literature has been analysed regarding the modelling techniques used, the problems addressed, the performance measures, and the scope of the RE analysis. More specifically, the following characteristics have been analysed to derive the classifications following a standard problem classifications in SC management at design, planning, and control decision-making levels (Ivanov et al. (2017a)): (i) SC structural and operational parameters at the SC design level, (ii) inventory, sourcing, shipment, and production control policies at the SC planning level, and (iii) recovery policies at the SC control level. The following classification have been obtained.

3.1 Problem Class 1. Static Ripple Effect Analysis

The models in the problem class allow computation of the performance impact of disruption and recommendation of a resilient SC design based on aggregate location and flow data subject to cost minimization or profit maximization. This problem class considers the following dataset:

Parameters

- Possible site locations and connections (nodes and paths) with back-ups
- Discrete and limited number of time periods

- Deterministic or stochastic demand in periods
- Production, storage, and shipment capacities in periods
- Lead time and service levels
- Operational costs

Variables

- Location opening or closure
- Beginning and ending inventory in periods
- Production, shipment, setup, holding, delay, lost sales, fixed, processing, ordering, backordering quantities in periods

Performance impact: service level, costs, lost sales at the end of planning horizon.

Mathematical network optimization have been typically used for this class (Snyder and Daskin 2005; Lim et al. 2010; Torabi et al. 2015; Hasani and Khosrojerdi 2016; Ivanov et al. 2017b; Rezapour et al. 2017; Sawik 2017). Those models are placed at the SC design level and help to analyse the impact of the disruption on the SC performance by deactivating some structural elements on changing some operational parameters (e.g., capacity) and observing the resulting changes on costs or sales. This analysis is helpful at the strategic decision-making level. At the same time, those models do not take into account dynamics of inventory, sourcing, shipment and production control policies.

3.2 Problem Class 2. Dynamic Ripple Effect Analysis

The models in the problem class allows SC behaviour to be analyzed over time, computation of the performance impact of the disruption and recommendation of a resilient SC design based on detailed and real time data and control policies subject to a variety of financial, customer, and operational performance indicators. In addition to the more detailed data from the Class 1 dataset, this problem class considers editional *logical* and *randomness constraints* such as randomness in disruptions, inventory, production, sourcing, and shipment control policies, and gradual capacity degradation and recovery. For problems in this class, simulation has been dominantly applied (Carvalho et al. 2012; Schmitt and Singh 2012; Ivanov 2017; Schmitt et al. 2017). Since simulation studies on the RE deal with time-dependent parameters, duration of recovery measures and capacity degradation and recovery, they have earned an important role in academic research. Simulation has the advantage that it can extend handling of the complex problem settings in Class 1 with situational behaviour changes in the system over time.

3.3 Problem Class 3. Dynamic RE Analysis with Recovery Considerations

The models in the problem class extend Classes 1 and 2 through recovery policy considerations. Independent of proactive or reactive policy domination, optimization and simulation techniques can mutually enhance each other. For problems in this class, a combination of network optimization and simulation (e.g., simulation runs over optimization results) can be recommended (Vahdani et al. 2011; Ivanov et al. 2014b; Paul et al. 2014; Ivanov and Rozhkov 2017). The research considering recovery stage is still new and requires an extension (Ivanov et al. 2017c). We consider the problem class 3 as an especially promising future research avenue.

4 Conclusion

The RE, or the propagation of disruption downstream or upstream from an initial disturbance point in a network, is complicated by supply chain structural dynamics. Since RE analysis includes both dynamic and static parametrical sets, this study identifies three problem classes and the corresponding datasets for which optimization, simulation, and hybrid optimization-simulation methods are recommended. While the optimization methods find their applications to the RE analysis in the SC design domain, the simulation methods have been predominantly used at the SC planning level. The combination of the optimization and simulation methods can be considered as a promising research avenue to incorporate the proactive and reactive RE analysis with recovery considerations. In the said area, other approaches such as control theory and reliability theory need to be analysed further.

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Models of Stochastic Optimization for Deteriorating Cargo Inventory Control at Port's Terminal

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Abstract. Perishable cargo service deals with the possibility of its deterioration during execution of particular links of transport and logistics chains, including cargo transshipment at ports. Therefore, it is reasonable to search for the ways to improve these goods inventory system aiming at deterioration rate decreasing during cargo storage. The paper presents the model of optimal inventory control for perishable product which has been transshipping through the port's terminal. Proposed approach takes into account the dependence of deterioration rate of cargo during its storage at terminal's warehouse on the additional investments intended for this rate decreasing. The corresponding stochastic optimization problem has been formulated and analyzed. The paper is illustrated by numerical example based on the real data, which validates the optimization problem.

Keywords: Port terminal · Stochastic model · Perishable cargo · Investments
Deterioration reduction · Stochastic optimization

1 Introduction

Recently, perishable products trade growth is observed on the global market that influences the increase of production/transportation of products, such as food, medicines etc. These goods delivery to the customers require maintaining special regimes (e.g. temperature conditions) during transportation using different transport modes (water, railroad) and storage in ports terminals and warehouses, etc. (Chen and Notteboom 2012; Laguerre et al. 2013; Zhang and Chen 2014). It should be noted that perishable products logistics faces the deterioration problem. It can deal with products spoilage, physical depletion, gradual loss of qualitative properties of materials with the passage of time and above all storage conditions changing (Evans 2011; Kundu et al. 2013). Therefore, the great attention in theory of logistics and its applications is paid to the problem of deteriorating products flow control. The known models of inventory control theory cannot be applied directly in the perishable products practices. In many situations arising in logistics management the adaptation and generalization of classical models is needed for the case of deterioration of perishable materials and finished product under prolonged

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warehousing. Inventory control models were reviewed by Williams and Tokar (2008) and Bakker et al. (2012), discussing main inventory system characteristics, i.e. price discounts, backordering or lost sales, single or multiple items, average cost or discounted cash flow, payment delay etc. Banerjee and Agrawal (2017), Li et al. (2017) in their works proposed inventory models for deteriorating products. It is naturally to suppose that the volume of perishable products deterioration depends on technical characteristics of refrigerating equipment and corresponding costs needed to support the special warehousing regimes (Postan and Filina-Dawidowicz 2016). In the articles (Dash et al. 2014; Li et al. 2010; Shah and Shah 2000) the simple models for optimal lot sizing of perishable product based on generalization of the classical Wilson and Wagner-Whitin models were studied. However, in these works the possibility of warehousing regime control was not considered.

Our paper aims to further develop the optimal inventory control models for perishable product, mainly, to develop the stochastic optimization model for the case of perishable product coming through the port's terminal considering deterioration process control at warehouse and taking into account additional investments intended for this rate decreasing. This idea was firstly mentioned in our previous works (Postan and Filina-Dawidowicz 2013, 2016, 2017).

2 The Basic Model

Let us consider the port's terminal warehouse used for temporal storage of perishable cargo subjected to deterioration during its storage and/or transshipment. This cargo has been irregularly delivered to terminal by transport units (TU), for example, ships, wagons or trucks. We will assume that the stream of these TU is described by the model of compound Poisson process (Prabhu 1998; Postan 2006). It means that the intervals of time between neighboring moments of TU arrivals form the sequence of mutually independent random variables with exponential distribution with the same mean $1/\lambda$ and amounts of cargo on TU are mutually independent random variables with the same distribution function (d.f.) $B(x)$. The cargo from any TU is unloaded immediately at

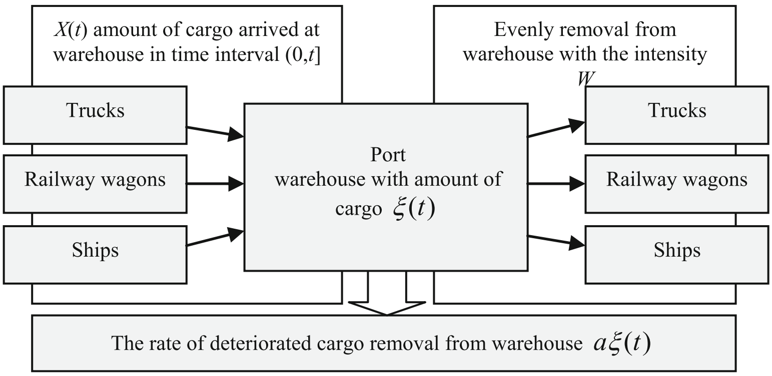

Fig. 1. Scheme of perishable cargo transport, transshipping, and storage at terminal

warehouse (for the sake of simplicity we ignore an unloading time in this Section). Cargo is removed from warehouse uniformly with the constant rate W. The cargo in warehouse is subjected to deterioration with the rate $a\xi(t)$, where $\xi(t)$ is the amount of storing cargo at moment of time t, a is the deterioration coefficient (see Fig. 1).

Due to above suppositions the random process $\xi(t)$ is the Markov process.

Let us find the limit distribution of this process. Firstly, note that process $\xi(t)$ satisfies the following balance equation (with probability 1)

$$\xi(t) = \xi(0) + X(t) - a\int_0^t \xi(\tau)d\tau - W\int_0^t I(\xi(\tau) > 0)d\tau, \tag{1}$$

where $X(t)$ is the amount of cargo delivered at terminal (that is, warehouse) in time interval $(0,t]$ (it is the compound Poisson process); $I(A)$ is the indicator of an event A; W is the rate of cargo removal from warehouse.

Note that by definition

$$X(t) = \sum_{n=0}^{\omega(t)} \gamma_n,$$

where $\omega(t)$ is the Poisson process, describing the process of TU arrivals at terminal and

$$\mathbf{P}\{\omega(t) = k\} = \frac{(\lambda t)^k}{k!}e^{-\lambda t}, k = 0, 1, 2, \ldots;$$

γ_n is the hold capacity of the nth TU and $\mathbf{P}\{\gamma_1 < x\} = B(x)$. Denote

$$F(x,t) = \mathbf{P}\{\xi(t) < x\}.$$

With the help of typical probabilistic reasoning based on theorem of total probability (Prabhu 1998; Gnedenko and Kovalenko 2005) one can show that limit distribution of process $\xi(t)$

$$F(x) = \lim_{t\to\infty} F(x,t)$$

(under supposition of its existing) satisfies the following integral equation

$$(W + ax)F'(x) = \lambda\int_{+0}^{x} F'(y)[1 - B(x-y)]dy + \lambda F(+0)(1 - B(x)),\ x > 0. \tag{2}$$

After integration of both parts of Eq. (1) from +0 to ∞ we obtain the following relation

$$\lambda g_1 = W(1 - F(+0)) + a\mathbf{M}\xi, \tag{3}$$

where $\int_0^\infty x dB(x) < \infty$, $\mathbf{M}\xi$ is stationary mathematical expectation of cargo amount in warehouse. Relation (3) expresses so called conservation law for streams of cargo arriving at warehouse and cargo removing from warehouse in result of its deterioration and transportation by surface TU. This conservation law is valid for steady-state regime of transportation/storage system under examination. The expression in the left-hand side of Eq. (3) is the intensity (rate) of cargo stream arrived at terminal and in right-hand side is total intensity of cargo stream removed from warehouse. The expression $a\mathbf{M}\xi$ is the average rate of deteriorated cargo stream removed from the warehouse.

In general case, solution of the Eq. (2) is a complex mathematical problem. First, consider its solving for the particular case

$$B(x) = 1 - e^{-x/g}, x \geq 0, \tag{4}$$

where g is the mean quantity of cargo on any TU. Taking into account (4), from (2) we obtain the following linear differential equation with respect to the function $f(x) = F'(x)$:

$$(W + ax)f'(x) = -f(x)(a - \lambda + \frac{W + ax}{g}), x > 0. \tag{5}$$

The solution of Eq. (4) takes the form:

$$f(x) = f(0)e^{-x/g}(1 + \frac{ax}{W})^{(\lambda/a)-1}. \tag{6}$$

From Eq. (2) as $x \to +0$ we get $f(0) = (\lambda/W)F(+0)$. Substituting this relation in (6) we find

$$f(x) = (\lambda/W)F(+0)\, e^{-x/g}(1 + \frac{ax}{W})^{(\lambda/a)-1}.$$

Hence, we finally find

$$F(x) = F(+0)[1 + \frac{\lambda}{W}\int_{+0}^{x} e^{-y/g}(1 + \frac{ay}{W})^{(\lambda/a)-1}dy]. \tag{7}$$

The constant $F(+0)$ may be found from condition $F(\infty) = 1$ and equals to

$$F(+0) = [1 + \frac{\lambda}{W}\int_{+0}^{\infty} e^{-y/g}(1 + \frac{ay}{W})^{(\lambda/a)-1}dy]^{-1}. \tag{8}$$

The improper integral in the right-hand side of (8) converges. Indeed, if for example $\lambda > a$ (this corresponds to reality) and $\lambda/a = n + \varepsilon$, where n is entire part, and ε is fractional part of above fraction, then

$$\int_{+0}^{\infty} e^{-y/g}(1+\frac{ay}{W})^{n+\varepsilon-1}dy = \frac{W}{a}e^{W/ag}\int_{1}^{\infty} z^{n+\varepsilon-1}e^{-Wz/ag}dz <$$

$$< \frac{W}{a}e^{W/ag}\int_{1}^{\infty} z^{n}e^{-Wz/ag}dz < \infty$$

since $z^{\varepsilon-1}$ *if* $z > 1$.

The stationary mathematical expectation of cargo amount in warehouse is

$$\mathbf{M}\xi = \frac{\lambda}{W}F(+0)\int_{0}^{\infty} xe^{-x/g}(1+ax/W)^{(\lambda/a)-1}dx. \tag{9}$$

In the models of optimal inventory control of perishable product it is expediently to consider the parameter a as control variable which is controlled by special investments directed into more modern refrigerating equipment (Postan and Filina-Dawidowicz 2013, 2016). It means that parameter a is a decreasing function of mentioned investments. Such function, for example, may have the following view

$$a(v) = a_0/(1+\mu v)^{\alpha}, \tag{10}$$

or

$$a(v) = a_0 e^{-\mu v^{\alpha}}, \tag{11}$$

where a_0 is the value of parameter a when the above investments equals to 0, i.e. it corresponds to norms of natural perish under old technology of storage; μ is a coefficient which characterizes the rate of cargo deterioration decreasing under positive value of investments directed into progressive storage technology; α is a positive parameter, $\alpha \leq 1$; v value of investments that port's terminal authorities direct in the beginning of planning horizon from own profit for decreasing of cargo deterioration.

Let us evaluate the average cost per time unit related to functioning of port's warehouse $\overline{c}$ in steady-state regime (i.e. in equilibrium). If we take into account only the cost for storage, the loss from cargo perish, and investments for decreasing the deterioration of cargo, then the expression for $\overline{C}$ takes the form

$$\overline{C}(v) = (c_{st} + ra)\mathbf{M}\xi + v/T, \tag{12}$$

where c_{st} is holding cost for cargo unit and per time unit; r is price of product in good state; T is a planning horizon. In expression (12), it is assumed that parameter a depends of control variable v according to one of the dependencies (10) and (11), and expression $\mathbf{M}\xi$ is defined by the formulae (8).

Since under condition $v \to \infty$ the parameter $a \to 0$ (see (10) and (11)) and $\mathbf{M}\xi$ tends to finite limit (Prabhu 1998; Postan 2006)

$$\mathbf{M}\xi = \lambda g^2/2(W - \lambda g),\ \lambda g < W,$$

then $a\mathbf{M}\xi \to 0$ with the growth of v.

Taking into account the conservation law (3) the formulae (12) may be presented in the following form

$$\overline{C} = (c_{st} + ra)[\lambda g - W(1 - F(+0))]/a + v/T. \tag{13}$$

The problem of optimal value finding of parameter v that minimizes the function (13) is sufficiently complex computational procedure, since this control parameter enters the integrals (8) and (9), i.e. the objective function is not expressed through the elementary functions. Therefore, for solving this optimization problem a special computational algorithm is required. The necessary condition of function (13) minimum is (taking into account expression (8))

$$d\overline{C}/dv = -c_{st}a'(v)[\lambda g - W(1 - F(+0))] + (c_{st} + ra)WdF(+0)/da + 1/T = 0$$

where

$$dF(+0)/da = (F(+0))^2\{\frac{\lambda}{W}\int_0^\infty [e^{-y/g}a'(v)(1 + \frac{ay}{W})^{\lambda/a-1}$$
$$\times[-\frac{\lambda}{a^2}\ln(1 + \frac{ay}{W}) + (\frac{\lambda}{a} - 1)\frac{y}{W}(1 + \frac{ay}{W})^{-1}]dy\}.$$

The last equation is rather complicated for solving; therefore, it is expediently to make some simplification. In practice, parameter a_0(and a) is small. It may be proven that under conditions $a \to 0$, $\lambda g = W$ the following asymptotic formulae for calculation of probability $F(+0)$ is valid

$$F(+0) \approx [\sqrt{\frac{\lambda\pi}{2a}} + \sqrt{\frac{a\pi}{2\lambda}}]^{-1}\ (\pi = 3, 14\ldots). \tag{14}$$

The above results may be generalized for the case of arbitrary d.f. $B(x)$. In this case, for solving the integral Eq. (2) the method of the Laplace-Stieltjes transformation may be applied. Denote

$$\varphi(s) = F(+0) + \int_{+0}^\infty e^{-sx}F'(x)dx, \mathrm{Re}\, s > 0,$$

and apply this transformation to Eq. (2) using the convolution theorem and taking into account the relation

$$\int_0^\infty xF'(x)e^{-sx}dx = -\partial\varphi(s)/\partial s.$$

In result, we obtain the following linear differential equation

$$a\partial\varphi(s)/\partial s = [W - \lambda\frac{1-\beta(s)}{s}]\varphi(s) - WF(+0), \mathrm{Re}\, s > 0, \tag{15}$$

where $\beta(s) = \int_0^\infty e^{-sx}dB(x)$. Due to the Tauberian's theorem (Shiff 1999)

$$\varphi(0) = F(\infty) = 1, \phi(\infty) = F(+0), \tag{16}$$

The solution of Eq. (15) may be presented by the following way

$$\begin{aligned}\varphi(s) &= \exp\{\frac{1}{a}[sW - \lambda\int_0^s \frac{1-\beta(u)}{u}du]\} \\ &\times \{1 - \frac{W}{a}F(+0)\int_0^s \exp\{\frac{1}{a}[-Wu + \lambda\int_0^u \frac{1-\beta(y)}{y}dy]\}du\}.\end{aligned} \tag{17}$$

Rewrite this solution in the form

$$\begin{aligned}\varphi(s) = \exp(-sW/a) &= \exp\{-\lambda\int_0^s \frac{1-\beta(u)}{u}du\} \\ &\times \{1 - \frac{W}{a}F(+0)\int_0^s \exp\{\frac{1}{a}[-Wu + \lambda\int_0^u \frac{1-\beta(y)}{y}dy]\}du\}\end{aligned}$$

and passing s to $+\infty$, taking into account (16), we find

$$F(+0) = [\frac{W}{a}\int_0^\infty \exp\{-\frac{Wu}{a} + \frac{\lambda}{a}\int_0^u \frac{1-\beta(y)}{y}dy\}du]^{-1}. \tag{18}$$

Now using the formulae (3) we can calculate the mathematical expectation of cargo in warehouse

$$\mathbf{M}\xi = [\lambda g_1 - W(1 - F(+0))]/a. \tag{19}$$

In particular case, for exponential distribution (4), $\beta(s) = 1/(1+gs)$. Using the integration by parts it may be proven that for exponential distribution the formulae (18) coincides with the (8).

If the hold capacity of any TU is constant and equals to g, then $\beta(s) = \exp(-sg)$.

The case of multi-item perishable cargo may be analyzed by analogy. For example, let us there are M kinds of cargo, the cargo of the mth kind is transported to terminal independently from cargoes of other kinds with TU arriving according to compound Poisson process $X_m(t)$, and removal of cargo from warehouse is regular with the rate W_m. Then for determination of the mth kind of cargo amount in warehouse distribution function at moment t the results obtained above may be used. Under the similar assumptions in respect of cargo deterioration reduction the corresponding optimization problem is formulated by the following way: to minimize the function

$$\bar{C} = \sum_{m=1}^{M} [(c_{mst} + a_m(v_m)r_m)\mathbf{M}\xi_m + v_m/T]$$

subject to $\sum_{m=1}^{M} \mathbf{M}\xi_m \le E$, where E is the warehouse's capacity and $v_m \ge 0, m = 1, 2, \ldots., M$, are the control parameters, that is the values of investments directed into decreasing of deterioration of every kind of cargo. Besides, for calculation of expression $\mathbf{M}\xi_m$ the formulas (8)–(11), (18) and (19) may be applied with corresponding modification.

3 Analysis of More General Model

Though the model of port's terminal examined in previous Section is simplified because it is based on assumption about infinite intensity of TU unloading it may be used for analysis of more realistic model with the finite intensity. In this Section this case will be analyzed in more details.

Now we assume that perishable cargo is transshipping from TU to warehouse with the rate W_0. To build the corresponding mathematical model in this case we introduce one yet stochastic process describing the fluctuation of cargo amount in TU under unloading. Denote $\varsigma(t)$ amount of cargo in TU at moment t and suppose that rate of deterioration of cargo in this TU is $a_1\,\varsigma(t)$, where parameter a_1 generally speaking does not coincide with the parameter a from Eq. (1).

It may easily be pointed out that system of balanced equations, describing the joint fluctuation of stochastic processes $\xi(t)$ and $\varsigma(t)$ with the probability 1 will take the following form (see (1)):

$$\begin{aligned} \varsigma(t) &= \varsigma(0) + X(t) - a_1 \int_0^t \varsigma(\tau)d\tau - W_0 \int_0^t I(\varsigma(\tau) > 0)d\tau, \\ \xi(t) &= \xi(0) + W_0 \int_0^t I(\varsigma(\tau) > 0)d\tau - a \int_0^t \xi(\tau)d\tau - W \int_0^t I(\xi(\tau) + \varsigma(\tau) > 0)d\tau, \end{aligned} \tag{20}$$

where $\varsigma(0)$ is initial value of cargo amount in TU.

Let's us consider the case $a = a_1$. Summarizing equations of the system (19) we obtain the following equation in respect of total amount of cargo at terminal (i.e. in TU and warehouse)

$$\varsigma(t) + \xi(t) = \varsigma(0) + \xi(0) + X(t) - a\int_0^t (\varsigma(\tau) + \xi(\tau))d\tau - W\int_0^t I(\varsigma(\tau) + \xi(\tau) > 0)d\tau. \tag{21}$$

From Eq. (21) it follows that the sample paths of process $\varsigma(t) + \xi(t)$ almost everything coincides with the sample paths of process $\varsigma(t)$ which was studied in the previous Section (where it was denoted as $\xi(t)$). From this note, particularly, we can conclude that its stationary distribution is determined by relations (17), (18) and stationary mathematical expectation of this process is determined by the formulae (19). Therefore,

$$\mathbf{M}\varsigma = \frac{1}{a}[\lambda g_1 - W_0(1 - F^*(+0))], \tag{22}$$

where $F^*(+0) = [\frac{W_0}{a}\int_0^\infty \exp\{-\frac{W_0 u}{a} + \frac{\lambda}{a}\int_0^u \frac{1-\beta(y)}{y}dy\}du]^{-1}$.

On the other hand, from (18) and (20), it follows that

$$\mathbf{M}(\varsigma + \xi) = \frac{1}{a}[\lambda g_1 - W(1 - F(+0))], \tag{22}$$

where $F(+0) = [\frac{W}{a}\int_0^\infty \exp\{-\frac{Wu}{a} + \frac{\lambda}{a}\int_0^u \frac{1-\beta(y)}{y}dy\}du]^{-1}$.

From (21) and (22) we find

$$\mathbf{M}\xi = \mathbf{M}(\varsigma + \xi) - \mathbf{M}\varsigma = \frac{1}{a}[WF(+0) - W_0F^*(+0) + W_0 - W]. \tag{23}$$

In particular case, for exponential distribution of TU hold capacity (4), we obtain (see (8))

$$\begin{aligned}\mathbf{M}\xi = {} & \frac{\lambda}{W}F(+0)\int_0^\infty xe^{-x/g}(1 + \frac{ax}{W})^{(\lambda/a)-1}dx \\ & - \frac{\lambda}{W_0}F^*(+0)\int_0^\infty xe^{-x/g}(1 + \frac{ax}{W_0})^{(\lambda/a)-1}dx,\end{aligned} \tag{24}$$

where $F(+0) = 1/[1 + \frac{\lambda}{W}\int_{+0}^\infty e^{-y/g}(1 + \frac{ay}{W})^{(\lambda/a)-1}dy]$,

$$F^{*}(+0) = 1/[1 + \frac{\lambda}{W_0}\int\limits_0^{\infty} e^{-y/g}(1 + \frac{ay}{W_0})^{(\lambda/a)-1}dy].$$

In this case the optimization problem may be formulated as follows: to minimize the objective function

$$\overline{C} = (c_{st}^{(1)} + a_1 r)\mathbf{M}\varsigma + (c_{st}^{(2)} + ar)\mathbf{M}\xi + (v_1 + v_2)/T, \tag{25}$$

where $c_{st}^{(i)}, i = 1,2,$ is holding cost of cargo storage in TU and in warehouse correspondingly; r is the price of cargo (product) in the good state; $v_i, i = 1,2$ is the volume of investments for refrigerating equipment in TU and warehouse correspondingly.

As above it is assumed that the parameters a, a_1 are non-increasing functions of the variables v_1,v_2, for example, (see (10)):

$$a(v_2) = a_0(1 + \mu v_2)^{-\beta}\ ,\ \ a_1(v_1) = a_{01}(1 + \mu_1 v_1)^{-\alpha}, \tag{26}$$

where μ, μ_1 are the coefficients, characterizing the rate of decreasing the velocity of product's deterioration under positive investments directed into more modern technology of cargo storage in TU and warehouse correspondingly; α, β are some positive coefficients.

It is naturally to assume that parameters a, a_1 are coincide. Then from (26) we obtain

$$v_2 = [(1 + \mu_1 v_1)a_0/a_{01} - 1]/\mu. \tag{27}$$

From the condition of non-negativity of variables v_1,v_2, it follows that the conditions

$$(1 + \mu_1 v_1)a_0/a_{01} \geq 1 \quad \text{or} \quad v_1 \geq (a_{01}/a_0 - 1)/\mu_1.$$

hold true. If, for example, $a_{01} \geq a_0$, then the last inequality is correct.

Substituting expression (27) in (25) we arrive at optimization problem with one variable v_1. Unfortunately, when solving this problem we may deal with the same computational difficulties as in previous problem analyzed in above Section.

4 Numerical Results

Let's consider numerical results concerning minimization of function (12) in the case of dependence (10) (with $\alpha = 1/2$) and under additional supposition $a \to 0$, $\lambda g = W$. In this case from (13) and (14), it follows

$$\overline{C} = \lambda g\sqrt{\frac{2\lambda}{\pi a_0}}\frac{[c_{st}(1 + \mu v)^{1/2} + ra_0](1 + \mu v)^{1/4}}{\lambda(1 + \mu v)^{1/2} + a_0} + \frac{v}{T}. \tag{28}$$

Put $c_{st} = 0{,}015$ per day per kg, $g = 20\ 000$ kg, $a_0 = 2 \cdot 10^{-2}$ 1/day, $r = 2$ Euro/kg, $\mu = 2 \cdot 10^{-3}$ 1/Euro, $T = 365$. Results of calculations conducted with the help of Microsoft Excel are presented in the Table 1.

Table 1. Optimal investments for different rate of TU's arrival

No.	Rate of TU with cargo arrival (λ), TU per day	Investments (v), Euro	min $\overline{C}$, Euro per day
1	0,1	962,05	1606,86
2	0,2	1898,05	2381,47
3	0,3	2237,80	2957,05
4	0,4	2404,05	3436,94
5	0,5	2525,80	3857,30
6	0,6	2600,05	4236,01
7	0,7	2650,05	4583,44
8	0,8	2700,45	4906,27
9	0,9	2725,80	5209,08
10	1,0	2751,25	5495,18

These results show that stochastic optimization model proposed above is applicable for making decision concerning optimal inventory control of deteriorating cargo at the port's terminal.

5 Conclusion

The paper presents the development of the inventory control model for perishable cargo for the case of its servicing in port's terminal considering deterioration process control. It forms the next step in the development of inventory control theory considering dependence of deterioration rate of cargo during its storage on the additional investments intended for this rate decreasing. Conducted numerical example proved the possibility to apply the model for solving real problems.

Presented stochastic model of port's terminal may be generalized in several directions, that will direct our future work. Two of them may be noted as follows:

(1) Refuse from the supposition of exponential distribution of inter-arrival periods of TU at terminal. In order to take into account more regular arrival of TU, it is possible to use the Erlang distribution or another kind of phase-type distribution (Kleinrock 1996; Gnedenko and Kovalenko 2005; Postan and Kurudzhi 2012). But in a result, we must solve a more general system of integro-differential equation in respect of limit distribution of process $\xi(t)$.

(2) Assume that the cargo is removed from warehouse irregularly, as well. The similar models (for non-perishable cargo) were studied in (Postan 2006).

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Modeling of Critical Products Supply Chain Required to Affected People on Earthquakes and Tsunamis Through Use of SCOR Model

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Abstract. The aim of this paper is modeling the critical products' supply chain to supply suffering population by strong earthquakes and tsunamis. The supply chain of these products is described through the use of Supply Chain Operations Reference (SCOR) model using a set of standard processes. The developed model allows minimization of companies' complexity in the chain and identifies which are the critical links, obtaining an integral vision of the chain. It is concluded that the proposed model will contribute the improvement of delivering critical products to affected people.

Keywords: Supply chain · SCOR model · Affected people
Earthquake and tsunamis

1 Introduction

Chile is characterized by having a seismic territory and it is known that the main Chilean settlements have been historically affected by these phenomena [1, 2]. This country is highly vulnerable to tsunamis, mainly due to its 4,000 km of coastline. The characteristics that this territory possesses make it very prone to suffer this type of catastrophes.

Thomas and Mizushima [3] define the humanitarian logistic process as: "the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from point of origin to point of consumption for the purpose of meeting the end beneficiary's requirements." It focuses on meeting the needs of the people as quickly as possible. This includes providing support, services, materials and transportation to who that are involved in disaster relief. Similarly humanitarian logistics is characterized by dynamism. This represents changes in real time during the occurrence of the disaster, in all its main activities [4]. Given this, adequate distribution of supplies to critic's areas becomes a crucial element.

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A breadth of models for commercial and industrial supply chains exists. This does not carry over into the humanitarian domain. Here, models remain scarce and if available only portray certain application contexts. Nonetheless, the need for a standardisation of processes of the humanitarian supply chain has been recognised. This article focuses on studying the different processes and links in the supply chain for the delivery of the critical products to affected people. Given the importance of these type of products, we use a case example of the "bottled water".

The article starts with the introduction and the second section presents the concepts of Supply Chain Management (SCM) and humanitarian logistics in natural disasters. Subsequently, the application of the SCOR model in natural disasters is shown in the third section and the conclusions of this article are presented in the fourth section.

2 SCM and Humanitarian Logistics

Supply chains nowadays are more prominent of all the business processes [5], and there has been increased interest in supply chain modeling [6]. By modeling supply chain processes, cross-organizational boundaries can be more easily defined, analyzed, and improved to provide companies with a sustainable competitive advantage.

Olorotunba and Gray [7] argued that commercial supply chains focus on the end customer, who is the source of profits for the entire supply chain. However, in a humanitarian supply chain the final consumer is viewed differently due it is rarely considered in a commercial transaction and has little control over supplies. Due to the above, customer service or marketing is focused on suppliers/donors, who must be convinced that humanitarian action is taking place.

The authors Kovacs and Spens [8] explained the challenge facing humanitarian logistics in times of natural disasters because they have a strong impact on physical infrastructure. There is destruction of transport facilities, bridges, airfields, electrical and communication networks. This destruction causes bottlenecks in the supply chain. Therefore, when talking about humanitarian logistics, it should be shown the corresponding importance, and design a proper planning to logistics pre and post events. In this way, it may be possible to better face the occurrence of sudden disasters.

Chile has a long history of earthquakes and tsunamis [1, 2]. Supply chain modeling can contribute to a deeper understanding of how to efficiently deliver critical products to affected people by an earthquake or tsunami. The SCOR model is a standardized tool for modeling any supply chain. In the following section the SCOR model is described and applied to a case example of "bottled water".

3 Application of the SCOR Model in Natural Disasters

A general description of the SCOR model and its application in a case example of "bottled water" supply chain is presented.

3.1 Description of the SCOR Model

The SCOR model is organized around the five primary management processes of Plan, Source, Make, Deliver, and Return [9]. By describing supply chains using these processes building blocks, the model can be used to describe supply chains using a common set of definitions. Supply Chain Council [9] explains each of the SCOR model levels as indicated below.

The planning processes are: P1 (Plan Supply Chain), P2 (Plan Source), P3 (Plan Make), P4 (Plan Deliver), P5 (Plan Return). The execution level 2 processes for stocked products are: S1 (Source Stocked Products), M1 (Make to Stock), D1 (Deliver Stocked Products) [9, 10]. In addition, the SCOR model allows to evaluate each process through key performance indicators (KPIs). The latter helps to establish comparisons, identify opportunities for improvement and identify best practices [10, 11].

3.2 Case Example of SCOR Applied to Bottled Water

For this case example the information of the last tsunami in Iquique city - Chile is used. Based on suggestions of experts and managers of different organizations for emergencies, bottled water was chosen as a critical product. The human being has the need of water for its vital functions, to prepare and cook food, and for hygiene and domestic purposes [12]. Good quality water is the main resource to be provided to populations victims of disasters [13].

The level 2 processes of SCOR model to describe the supply chain of bottled water are shown in Fig. 1. This chain is described starting from the last link on the right side called “Affected People”. This link includes who live in shelters, neighborhood and private buildings. The S1 process of the SCOR model in this link describes the activities to obtain, receive and transfer the water to people. These people receive the water that comes from the organizations located in the previous link denominated “Distribution to Detail”.

In the link “Distribution to Detail” there are two organizations, the Municipality and the Red Cross. The planning of actual situation is represented with P1, P2 and P4 processes. The planning of bottled water deliveries corresponds to P4. The planning of the bottled water supply from suppliers is represented by P2. The integrated planning is performed by P1, which integrates key information of P2 and P4 and with every links in the supply chain. According to Fig. 1, P2 coordinates with S1 (Municipality) for the acquisition of the required water. S1 receives (from previous link) and transfers bottled water to the warehouses. Subsequently the process D1 (Municipality) delivers the available water in warehouses based on the needs from the link “Affected People”. In relation to the Red Cross in Iquique city, S1 receives (from Central Red Cross) and transfers bottled water to warehouses. Then, D1 delivers bottled water available in warehouses to the link “Affected People”. It is emphasized that S1 and D1 of Red Cross Iquique city do not have an adequate articulation with the planning processes P2 and P4, there is a disconnection among the planning and execution processes. In addition, information is often limited due to the failure of communication technologies in natural disasters.

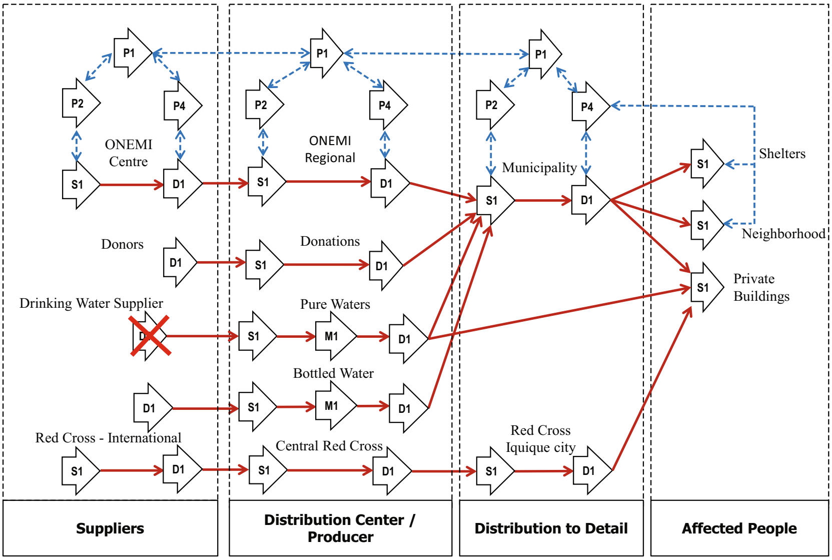

Fig. 1. Current supply chain of bottled water using SCOR model

Based on the supply chain described in Fig. 1 using the SCOR model, the main problems detected are the followings. The non-existence of the planning processes P1 and P2 in the last link of "Affected People". This lack of planning in this link affects coordination with the rest of the planning processes. In addition, it does not allow generating good quality information related to the demand of bottled water, information that is required in the entire supply chain. Regarding the execution processes (S1 and D1) in the link "Distribution to Detail", S1 (Municipality) has a limited stock of bottled water. The same happens with all S1 processes in the link "Distribution Center/Producer". In addition, it must be considered that the product bottled water is perishable, so it has an expiration date. This product expiration causes economic losses due to the fact that there are no return processes of products in the chain, due to certain legal procedures in state organizations in Chile.

4 Conclusions

The developed model allows visualizing the actors in the current chain and identifies those critical links of the chain. The model allows an analysis of the weaknesses in the bottled water supply chain, where some processes are missing. In addition, there are some disconnections among the planning processes P1, P2 and P4 and the execution S1 and D1 processes in the supply chain. The planning processes are very important in the preparation phase.

As a result of these analyzes, it is proposed to add planning processes in the last link of the chain and to incorporate lines of interaction between P2-S1 and P4-D1 in all the links of the chain. It is concluded that the proposed model contributes to improve the efficiency in the delivery of critical products, such as bottled water. In addition, a research is being carried out to include the key performance indicators (KPIs) that are suitable in this type of supply chain, through the selection and adaptation of the KPIs of SCOR model.

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Designing a Model for Supply Chain Agility (SCA) Indexes Using Interpretive Structural Modeling (ISM)

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Abstract. Competitive environments in today's world are characterized by rapid changes and unpredictable markets. The approach concerned with the interaction of the organization, the market, and an external perspective to flexibility, is known as the Supply Chain Agility (SCA). The main purpose of this paper is designing the model of agile supply chain in Fars Nov Cement Company. For achieving this objective and for extracting agility indexes, research literature has been first reviewed in detail, and then a part of identified indexes were subjected to final confirmation according to the opinions of experts and Fuzzy Screening Method. After this stage agility model of supply chain was designed for this company based on opinions of experts and using Structural Interpretive Modeling (ISM) method. The results of this research show that proper planning and network orientation indexes form the basis of agility in supply chain are acted as a foot-stone of model. These two indexes also have the highest importance among other indexes of model.

1 Introduction

Supply chain management is a set of approaches and attempts concentrated on supporting producers, suppliers and distributors, while coordinating the chain value in such a way that goods are produced and distributed in the right place at the right time. Competitive environments in today's world are characterized by rapid changes and unpredictable markets. The approach concerned with the interaction of the organization, the market, and an external perspective to flexibility, is known as the Supply Chain Agility (SCA). This approach is basically concentrated on responding to unexpected market changes, solving unpredicted problems through making fast transition, making delays flexible, and employing new technologies. The cement industry, as a basic industry, has a fundamental role in constructing the infrastructures of every country. This industry has been continually developing in Iran, as the country ranked fourth worldwide in cement

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production in 2012. Thus, cement is considered as an important commodity and its commodity markets are among the most active ones in the Iranian economics. Since supply chain management is one of the challenges facing developing and competitive markets, and also regarding lack of research in Supply Chain Agility (SCA) field in cement industry the present study is an attempt to take a step further as far as SCA is concerned and can be used by managers which are engaging in dynamic and complex environment of this industry and trying to make their supply chain or organization agile.

2 Theoretical Foundations and Review of Literature

While the external environment influences organizations, it is becoming more difficult and expensive for one company to handle all these issues and to adapt in a competitive context. Therefore, many companies are paying more attention on collaboration and investing in more flexible logistics processes and supply chain (SC) [13]. Former strategies and approaches cannot deal with today's organizational challenges and the external environment. As a result, new approaches should be proposed including agility. Under such circumstances, SCA represents itself as highly important because such a chain can respond to market changes fast and effectively [17]. Companies are progressively linked to each other through materials and information flow in feedback-loops. SCA emphasizes the enhancement of adaptability and flexibility, it is capable of making fast responses and effective reactions to variable market conditions. SCA is thought of as the supply paradigm in the twentieth century and as the "winning" strategy for companies which seek to become national or international leaders [10]. SCA does not only react to ordinary changes, but also it can appropriately respond to dramatic market changes which take place for the first time. Therefore, the general belief is that agility is a characteristic required for the organization's future competitive pressures and the achievement of competitive advantage [7,21]. SCA enables an organization to effectively and rapidly react to market discrepancies and other issues of uncertainty, consequently making it possible for the organization to obtain a special competitive position [16]. Furthermore, organizations with agile SC processes will be sensitive to the market, capable of synchronizing supply and demand, and able to obtain a shorter cycle to provide products. SCA also directly affects the capacity for producing innovative goods (new products) and their delivery to customers, although [16] contend that SCA is the crucial factors affecting the general and comprehensive competitiveness. Table 1 shows the most important and iterated indicators of agility in supply chain which are extracted from the previous studies.

3 Research Methodology

This research follows an applied purpose and is an analytical survey. The population under study included managers and experts who had knowledge of SCA in Fars Nov Cement Company. These participants were CEOs, planning managers, supply/purchase managers, sales managers, quality control managers, production/engineering managers, commercial managers, and superior managers of each units. The samples were selected through total census sampling. To collect data for investigating the theoretical foundations and literature, library resources, papers, books, and the Internet were used. Another data collection tool was a researcher-made questionnaire which was distributed in two phases: first, to identify the factors affecting the SCA, library and field studies were conducted. Then, to certify these factors in the Fars Nov Cement Company, a questionnaire for determining the significance of each factor was used based on the 7-point Likert scale and was submitted to a number of experts of SCA at universities and Fars Nov Cement Company. Then, fuzzy screening was used to analyze the data collected and finalize the factors affecting the SC in this Company. After the final selection of factors, ISM was used to design the model of relationships among the factors affecting SCA. Data analysis was conducted in Matlab and Excel. Figure 1 presents the research steps in brief.

Table 1. Indicators of agility in supply chain

Item number	Agility indexes	Researchers
1	Planning	[1,3,8,18,22]
2	Employee's skill development	[3,22]
3	IT use	[1,3,11,18,22]
4	Flexibility	[1,3,10,14,22]
5	Market sensitivity and response	[1,3,8,18,19,22]
6	Just-in-time delivery	[1,3,6,11,18]
7	Integrated processes	[1,3,8,19,22]
8	Product quality	[3,10,22]
9	Cost reduction	[1,3,22]
10	New product introduction	[3,22]
11	Customer satisfaction	[1,3,18,22]
12	Net-Centricity	[5,18,19]
13	Trust development	[1,18]
14	Data validity	[1,15]
15	Reducing mistrust	[1,15]
16	Continued improvement	[1,11,18]

3.1 Fuzzy Screening

Multiple-attribute decision-making problems require the evaluation and determination of the operational value of themes and phenomena under study by relying on screening, recognizing and selecting key evaluation indexes for evaluation. In cases where one small subset should be screened from among several options for further investigation, the screening method is used. Screening problems start with a larger subsets (X) of the set of all possible alternatives. The process of selecting a subset A from subset X is called screening.

Each alternative is basically described with the least important information necessary for representing it as the best choice, and in the following evaluations, it is used for selecting subset A from subset X. In addition, screening problems, besides involving the least important information, normally consist of the participation of a number of decision-makers [3]. The existence of the least important information about the alternatives/criteria would further complicate the problem as it limits the process of aggregating the individuals' opinions. This method is based on preliminary information and the technique used here only requires a non-numerical scale for the evaluation and selection of the alternatives. This technique was proposed by Yager and uses the Yager's operator. Yager suggested a technique for fuzzy screening to manage the whole process, which can compute consensus with the least information available (shortage of information regarding the criteria) [4]. Employing this technique requires a linguistic value within an ordinal scale, this aspect enables the decision-making team to evaluate their knowledge and information about the criteria/alternatives using linguistic variables such Outstanding, Very High, High, Medium, Low, Very Low, and None. Doing the operation with imprecise linguistic values enable the

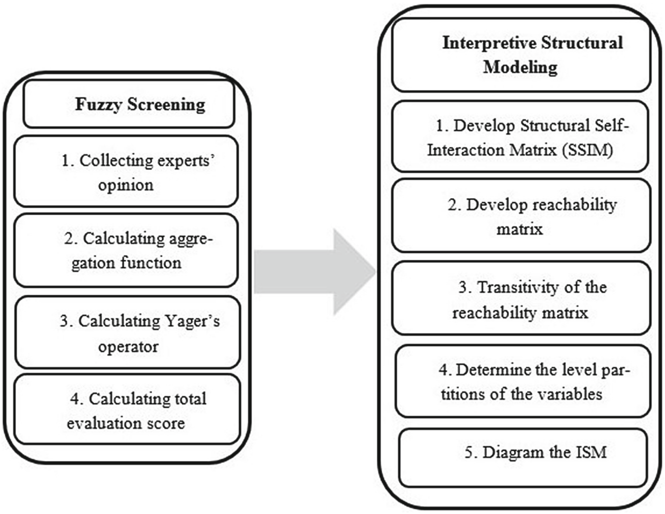

Fig. 1. Research's step diagram

evaluators to employ the resources with the least amount of information at hand. In other words, each decision-maker expressed his/her opinion about the degrees of importance. This evaluation relies on a quantitative scale. Using such a scale provides a natural definition of Sk's in such a way that for each $h > k$, we have $Sh > Sk$, and the maximum and minimum are defined as follows:

$$min(Sh, Sk) = Sk, if Sh > Sk, \tag{1}$$

$$max(Sh, Sk) = Sh, if Sh > Sk \tag{2}$$

Thus, based on such a scale, each decision-maker provides a set of n values for the criteria of indexes under evaluation. These values represent the degrees of importance. In order to avoid presenting large scale tables, Table 2 represents the final result for first third indicates which are selected according experts opinion by using fuzzy screening (T-S shows Total Score and F-R shows Final Result). As it showed below the total score of employment's skill development (item number 2) is not large enough to pass the criteria (outstanding) and this item will be eliminate (*), Overall, in this step there indexes (employee's skill development, integrated processes and data validity) will be eliminated.

Table 2. The final result of fuzzy screening approach

Item number		VL	VL	L	M	M	H	H	VH	OU	T-S	F-R
1	sort	H	H	VH	VH	VH	OU	OU	OU	OU	OU	✓
	min	VL	VL	L	M	M	H	H	VH	OU		
2	sort	H	H	H	H	H	VH	VH	VH	VH	VH	*
	min	VL	VL	L	M	M	H	H	VH	VH		
3	sort	H	H	H	H	VH	VH	VH	OU	OU	OU	✓
	min	VL	VL	L	M	M	H	H	VH	OU		

3.2 Interpretive Structural Modeling (ISM)

ISM is a technique suitable for analyzing the effect of one element on another. This methodology investigates the order and direction of relations among the elements of a system, serving as a tool which helps teams overcome complexity. As a result, in this research, to determine the interrelationships among the indexes, ISM was applied.

This approach is a methodology based on generating and understanding major relationships in systems and situations [2]. ISM, proposed by [20], is a technology for creating and understanding the relationships among the elements of a complex system [9]. In other words, ISM is an interactive process that is systematically structured within a set of connected and different elements.

ISM methodology significantly helps regulate complex relationships among the elements of a system [1]. ISM helps identify the internal relationships of variables and is an appropriate technique for analyzing the effect of one variable on others. Furthermore, this method can prioritize and rank elements of a system, as a highly important contribution for managers to implement the model obtained [12]. In order to model the interrelationship among indicates we should develop the reachability matrix. The transitivity of the reachability should be checked first. For instance, if variable 1 is related to variable 2, and variable 2 is related to variable 3, then variable 1 should necessarily be related to variable 3. If this condition is not established in the reachability matrix, it should be corrected and the missing relationships should be substituted (shown by 1* in the table) and 1 means there is relationship between the item of row and column and 0 shows two items are irrelevant. The final reachability matrix is shown in the Table 3.

Table 3. Final reachability matrix

Item	10	5	1	12	6	13	3	8	15	16	9	11	4	Dr-P
10	1	0	0	0	0	0	0	1	1	1	1*	1	0	6
5	1	1	0	0	0	1	0	1	1	1	1	1	0	8
1	1	0	1	0	1	1	0	1	1	1	1	1	0	9
12	1	1	0	1	0	1	0	1	1	1	1	1	0	9
6	1	0	0	0	1	1	0	1	1	1	1	1	0	8
13	1	0	0	0	0	1	0	1	1	1	1	1	0	7
3	1	0	0	0	0	0	1	1	1	1	1	1	0	7
8	0	0	0	0	0	0	0	1	0	0	1	1	0	3
15	1	0	0	0	0	0	0	1*	1	1	1	1	0	6
16	1	0	0	0	0	0	0	1	1	1	1*	1	0	6
9	0	0	0	0	0	0	0	0	0	0	1	1	0	2
11	0	0	0	0	0	0	0	0	0	0	0	1	0	1
4	1	0	0	0	0	1	0	1	1	1	1	1	1	8
De-p	10	2	1	1	2	6	1	11	10	10	12	13	1	

Then based on the final reachability matrix level partitions should be found for every variable (element). In the first table, the variable with identical reachability and the antecedent sets will have the highest level. After finding this variable (or such variables), they are removed from the table and the table is developed again with all of the remaining variables. In the second table, too, the second-level variable is recognized and the process is continued until the level of all variables is determined. To determine the levels of all indexes the agile supply chain model is designed by using ISM, Fig. 2.

Furthermore, the row addition of values for every element in the final reachability matrix shows the degree of power, whereas the column addition of values shows the degree of dependence. Based on these two factors, four groups of elements are recognized: autonomous, dependent, linkage and independent [16]. In the MICMAC analysis, the variables are divided into four types based on driving

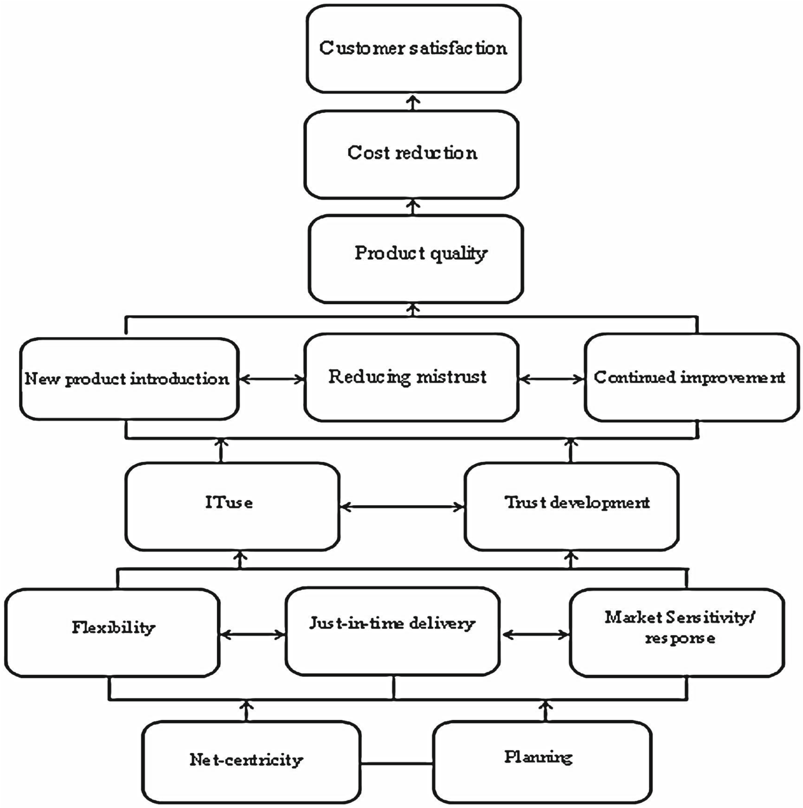

Fig. 2. The extended interpretive structural modeling model for agility in supply chain

power (Dr-P) and dependence power (De-P). The first set consists of autonomous variables, which have weak Driving and Dependence powers. These variables are relatively disjoint to the system and have a weak relationship with the system [6]. Dependent variables are in the second set which have a weak driving power but a strong dependence power [17]. The third set of variables are connective ones which have a strong driving power and a strong dependence power. The fourth set of variables consist of independent ones which have a strong driving power but a weak dependence power [22]. This set serve as the cornerstone of the model and, for the sake of system operation, they should be basically emphasized. Figure 3 illustrates the MICMAC matrix for this research case.

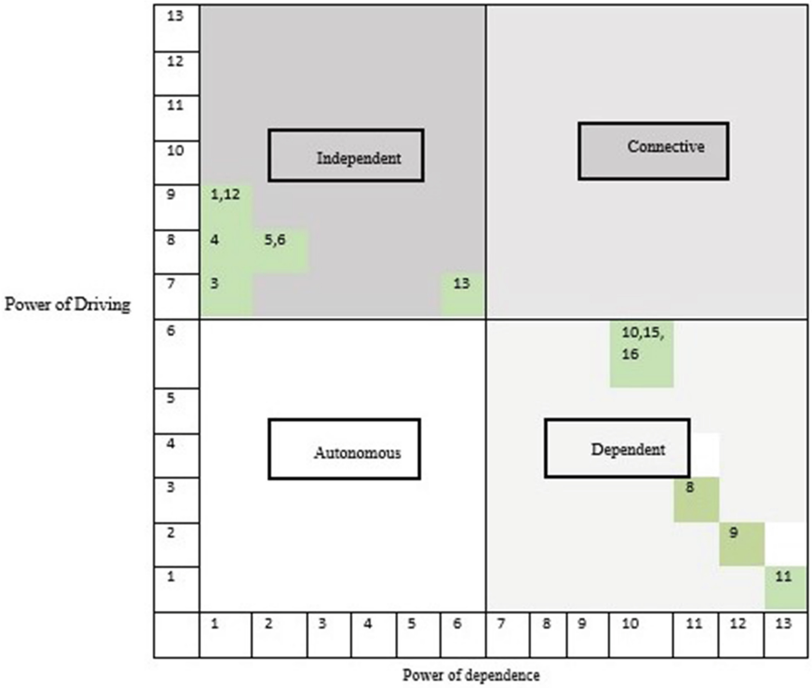

Fig. 3. Grouping of the agility indexes in supply chain

4 Conclusions

The main purpose of this study was to construct the model of indexes in the supply chain. To do this, after identifying factors of supply chain agility in Fars Nov Cement Company, interrelationships among the factors were determined. The model revealed that indexes as net-centricity and planning, which placed at the seventh level, had the maximum driving power but minimum dependence power. As the matrix illustrated in MICMAC shows, these two indexes were categorized in the independent group. Independent variables are a cornerstone for the model and, to initiate system operation, they must be given primary importance. On the other hand, customer satisfaction, which was found to be in the first level, and cost reduction, which was in the second level of the model, showed maximum dependence power and minimum driving power. According to MICMAC, these indexes belonged to the dependent group of valuables. As a result, these variables are generally the results of agility which are generated by many different factors, whereas they do not normally generate other factors. As it described in analysis of results of MICMAC matrix, this parameter is classified among dependent variables. This issue may show that this variable is mainly the consequence of agility. Namely, there are many intervening factors to create it but at the same time this parameter may be less able to prepare the ground for other variables.

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A Collaborative Framework for Governance Mechanism and Sustainability Performance in Supply Chain

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Abstract. The results indicate that socially sustainable development is two-fold:firstly, involves fostering interaction through relational governance and secondly, ensuring cohesion with cultural intelligence capability. We develop a theoretical framework and empirical research approach for understanding how cultural intelligence capabilities can be used to transform relational governance to improve social sustainability in an inter-firm exchange relationship. The analysis is based on cross-sectional base survey questionnaires on a sample of 239 senior managers from four manufacturer industries using partial least squares structural equation modelling approach. Sustainability performance framework is conceived on a foundation of the theoretical body of knowledge in the literature. This study contributes by identifying key cultural intelligence capabilities; management is more likely to work effectively with their cross-border supply chain partners. The dynamic capability theory helps explain how culturally intelligent individuals are able to dynamically adjust, protecting and adapt to the partner cultural in inter-organizational collaborations. Our results through structural equation modelling approach confirmed that collaborative relational governance is useful to improve the social sustainability performance.

Keywords: Relational governance · Cultural intelligence capability
Social sustainability performance · Buyer-supplier relationship
Sustainable social development

1 Introduction

The effectiveness of relational governance mechanism has been a severe problem to supply chain management. Managing cultural differences across geographically dispersed locations is one of the central challenges for International business firms (Caprar et al. 2015). Collaboration challenges arise from differences in cultural values between managers with different national backgrounds when dealing with their foreign partner (Shin et al. 2017). By promoting cooperation between the partners, sustainable collaborative governance mechanism is expected to achieve a win-win situation (Zhao et al. 2017). Meanwhile, supply chain collaboration governance is becoming

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increasingly complex, as global competition and cultural difference drive growing customer requirements. Hence, the literature provides little evidence as how to make collaboration with partners more comprehensive and improve sustainability performance. Given the limitation and advantage of relational governance, firms often employ them in their performance improvement. Previous research has established a direct relationship between the relational governance and economic performance, relationship performance (Chen et al. 2013) and firm social performance (Awan and Kraslawski 2017). Much research has attempted to explain the effects of relational governance structure on performance, but few studies have incorporated strategic consideration the role of culture in managing interfirm relationship (Handley and Angst 2015). Thus, little is known about the relative importance of cultural intelligence capabilities which facilities inter-firm cultural differences and lead in the successful management of relational governance.

We argue that individuals who possess a high level of cultural intelligence must act to make progress towards build interpersonal connections. If either partner not intended to share cultural knowledge, the supplier firm may be harm, damaged the collaborative process, and result in loss of sustainability performance. To pursue social sustainability performance, the cultural intelligence capabilities aimed to strengthen by integrating social, cultural perspective into firm's operation strategy (Awan and Kraslawski 2017). Although a significant literature has been developed on the triple bottom line in the developed and emerging economies, thus so far very little attention has been paid to such social sustainability issues to the less developed countries in Asia region. The purpose of this article is to propose and empirically examine a theoretical model about how cultural intelligence capability affects the process of governing inter-frim exchange relationship and how those changed processes result in different outcomes. Our study addresses the following research questions: (1) How can relational governance improve be incorporated into the design of governance and improve social sustainability performance? (2) Do cultural intelligence capabilities mediates the relationship between relational governance mechanisms and realized social performance? This paper is structured as follows. In the next section, we discuss the main concept of social sustainability performance, followed by hypothesis development which results in the presentation of propositions. Next section described the methodology and data analysis methods. The final sections provide discussion, conclusion and provide a future outlook on the new framework.

2 Literature Review

Relational governance refers to the extent to which relationship between the parties are governed by shared norms and social mechanism (Liu et al. 2009). Relational governance is a necessary component of firm performance (Schepker et al. 2014). In a recent study on the relationship between governance mechanism and performance, (Huang et al. 2014) examined a sample of managers and found that governance mechanism was a strong predictor of performance. Through relational governance based on joint planning and joint problem solving, a partner may replace opportunism behaviour and increase performance (Liu et al. 2009). Zheng et al. (2011) suggest that joint problem is solving affect the knowledge combination capability. Hence, joint problem solving is a way for the firm to acquire different kinds of knowledge and integrate (Zheng et al. 2011). Relational mechanism increases the likelihood of joint planning and problem-solving, which deter opportunism and enhance performance (Huang et al. 2014).

World Commission on Environment and Development (WCED) broad definition is widely accepted, and it integrates social, environmental and economic issues. The sustainability definition is followed by the concept of sustainable development is based on the balance of three pillars of environmental, social and economic sustainability (Elkington 1997). According to (Sharma and Ruud 2003) social sustainability "ethical code of conduct for human survival and outgrowth that needs to be accomplished in a mutually inclusive and prudent way". Sustainable Supply Chain Management define as "The strategic, transparent integration and achievement of an organization's social, environmental, and economic goals in the systemic coordination of key inter-organizational business processes for improving the long-term economic Performance of the individual company and its supply chain." (Carter and Rogers 2008). Social sustainability performance defines as the "incorporate the health and safety issues, improvement of environmental issues and child labours (Hutchins and Sutherland 2008). Therefore, a firm commitment to sustainability requires collaborative capabilities to devote specify resources to cooperative activities addressing environmental and social issues (Vachon and Klassen 2007). Thus, we hypothesize that:

Hypothesis 1: Relational governance is positively associated with the firm social performance.

2.1 Mediation Impact of Cultural Intelligence

This study adopts the definition of CQ (Earley and Ang 2003) defined as "the capability of an individual to function effectively in situations characterized by cultural diversity and also the capability to efficiently function in interactions across culture groups (Ang and Inkpen 2008). Metacognitive emphasizes the importance of thinking consciously to assess which aspects of culture are more relevant (Van Dyne et al. 2012). Cognitive CQ "reflects knowledge of the norms, practices and conventions in different cultures acquired from education and personal experiences" (Ang et al. 2007). Understanding of subjective and objective cultural knowledge help to shape the relationship mutually beneficially and with high cognitive CQ are better able to interact with a cross-culturally diverse set of peoples (Ang et al. 2015). Such challenges require organizations to assemble and develop resources and capabilities to resolve such problems (Husted and de Sousa-Filho 2017). Thus,

Hypothesis 2: Metacognitive CQ is positively and strongly mediates the effect of relational governance and supplier social performance.

Hypothesis 3: Cognitive CQ is positively and strongly mediates the effect of relational governance and supplier social performance.

2.2 Behavioral and Motivational CQ

Greater social benefits accrue from the firm ability to develop capabilities for its core business to the social and environmental problems (Husted and Sousa-Filho 2017). These internal capabilities can improve the firm social sustainability due to the firm is able to implement sustainability initiatives in more efficient way to appropriate the benefits of the relational governance. Behavioral CQ is “the capability to exhibit appropriate verbal and nonverbal actions when interacting with people from different cultures” (Ang et al. 2006). The management of social initiatives in operations largely depends on the firm ability to flexibility and adaptability towards the partner understanding the cultural norms. Adopting socially responsible practices by the firms to address the social issues are grounded in communication and compliance (Yawar and Seuring 2017). Motivation has focused on measuring the effort expended to achieve a task-relevant reward (McCarthy et al. 2016). Therefore, CQ explains the success of joint problem solving and planning in international business, and also positively influences performance (Korzilius et al. 2017). Therefore, we hypothesize:

Hypothesis 4: Behavioral, cultural intelligence fully mediates the positive relationship between the relational governance and supplier social performance.
Hypothesis 5: Motivational cultural intelligence mediates the positive relationship between the relational governance and supplier social performance (Fig. 1).

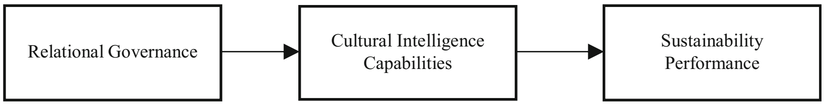

Fig. 1. Conceptual framework

3 Methodology

The construct of CQ is consist of 20 items assesses each of the four subscales: cognitive, metacognitive, motivational and behavioural (Ang et al. 2015). All items and construct were adapted from previous studies and were measured by using a seven-point Likert scale, which ranged from 1 (“not at all”) to 7 (“to a strong extent”). We used (Ang et al. 2007) dimensions of meta-cognitive, cognitive, behavioural and motivational to operationalize culture intelligence scale. A supplier firm sustainable social performance is measured by subjective performance outcomes along four dimensions based on (Awaysheh and Klassen 2010; Kleindorfer et al. 2005). Social performance (towards the focal buyer) including improvement in human rights, health and safety, community wellbeing and safety measures. The items of social performance use 7 points Likert scale 1: not at all, 2: a limited extent, 3: Slightly improve 4: Neutral, 5: a moderate extent, 6: a great extent, 7: a very great extent. Relational governance scale was operationalized on the basis of the work by (Lusch and Brown 1996). We adapted existing measures from previous studies

Survey data were collected on site from the manufacturing firms from Pakistan in March to April 2017 from seniors operations and supply chain managers. Out of 316 firms, a total of 257 companies completed the questionnaire. In total, we obtained 186 surveys in the first three weeks. We then followed by telephone calls and by sending them an email, and a total of 71 responses received after the three weeks. As a result of this approach, a total of 257 responses received, of which 18 response were unusable due to missing values, and firm respondents lack knowledge, resulting in 239 useable responses. Harmon's one-factor test (Podsakoff et al. 2003) was carried out using an un-rotated factor analysis of all independent and dependent variables. The results revealed that a total of 71.2% of the variance was accounted for that the first factor captured only 28.8% of the variance. This suggests that common method variance is not a significant problem in this study.

3.1 Reliability and Validity

All analysis was carried out using partial least square (PLS) version 2.3.1 and statistical package for social sciences (SPSS 23). Overall, the results showed acceptable reliability and validity. The results are summarized in Tables 1 and 2.

We used partial least square-Structural equation modelling (PLS-SEM) to test the model and measure direct hypothesis. The Cohen's effect size (*f*) and R^2 value provides a satisfactory prediction power. This study assesses the model fit by means of its standardized root mean square residual (SRMR) as an index for model validation (Henseler et al. 2014). The overall model fit was assessed based on the standardized root mean square residual (SRMR) with a value of 0.06. The results obtained in blindfold procedure provide evidence that value Q2 > 0 for BCQ, COQ, MCQ, MEC and SP are 0.014, 0.017, 0.051, 0.02 and 0.13 respectively. The mediation model estimated with a maximum 5000 iterations and stop criterion 10-7 was chosen. We tested all hypothesis except mediation using partial least square-Structural equation modelling (PLS-SEM). The results reveal that relational governance positively predicts the social sustainability ($\beta = .24$, $t = 4.63$) in support of H1. The relational governance (RG) is positively related to meta-cognitive (MEC) ($\beta = 0.14$, $t = 2.87$, $p < 0.01$) and cognitive (COQ) ($\beta = 0.15$, $t = 2.84$, $p < 0.05$). Whereas RG is significantly related to behavior cognitive (BCQ) ($\beta = 0.11$, $t = 2.50$, $p < 0.01$) and motivational cognitive (MCQ) ($\beta = .0.23$, $t = 4.84$, $p < .0.05$). The results also show significant relationship between the MEC to SP ($\beta = 0.13$, $t = 2.08$, $p < 0.01$), COQ to SP ($\beta = 0.25$, $t = 4.289$, $p < .0.05$), BCQ to SP ($\beta = 0.37$, $t = 5.20$, $p < .0.05$), and MCQ to SP ($\beta = 0.14$, $t = 2.09$, $p < 0.01$) provide support to proceed for the mediation analysis.

The mediation analysis of Cultural Intelligence (CQ) between the relational governance and social sustainability was performed using (Preacher and Hayes 2008) macro process for SPPS. We test indirect and total effects to account for potential mediation through cultural intelligence. We followed the causal step approach in testing for mediation proposed by (Baron and Kenny 1986) and a bootstrap approach (Bollen et al. 2009). The indirect effect of MEC is not significant because confidence interval contains zero (b = .02, SE: 0.15, CI = −0.0008, 0.0623). The results do not support the hypothesis 2. The indirect of RG on SP through cognitive CQ is significant (b = 0.039, SE = .022, CI = 0.0084, 0.1012). As it can be seen, CI at 95% does not

Table 1. Validation of constructs survey items

Items	Factor loadings a	t-value	Error variance	Item R2
Relational Governance (RG) AVE:0.649, α:0.820, CR:0.880				
RG1	0.864	36.494	0.254	0.746
RG2	0.805	22.070	0.352	0.648
RG3	0.772	22.175	0.404	0.596
RG4	0.778	18.277	0.395	0.605
Social Performance (SP) AVE:0.649, α:0.819, CR:0.881				
SP1	0.770	17.396	0.407	0.593
SP2	0.850	32.092	0.278	0.722
SP3	0.827	27.956	0.316	0.684
SP4	0.774	21.363	0.401	0.599
Cultural Intelligence (CQ) Meta cognitive AVE:0.634, α:0.720, CR:0.839				
MEC1	0.817	10.467	0.333	0.667
MEC2	0.821	10.256	0.326	0.674
MEC3	0.749	7.482	0.439	0.561
Cognitive AVE:0.656, α:0.744, CR:0.851				
COQ1	0.730	7.148	0.467	0.533
COQ2	0.871	23.042	0.241	0.759
COQ3	0.823	16.055	0.323	0.677
Behavior Cognitive AVE:0.557, α:0.759, CR:0.845				
BCQ1	0.769	15.538	0.409	0.591
BCQ2	0.736	12.485	0.458	0.542
BCQ3	0.776	19.065	0.398	0.602
BCQ4	0.756	11.846	0.428	0.572
Motivational Cognitive AVE:0.602, α:0.784, CR:0.858				
MCQ1	0.758	13.377	0.425	0.575
MCQ2	0.782	14.368	0.388	0.612
MCQ3	0.822	26.473	0.324	0.676
MCQ4	0.740	12.725	0.452	0.548

Notes: MEC: Meta Cognitive Cultural Intelligence, COQ: Cognitive Cultural Intelligence, BCQ: Behavior Cultural intelligence, MCQ: Motivational culture Intelligence
AVE: Average Variance Extraction, α: Cronbach's alpha, CA: Composite Reliability

Table 2. Mean, Standard deviation, correlation and results of discriminant validity

	M	SD	BCQ	COQ	MCQ	MEC	RG	SP
BCQ	5.809	.817	0.759					
COQ	6.114	.622	.125*	0.810				
MCQ	5.997	.649	.188**	.127*	0.776			
MEC	5.921	.709	.257**	.205**	.142*	0.793		
RG	6.211	.565	.176**	.190**	.310**	.195**	.805	
SP	6.082	.625	.355**	.319**	.227**	.188**	.295**	.806

M = mean, SD: Standard deviation, BCQ = Behavior Cognitive, COQ = Cognitive, MCQ = Motivational Cognitive, MEC = Meta cognitive, RG; Relational governance, SP: Social performance
*Correlation is significant at the $p < 0.01$ level. **Correlation is significant at the $p < 0.05$ level

contain zero, and direct effect of RG on SP is significant. This provides the partial support for the H3. The indirect of RG on SP through behavior CQ is significant (b = .042, SE = .023, CI = 0.0021, 0.0939). As it can be seen, CI at 95% does not contain zero, and direct effect of RG on SP is significant, support the hypothesis H4. The mediation result of motivational CQ fails to support H5, because indirect effect is not significant (b = .03, SE = .022, CI = −0.0046, 0.0843).

4 Conclusion

The results indicate that socially sustainable development is two fold:firstly, involves fostering interaction through relational governance and secondly, ensuring cohesion with cultural intelligence capability. Cultural intelligence is at the heart of the socially sustainable development processes. Collaboration governance mechanism is seen as a means to learn about customer culture and to understand their preferences and needs on social initiatives. This study demonstrates that integration of cultural intelligence helps define what the social sustainability issues mean to a firm and how to integrate the culture of partner firm into practices and process. The idea of cultural intelligence capability (CQ) lens is to ensure supply chain operations proceed in harmony with partner cultural context. Therefore, companies need to focus on the type of cultural intelligence capability they have with their supply chain partners. Firms with such CQ capabilities are likely to stand out in terms of social sustainability performance. Strategic orientation towards cultural intelligence should be integrated into the company's governance mechanism. This study found that the supplier-buyer engagement in a supply chain is essential for the adoption and diffusion of new sustainability practices. In summary, social sustainability emphasizes the importance of fostering the relationship between buyers-suppliers and cohesion among these. Thus, cultural sustainability in firms operations is an essential part of sustainable development.

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Ranking Parameters of a Memetic Algorithm for a Flexible Integrated Logistics Network

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Abstract. Increasing level of competitiveness in real word cases, forces enterprises to collaborate in multiple dimensions like resource sharing, information sharing, capacity planning and delivery path flexibility. These efforts make the logistics network problem more complex and most of the time impossible to find an optimal solution in a traditional way with acceptable time. In this paper, we present an costumization approach for a memetic algorithm to an integrated forward/reverse supply chain model which is flexible in delivery path. To this end, Taguchi method is adapted to identify the most important parameters and rank the latter. The results are illustrated by a numerical case study.

Keywords: Integrated logistics network · Flexible path
Memetic algorithm · Taguchi method · Ranking parameters

1 Introduction

Typically, in supply chain network, the goods are transferred through several facilities such as plants, distributions, and retailers in forward flow [1,2]. The aim of supply chain design is minimizing total cost [3,4] or maximizing profit [5] while customer satisfaction needs to be fulfilled. The decision made in a supply chain network problem involves determining the number, location, quantity of the flow between facilities as well as capacity of them [4]. In this regard considering flexibility in delivery path to have optional short ways delivery is noticeable as fast and on time delivery of products is important for customer satisfaction [6]. At the same time, environmental protection forces firms to pay more attention to collect, recover, recycle and safe disposal in a supply chain network [7]. Although industrial players are under pressure to take back products after use, most of the logistics networks are not equip to handle these products. Within this paper, we utilize an integrated design of forward/reverse supply chain network, which allows to avoid sub optimal solutions derived by separated designs at cost of complexity, cf. Fig. 1 for a sketch.

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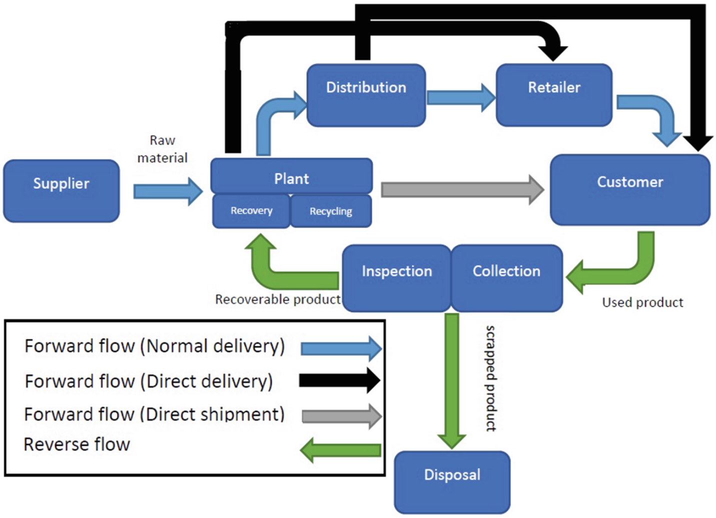

Fig. 1. Framework of the proposed flexible closed-loop supply chain network.

In particular, we are facing with an integrated multi-stage, single period, single product logistics network with a full delivery graph from plant to customer. This model present a NP-hard mixed integer linear programming that is not possible to solve in acceptable time particularly in large size. Due to the latter, many heuristics [8,9] and metaheuristics [6,10] have been proposed in the literature. In this work, we consider a memetic algorithm with a problem specific chromosome representation. Our aim is to identify, assess and rank the parameters of this method in order to improve its efficiency.

The remainder of the paper is structured as follows: In Sect. 2 we present the mathematical model of the network as well as the description of the solution method. Thereafter, we focus to answer why Taguchi method is selected in this research in Sect. 3. Last, we present a ranking parameters for the proposed algorithm in Sect. 4 before concluding our article in Sect. 5.

2 Description and Mathematical Formulation

To describe the supply network mathematically, $G = (N, E)$ is define as a digraph, where N denotes the set of nodes and E the set of edges. The cost involved in the proposed model can be split into two types: (1) fixed cost for node $i \in N$ by c_i and (2) unit transportation cost on edge $(i, j) \in E$ by c_{ij}. Furthermore, y_i and x_{ij} represent decision variables, where $y_i \in \{0, 1\}$ and $x_{ij} \in \mathbb{N}_0$. These variables indicate whether a stage $i \in N$ is used, and which quantity is transported from node i to j respectively. The model shall be used to minimize the total cost including transportation and operation cost by determining the optimal capacity of each node as well as the flows between the nodes. Based on the aforementioned description, the following mixed integer minimization problem arises:

$$\begin{aligned} \min_{x_{ij},y_i} \quad & \sum_{(i,j)\in E} c_{ij}x_{ij} + \sum_{i\in N} c_i y_i \\ \text{s.t.} \quad & \sum_{(i,j)\in E} a_i x_{ij} \leqslant b_i y_i \\ & x_{ij} \geq 0,\ y_i \in \{0,1\} \end{aligned} \tag{1}$$

To adapt problem (1) to the special case of an integrated forward/reverse supply chain, we consider the assumption presented in [11]. Utilizing the respective notation, the set of nodes N is given by the set of suppliers S, plant P, distribution centers Dc, retailers R, customers C, collection centers Co and disposal centers Di. Accordingly, the constraints are divided into three parts:

1. Constraints regarding the capacity in each node are given by

$$\sum_{(i,j)\in E} x_{ij} \leq \begin{cases} b_i & \forall i \in S \\ b_i y_i & \forall i \in N \setminus \{S \cup C\}. \end{cases} \tag{2}$$

2. Constraints revealed by the law of the flow conservation read

$$\sum_{(j,k)\in E} x_{jk} = \begin{cases} \sum_{(i,j)\in E} x_{ij} & \forall j \in N \setminus \{C \cup Co\} \\ p_j^{\text{return}} \sum_{(i,j)\in E} x_{ij} & \forall j \in C \\ p_j^{\text{disposal}} \sum_{(i,j)\in Co\times Di} x_{ij} & \forall j \in Co \\ (1 - p_j^{\text{disposal}}) \sum_{(i,j)\in Co\times P} x_{ij} & \forall j \in Co \end{cases} \tag{3}$$

3. Constraints emphasising the demand of customers must be identical reveal

$$\sum_{(i,j)\in E} x_{ij} = b_j \quad \forall j \in C. \tag{4}$$

In this context, p^{return} and p^{disposal} represent the return and disposal rates. The resulting optimization problem is NP-hard. To approximate a respective solution, we follow [11] and apply a memetic algorithm, cf. Fig. 2 for a corresponding flowchart.

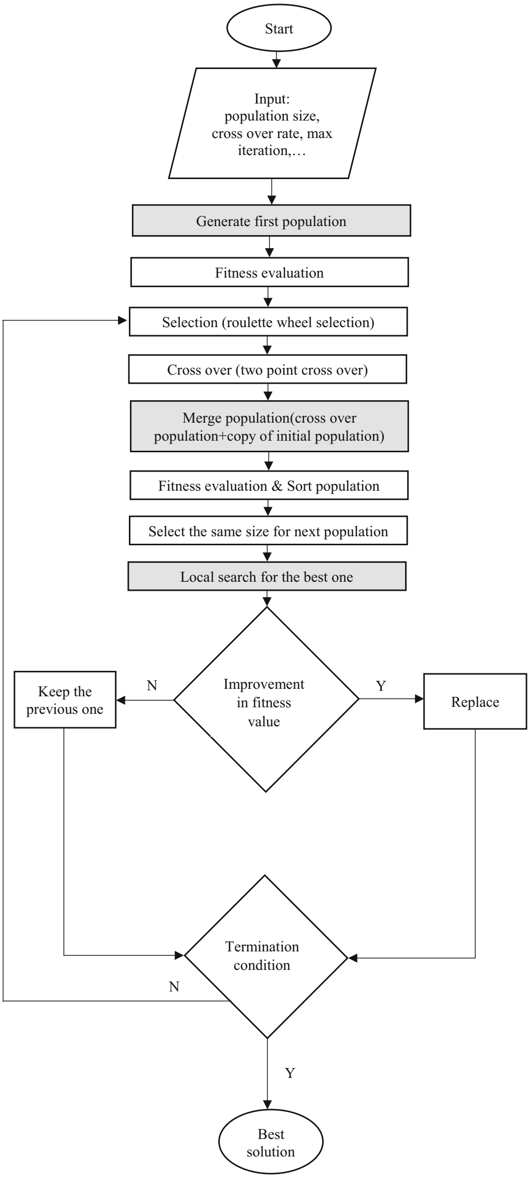

Fig. 2. Flowchart of the utilized memetic algorithm [11]

3 Parameter Analysis Methods

Many approaches have been introduced, developed and implemented to improve the performance of the processes parameters [12]. Amongst them the most popular ones are “One factor at a time” and “Design of Experiment (DOE)”. In “one factor at a time" method one particular condition is considered and the experiment are repeated by changing any other one factor till the effect of all factors are recorded. Design of experiments (DOE) as one of the most comprehensive statistical approach is capable to provide a predictive knowledge of a complex, multi-variable process with not many testing. There are two major approaches to DOE [12]:

- **Full factorial design:** A full factorial design studies all possible combinations of parameters to find the respective individual impact. Hence, the computational effort of the method grows combinatorially.
- **Taguchi method:** As statistical theory proved that not every combination of parameters needs to be checked [13], Taguchi [14] proposed a fractional replicated design using orthogonal arrays [15].

In [12] a comparison confirmed that the Taguchi method is more efficient, i.e. provided similar results at much lower experimental costs.

4 Ranking Parameters Using Taguchi

In order to find the sequence of the selected parameters of the memetic algorithm proposed in [11], we apply the following steps from the Taguchi analysis [12]:

1. Identify the objective function to be optimized
2. Identify the parameters and their possible levels
3. Select a suitable orthogonal array and construct the matrix of experiments
4. Conduct the matrix of experiment
5. Examine and analyze data, detect sequence and predict the best parameter levels
6. Confirm by experiment.

To apply the above steps, we generated three test problems. Since the framework of the proposed logistics network in this study is not the same by previous research, all parameters were generated randomly. One of these test problems is presented as an example of obtained results. This test problem features 4 suppliers, 8 plants, 20 distribution centers, 32 retailers, 8 customers, 8 collection/inspection centers and 4 retailers.

4.1 Identify the Objective Function to Be Optimized

In Taguchi method, it is recommended to use a loss function as a measurement. Afterwards, the obtained value of this loss function is transformed into a signal to noise S/N ratio as defined as in [15]

$$\frac{S}{N} ratio = -10 \log \left[\frac{\sum_{i=1}^{n} y_i^2}{2} \right]. \tag{5}$$

where n denotes the number of repeated experiments. In general, there are three different classes to analyze the S/N ratio including: nominal is better, larger is better, and smaller is better. As our objective is to minimize the total cost, "smaller is better" is selected for this study. When the total cost is minimum, the best result is obtained, which defines the highest S/N ratio.

4.2 Identify the Independence Factors and Number of Level for Each

From a comprehensive review related to this work [16,17] three keys parameters were identified, which are required to assess for the algorithm including: population size, cross over rate and number of local search iteration. According to [18], all factors have a significant effect on the total cost of the proposed model and are therefore important for the efficiency criterion. Within our study, we considered the levels given in Table 1.

Table 1. Selected parameters and levels

Parameters (factors)	Level 1	Level 2	Level 3	Level 4	Level 5
Population size	20	60	100	140	180
Cross over rate	0.1	0.3	0.5	0.7	0.9
Local search iteration	2	4	8	16	32

4.3 Select a Suitable Orthogonal Array and Construct the Matrix

Apart from the S/N ratio discussed in previous subsection, orthogonal array is applied in the Taguchi analysis as the second tool using a special set of arrays. It is known as an efficient method as compared to many other statistical designs [19]. This method is dealing with conducting the minimal number of experiments which could give us a more reliable estimation of all the factors that affect the performance parameter. Selecting an appropriate orthogonal arrays is the basic difficulty of the Taguchi's method. Although previous studies reported many orthogonal array, a full scheme that can cover all the possibilities of orthogonal arrays, could not be found [19]. To overcome this issue, standard orthogonal arrays have been introduced. Each of them is designed for a specific number of factors and levels. To select a suitable orthogonal array, the minimum number of experiments to be carried out should be computed based on the total number of degrees of freedom [13]

$$N_{Taguchi} = 1 + \sum_{i=1}^{n_f} (L_i - 1) \tag{6}$$

where n_f is the number of factors and L denotes the level for each factor. As we have three different factors with 5 levels each, the degree of freedom for the interested case is $1+(3*4) = 13$. Once the minimum number of 13 experiments is obtained, another selection of orthogonal array may be used to increase accuracy. Here, we utilized Minitab software for automatic design of the orthogonal array as well as for the analysis of experiments. Minitab software suggested using L_{25} orthogonal array, i.e. 25 instead of $5^3 = 125$ experiments.

4.4 Conduct the Matrix Experiment

We conducted each of these 25 experiments 10 times to generate more reliable averaged results. The respective parameter values are shown in Table 2.

Table 2. Orthogonal array with the specified values

Trial	Population size	Cross over rate	Local search iteration
1	20	0.1	2
2	20	0.3	4
3	20	0.5	8
4	20	0.7	16
5	20	0.9	32
6	60	0.1	4
7	60	0.3	8
8	60	0.5	16
9	60	0.7	32
10	60	0.9	2
11	100	0.1	8
12	100	0.3	16
13	100	0.5	32
14	100	0.7	2
15	100	0.9	4
16	140	0.1	16
17	140	0.3	32
18	140	0.5	2
19	140	0.7	4
20	140	0.9	8
21	180	0.1	32
22	180	0.3	2
23	180	0.5	4
24	180	0.7	8
25	180	0.9	16

4.5 Examine and Analyze Data to Predict the Best Parameter Levels

Since the proposed parameters are sensitive to the results ([18]), their best values have to be determined. As we are dealing with a strategic problem, there is no time limitation. Instead, we are interested in determining a ranking amongst the parameters. Figures 3 and 4 display the effect of the parameters on the objective function value and S/N ratio respectively.

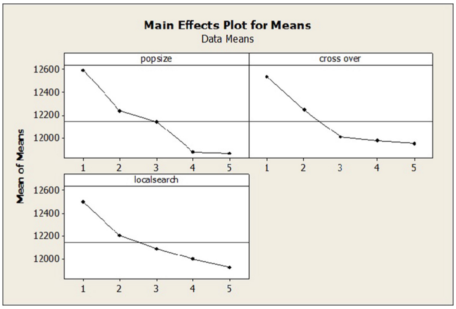

Fig. 3. Effect of parameters on total cost

Since S/N ratio has the "large is better" characteristic, the analysis of the results leads to the population size at level 4, cross over rate at level 4 and local search iteration at level 5. A ranking of parameters is made based on the range values of S/N ratio, cf. Fig. 4. We like to note that parameter population size has the largest effect on the outcome of the experiment while local search iteration has the least effect.

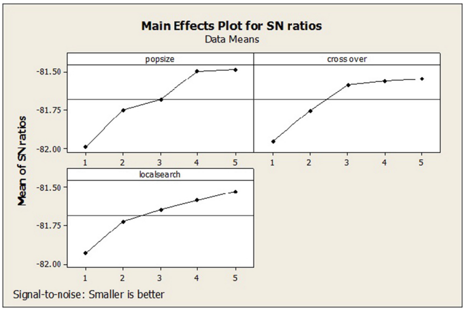

Fig. 4. Effect of parameters on S/N ratio

4.6 Confirmation Experiment

Purpose of confirmation experiment is to validate the conclusions obtained from the experiments. The actual value of cost obtained by MATLAB is equal to 11624, calculated based on the experiments. The predicted value is equal to 11575.8, computed according to statistical data with Minitab software. The results shown that utilizing Taguchi analysis, we obtain an error of 0.414%. This validates the method for predicting the ranking of the proposed parameters.

5 Conclusions

In this work, we focused on a comprehensive mix integer linear programming formulation for a seven-stage, flexible, closed-loop supply chain network. We applied the Taguchi method to identify the most important parameters as well as the ranking amongst these parameters and validated these results in numerical experiments. Finding the optimum parameter levels with regards to cost and time can be the next step of this research.

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Fleet Management for Pickup and Delivery Problems with Multiple Locations and Preferences

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Abstract. To provide more routing flexibility and improve service in delivery processes, we extend the Pickup and Delivery Problem with multiple time-location combinations for service. Furthermore, we introduce preference possibilities for each option, and aim for finding solutions that balance minimizing total travel costs and customer or operator dissatisfaction. We compare an Adaptive Large Neighborhood Search metaheuristic with solving the problem exactly. Simulation experiments indicate that a multiple-location scenario is highly beneficial compared to the corresponding single-location scenario and that the metaheuristic always finds the optimum if this could be computed by the exact solver.

Keywords: Vehicle routing · Pickup and delivery problem
GPDPTWP · Multiple locations · Time windows · Preferences
Customer satisfaction

1 Introduction

In home delivery processes, a frequently encountered problem is the absence of the customer at the moment a parcel is delivered. A solution could be to serve each customer in a customer-defined time window, but this can highly impair the efficiency of vehicle routes, and hence result in high delivery costs. We propose another solution, by allowing customers to specify multiple time-location combinations for delivery. Other scenarios where choosing from multiple pickup or delivery locations can be beneficial are, for instance, distribution from companies with different production locations, or taxi services where the customer is willing to conduct part of the trip by foot or other modality. From the alternative pickup and delivery locations and times, some might be preferred over others by customers, companies, the carrier, or other stakeholders. Taking these preferences into account could result in a higher service level.

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There is no choice for alternative pickup or delivery locations and times in the classic Pickup and Delivery Problem (PDP). We therefore develop a general problem framework that is able to utilize the available agenda and preferences information.

1.1 State of the Art and Contributions

To deal with multiple pickup or delivery options, several extensions of the classic Vehicle Routing Problem (VRP) have been proposed. The Generalized VRP (GVRP) considers clusters of possible customer locations (Golden 1978; Ghiani and Improta 2000). For each cluster, a delivery needs to be performed at one location. To our knowledge, only Moccia et al. (2012) study the GVRP with Time Windows (GVRPTW). On the other hand, the Multi-Depot VRP (MDVRP) has single delivery locations for each customer, but allows pickup at one of several depots (Renaud et al., 1996; Cordeau et al. 1997; Vidal et al. 2012; Montoya-Torres et al. 2015). The MDVRP has its applications in cases where a company with multiple production facilities or warehouses has to supply customers. The GVRP, in contrast, is generally applied in situations where it is too costly or time-consuming to serve all customers. Instead, one central point in each cluster is chosen and all customers in the area will be served from that point (Baldacci et al. 2010; Bektaş et al. 2011). More recently, Reyes et al. (2017) and Ozbaygin et al. (2017) proposed a trunk delivery application: instead of only at one home location, parcels can be delivered to the car of a customer, that can be at different locations during a day. The resulting VRP with Roaming Delivery Locations differs from the GVRPTW in the fact that time windows cannot overlap: the itinerary of a car is respected.

So far, no application of service levels or preferences has been proposed for multiple-location scenarios. Besides soft time windows, linear preference functions have been proposed for VRPs (Ghannadpour et al. 2014; Lin et al. 2014), but are currently limited to a single time window per customer.

In all models described above, all requests have the same pickup location(s). In contrast, we consider problems where each request has its own set of possible pickup and delivery locations. The transport operator must choose one pickup location and one delivery location from these sets to actually visit. In addition to a time window for each location, we expand the model with a preference value for each location, resulting in the Generalized Pickup and Delivery Problem with Time Windows and Preferences (GPDPTWP). With this framework, we provide a balance between route costs and satisfaction of customers or other stakeholders.

1.2 Outline

This paper is organized as follows. In Sect. 2, we define the GPDPTWP. In Sect. 3, we introduce a small case study of 5 cooperative retail chains supplying customers from different branches; we shortly describe the exact and metaheuristic method we use, and report on experimental results. Finally, in Sect. 4, we summarize our main findings and give suggestions for future research.

2 Problem Definition

A GPDPTWP instance is described by the structure given in Table 1, constrained to the restrictions of Table 2. Given are a set of customers with a transport request, a set of locations, travel times and travel costs associated with each pair of them, and a fleet of vehicles for conducting the transport requests. Instead of single pickup and delivery locations, as is the case in the PDP, each customer $c \in C$ has a set of possible pickup nodes N_c^p and a set of possible delivery nodes N_c^d. Multiple separated time windows for the same location can be modeled by introducing location duplicates. This contrasts with current definitions, where only one time window per location is considered, even in case of soft time windows.

A parcel size, modeled as integer number, is associated with each request.[1] Time windows in which the loading or unloading can start are given by $[e_i, l_i]$; note that these can differ per location for the same customer. The same holds for the service times (loading or unloading duration). For each customer, a preference value of 1 is assigned to the most preferred delivery location. The other delivery locations for that request (if they exist) will be assigned a number in $(0, 1]$ to describe the satisfaction if that location is served, relative to the most preferred delivery location. The same holds for pickup locations: at least one pickup location is fully preferred and the others are measured relative to it.

Note that the stakeholder having the preferences is not made explicit, and can differ depending on the problem domain. For instance, in multi-depot grocery distribution applications, the company can have preferences for pickup locations (based on stock and work force available in the depots), where the customer can have preferences for delivery locations (based on, for instance, distance from home or parcel weight).

The fleet of vehicles, each with its own capacity, is dispersed over multiple locations. Vehicles may start at the same location, but this is not necessary. Start and terminal locations of the vehicles are independent, i.e., it is not required that a vehicle ends at the point where it started its route.

A solution to a GPDPTWP instance consists of a set of routes, such that all transport requests are handled: for each request, a vehicle needs to pick up the load at one of the possible pickup locations in the corresponding time frame; the same vehicle needs to deliver the load later on in its route at one of the possible delivery locations, respecting the time window. Vehicle capacities need to be respected during the route, and all vehicles need to satisfy their start and end location requirements. The goal is to find a solution with minimal cost. Cost is defined as the sum of travel costs for all vehicles added to the sum of realized dissatisfaction values multiplied by a weight β, as is formalized by the mathematical program objective (1). The larger the value of β, the more important it is to satisfy the stakeholders. Note that all dissatisfaction values are counted equally in this model, but that any individual differences can be

[1] For ILP modeling purposes, this load quantity is related to all possible pickup nodes of the request and the negative load is related to all its delivery nodes.

Table 1. Problem structure

$C = \{1, \cdots, l\}$	A set of l customers
$V = \{1, \cdots, m\}$	A set of m vehicles
$N = \{1, \cdots, n\}$	A set of n nodes
$N = N^p \cup N^d \cup N^\alpha \cup N^\omega$	A partition of N
$N^p = N_1^p \cup \cdots \cup N_l^p$	A partition of N^p, where N_c^p is the set of possible pickup nodes for customer $c \in C$
$N^d = N_1^d \cup \cdots \cup N_l^d$	A partition of N^d, where N_c^d is the set of possible delivery nodes for customer $c \in C$
$N^\alpha = \{\alpha_1, \cdots, \alpha_m\}$	The set of start nodes of the vehicles, such that vehicle $k \in V$ will start at node α_k
$N^\omega = \{\omega_1, \cdots, \omega_m\}$	The set of end nodes of the vehicles, such that vehicle $k \in V$ will end at node ω_k
$G = \langle N, E \rangle$	A complete directed graph over N
$H \in \mathbb{N}^+$	The time horizon of the problem
$Q_i \in \mathbb{Z}$	The load quantity corresponding to node $i \in N^p \cup N^d$
$e_i \in \{0, \cdots, H\}$	The earliest service start time at location $i \in N$
$l_i \in \{0, \cdots, H\}$	The latest service start time at location $i \in N$
$d_i \in \mathbb{N}$	The service duration at location $i \in N$
$t_{ij} \in \mathbb{N}$	The travel time from i to j for each edge $\langle i, j \rangle \in E$
$c_{ij} \in \mathbb{R}^{\geq 0}$	The travel cost from i to j for each edge $\langle i, j \rangle \in E$
$p_i \in (0, 1]$	The customer's or operator's preference value for each node $i \in N^p \cup N^d$
C^k	The maximum load capacity of vehicle $k \in V$
β	The weight of customer dissatisfaction relative to travel cost

Table 2. Problem constraints

$\forall i \in N^p \quad Q_i \geq 0$	Pickup quantities are non-negative
$\forall c \in C \quad \forall i \in N_c^p \quad \forall j \in N_c^d \; Q_j = -Q_i$	Delivery quantities are the opposite of corresponding pickup quantities
$\forall i \in N^\alpha \cup N^\omega \; (e_i = 0 \wedge l_i = H \wedge d_i = 0)$	Start and end locations can be represented as requests with specific properties
$\forall c \in C \quad \exists i \in N_c^p \quad \exists j \in N_c^d \; p_i = p_j = 1$	At least one of the pickup and delivery locations of each request is fully appreciated
$\forall \theta \in \Theta(G) \quad \exists \langle i, j \rangle \in \theta \; d_i + t_{ij} > 0$	Each cycle of pickup and delivery locations in G takes at least some travel time

$\Theta(G)$ denotes the set of cycles in G for which all nodes are element of $N^p \cup N^d$

Table 3. Decision variables

$x_{ij}^k \in \{0, 1\}$	Assigned the value 1 when vehicle k travels along the arc $\langle i, j \rangle$
$s_i \in \{0, \cdots, H\}$	The service start time at location $i \in N$
$q_i^k \in \{0, \cdots, C^k\}$	The load of vehicle k after serving node $i \in N$

captured by setting the p_i values wisely. In more advanced models, different weight factors could be introduced for different stakeholders, or the product of all dissatisfaction values could be used to make sure that dissatisfaction is evenly distributed among the different stakeholders.
Given the problem structure and constraints in Tables 1–2 and the decision variables in Table 3, the mathematical programming formulation of the problem is as follows. The ILP can easily be obtained by applying standard linearization techniques on constraints (4), (14), and (15).

$$\min \sum_{k\in V}\sum_{\langle i,j\rangle\in E} c_{ij}x_{ij}^k + \beta \sum_{k\in V}\sum_{i\in N}\sum_{j\in N^p\cup N^d}(1-p_j)x_{ij}^k \tag{1}$$

s.t.

$$\sum_{k\in V}\sum_{i\in N}\sum_{j\in N_c^d} x_{ij}^k = 1 \qquad \forall c\in C \tag{2}$$

$$\sum_{i\in N_c^d}\sum_{j\in N} x_{ij}^k - \sum_{i\in N_c^p}\sum_{j\in N} x_{ij}^k = 0 \qquad \forall c\in C\ \forall k\in V \tag{3}$$

$$\sum_{i\in N_c^d}\sum_{j\in N} s_i x_{ij}^k - \sum_{i\in N_c^p}\sum_{j\in N} s_i x_{ij}^k \geq 0 \qquad \forall c\in C\ \forall k\in V \tag{4}$$

$$\sum_{j\in N} x_{ij}^k - \sum_{j\in N} x_{ji}^k = 0 \qquad \forall i\in N^p\cup N^d\ \forall k\in V \tag{5}$$

$$\sum_{j\in N} x_{\alpha_k j}^k = 1 \qquad \forall k\in V \tag{6}$$

$$\sum_{k\in V}\sum_{j\in N} x_{ij}^k = 1 \qquad \forall i\in N^\alpha \tag{7}$$

$$\sum_{i\in N} x_{i\omega_k}^k = 1 \qquad \forall k\in V \tag{8}$$

$$\sum_{k\in V}\sum_{i\in N} x_{ij}^k = 1 \qquad \forall j\in N^\omega \tag{9}$$

$$\sum_{k\in V}\sum_{i\in N}\sum_{j\in N^\alpha} x_{ij}^k = 0 \tag{10}$$

$$\sum_{k\in V}\sum_{i\in N^\omega}\sum_{j\in N} x_{ij}^k = 0 \tag{11}$$

$$\sum_{k\in V}\sum_{i\in N} x_{ii}^k = 0 \tag{12}$$

$$e_i \leq s_i \leq l_i \qquad \forall i\in N \tag{13}$$

$$(s_i + d_i + t_{ij})x_{ij}^k - s_j x_{ij}^k \leq 0 \qquad \forall i,j\in N\ \forall k\in V \tag{14}$$

$$(q_i^k + Q_j)x_{ij}^k - q_j^k x_{ij}^k = 0 \qquad \forall i\in N\ \forall j\in N^p\cup N^d\ \forall k\in V \tag{15}$$

$$q_{\alpha_k}^k = 0 \qquad \forall k\in V \tag{16}$$

Constraints (2) state that all requests are handled exactly once. Constraints (3) and (4) enforce that pickup and delivery tasks of the customers are coupled into the same vehicle, and occur in the right order. A consistent vehicle flow is guaranteed by (5)–(12), together with the subtour elimination properties given by (14) and the last constraint of Table 2. Temporal requirements are represented by (13) and (14) and capacity constraints by (15) and (16).

3 Experiments

To get insight in the complexity of the newly defined problem, we model a scenario with and without multiple locations, for which we compare computation times as well as objective values, both for an exact solution and a metaheuristic approach.

3.1 Instances

We model a scenario with 5 cooperative retail chains, each having 2 branches, on a 100×100 area. The retail chains have vehicles available, which they share in a fleet to serve all customers as well as possible. All vehicles, with capacity 250 or 500, have one branch location as start and end point.

We consider l customers that place an order. Each customer has 4 randomly generated possible delivery locations, and the two branches of a random chain are the possible pickup locations. We generated 40 instances, 10 of each for $l \in \{2, 5, 10, 20\}$. To compare the multiple-location scenario with the single-location scenario, we make a duplicate of each instance in which we keep only one pickup and one delivery location with preference value 1. Requests have a random load between 1 and 100. For large loads (>50), delivery preference values for all but one location are set to 0.1, 0.2 or 0.3 to represent that the customers prefer home delivery. For small loads (<10), they are set to 0.8, 0.9 or 1. For other load quantities, delivery preference values are assigned randomly. All pickup preference values equal 1, i.e., it does not matter from which branch the goods are picked up. Travel times are equivalent to the Euclidean distance between two locations (rounded up to integers) and travel costs are about half of the travel time to represent an operation cost of about 30 euro per hour per vehicle. Furthermore, β is set to 20 to represent that a dissatisfied (but still served) customer can be compared to an extra cost of 20 euro. Hence, about 40 min extra driving time is allowed to fully satisfy a customer. Further instance details can be found in Table 4.

3.2 Methods

We solve the GPDPTWP both with an Adaptive Large Neighborhood Search (ALNS) algorithm and with the exact solver Gurobi. The first method has shown promising results in solving other routing and scheduling problems (Ropke and Pisinger 2006; Pisinger and Ropke 2007). Based on an initial solution, part of the orders is removed from the routes, and subsequently reinserted into the impaired solution. By iteratively applying this procedure, we aim for convergence to a low-cost solution. ALNS combines different heuristics for exploring the neighborhood; in each iteration, the destroy and reinsert heuristic are selected based on their performance in previous iterations. We mainly follow the procedure described by Ropke and Pisinger (2006), adapted to the GPDPTWP where necessary.

We apply ALNS, which was implemented in Go, 10 times on each instance. We stop each run if there is no improvement in the last I iterations, with $I = \max(2000, 100l)$. The best result of these 10 runs is provided as initial solution to the ILP solver. We restrict the time for finding an exact solution to 9000 s. All experiments were performed on a 64-bit machine running Linux with Intel i5-4590 CPU at 3.30 GHz and 8 GB of RAM.

3.3 Results

Table 5 shows the computational results for both scenarios per group of instances with the same number of customers. The solution found by the ILP solver is never better than the ALNS solution. Hence, the metaheuristic finds optimal solutions for all cases where optimality is proven by the ILP solver. The gap between the solver's best value and its best bound is given, as well as the computation times for both methods. In the comparison column, the improvement of objective value of the multiple-location scenario with respect to the single-location scenario is given, as well as the factor by which computation times for ALNS slowed down.

Note that the single-location scenario with 5 customers is always solved to optimality by the ILP solver, whereas the multiple-location scenario with 5 customers is not always solved to optimality. In fact, 4 out of 10 instances were solved within the time limit. In Table 5, we separated the results for the 4 solved and the 6 unsolved instances for this scenario. For 10 customers, both scenarios are already too complex to solve exactly in 9000 s, whereas ALNS uses about 16 s. For the multiple-location scenario with 20 customers, the exact solver runs out of memory, whereas the metaheuristic still quickly comes up with a solution.

When comparing the multiple-location scenario with the single-location scenario, we see that improvements of about 30% can be made. This comes at the cost of a slowed down computation time with a factor up to 5.

Table 4. Instance parameter specifications

General	$i \in N^p$	$i \in N^d$
$H = 960$	$d_i = 3$	$3 \leq d_i \leq 15$
$t_{ij} = \left\lceil \sqrt{\lvert x_i - x_j \rvert^2 + \lvert y_i - y_j \rvert^2} \right\rceil$	$e_i = 0$	$30 \leq l_i - e_i \leq 960$
$c_{ij} = 0.5t_{ij} + z, \quad z \in [-4, 4]$	$l_i = 960$	$-100 \leq Q_i \leq -1$
$\beta = 20$	$p_i = 1$	
$C^k \in \{250, 500\}$		

Table 5. Mean results and standard deviations for solutions by ALNS and the exact solver, based on 10 instances per customer number group. If the exact solver suffers from time or memory limitations, this is denoted by ⊕ and ⊗, respectively.

			1 pickup, 1 delivery			2 pickups, 4 deliveries			Comparison	
			Exact		ALNS	Exact		ALNS	ALNS	
#Customers	#Instances		Gap (%)	Time (s)	Time (s)	Gap (%)	Time (s)	Time (s)	Improvement (%)	Slowdown factor
2	10	μ	**0.00**	**0.71**	**0.45**	**0.00**	**11.25**	**0.66**	**40.02**	**1.49**
		σ	*0.00*	*0.48*	*0.05*	*0.00*	*22.22*	*0.10*	*23.80*	*0.24*
5	10	μ	**0.00**	**324.77**	**2.14**			**2.31**	**38.10**	**1.13**
		σ	*0.00*	*241.85*	*0.65*			*0.68*	*13.85*	*0.36*
	4	μ				**0.00**	**3765.23**			
		σ				*0.00*	*2659.10*			
	6	μ				**29.88**	⊕			
		σ				*6.03*				
10	10	μ	**32.45**	⊕	**5.55**	**43.28**	⊕	**15.86**	**31.88**	**2.98**
		σ	*11.46*		*1.67*	*9.13*		*5.12*	*8.27*	*0.88*
20	10	μ	**50.62**	⊕	**27.20**	⊗		**132.33**	**28.67**	**4.85**
		σ	*6.27*		*2.81*			*28.84*	*12.94*	*0.83*

4 Conclusions and Future Research

We have introduced the GPDPTWP to be able to model logistical problems with multiple alternative service locations where preferences are taken into account. As expected, adding multiple pickup and delivery locations to a problem instance is highly beneficial in terms of total costs: our scenario allowed for objective value improvements of about 30% when 1 other pickup location and 3 other delivery locations were added. Although the amount of improvement may highly depend on the specific problem characteristics, these results indicate that a significant gain can be obtained when multiple locations are taken into account.

First experiments show that exact solutions to the problem can be obtained in reasonable time only for very small instances. An ALNS approach, however, solves larger instances in reasonable time, and finds optimal solutions for all instances that were solved to optimality by the ILP solver.

Future research consists of experiments on real-world multiple location problems to fully investigate the potential of our approach. Furthermore, the influence of ALNS heuristics specially designed for the GPDPTWP will be examined.

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Collaborative Distributed Operational Planning for Spare Parts Supply Chains

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Abstract. Supply chains are usually challenged with situations of information divergence, since multiple agents with individual goals are involved. To cope with this challenge, thus improving supply chain efficiency, collaborative operational planning embodies a promising opportunity. In this paper, a structured procedure for implementing distributed planning in spare parts supply chains integrated to intelligent maintenance systems was developed, tested through simulation and had its performance compared to a classical management approach. Results indicate that distributed planning provides more efficiency even in scenarios with higher uncertainties.

Keywords: Supply chain planning · Collaboration · Optimization · Simulation Distributed planning

1 Introduction

Individual businesses no longer compete as solely autonomous entities, but rather as supply chains (Lambert and Cooper 2000). Therefore, supply chain management (SCM) considered to involve integration, coordination, and collaboration across organizations and throughout the supply chain (Stank et al. 2001). Collaboration in the supply chain comes in a wide range of forms, but in general has a common goal: to create a transparent, visible demand pattern that paces the entire supply chain (Holweg et al. 2005). This way, Collaborative Planning can be defined as a "joint decision making process for aligning plans of individual SC members with the aim of achieving coordination" (Stadtler 2009). (Ireland and Webb 2007) highlights that the challenging nature of competing in a global environment creates several tension-filled questions for today's firms, for example: in what markets should the company compete? How much risk is the company willing to accept to compete in markets with which they are not deeply familiar? What kinds of skills should the company develop in order to become more innovative? According to (Stadtler 2009), "one important way to achieve coordination in an inter-organizational supply chain is the alignment of future activities of supply chain

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members, hence the coordination of plans". Thus, a collaborative SC strategy recognizes that integrated business processes create value for the customers. (Huiskonen 2001) argues that the only way to bring the conflicting views of suppliers and customers into alignment is through the collaborative design of the logistical network structure as a whole.

Added to this, in the particular case of spare parts supply chains (SPSC), several aspects make the task of providing spare parts and maintenance services challenging: the high number of parts to be managed, sporadic demand, the high responsibility required due to customer downtime cost, the risk of obsolete inventory, among others (Espíndola et al. 2012). (Israel et al. 2016) affirms that proper maintenance and the availability of needed spare parts directly influence the production systems effectiveness and efficiency. With the current state of microelectronics and software development, a new maintenance approach can be introduced: condition-based maintenance. In the condition-based maintenance, physical information on each part of the machines will be given in real time, while algorithms developed by Intelligent Maintenance Systems (IMS) will provide the parts' breakdown forecasts and increasing costs. Information will be given by sensors and embedded systems, while health-estimation algorithms will predict the failures. Breakdown forecasting is not only important to improve maintenance but also to inform the whole supply chain to support the demand planning on a tactical and operational level (Frazzon et al. 2014). Israel et al. (2016) proposes a mathematical model for optimization at the operational level of the transportation and storage strategy of a spare parts supply chain. This model was suggested as effective through simulations but still has improvement points for further studies. The model presented by the author establishes a hierarchical system, optimizing the total costs of the chain, disregarding the individual objectives of the participating agents and the confidentiality of their information. Dudek and Stadtler (2005) and Jung et al. (2008) consider that a hierarchical planning model can be inconvenient for the privacy of the organization, and both studies propose distributed planning approaches, where the optimization is usually divided between actors that exchange minimum information among each other. Therefore, the relevance of the present work is justified by the necessity of support for the implementation of collaborative distributed planning in spare parts supply chains, which lacks application examples according to the literature.

In this context, this paper aims to propose a structured procedure for fitting an operational planning concept to the collaboration specificities of spare parts supply chains. The paper is structured in two main sections. In the first section a procedure to distributed collaborative planning application in spare parts supply chains is presented. Then, a test case including obtained results and analysis is presented. The paper wraps up with concluding remarks regarding the managerial and scientific impact.

2 Distributed Collaborative Planning in Spare Parts Supply Chain

In the present session, a procedure to apply distributed collaborative planning approach to a spare parts supply chain integrated to intelligent maintenance systems will be proposed.

The first step is to define the spare parts supply chain to be applied. The SPSC must be known as much as possible, since each step will require a significant amount of information in order to be applied. The information required will depend on the result of each step (for example, different planning models defined on the second step will require different types of information).

In the second step a planning model shall be defined. For this task, a systematic procedure, the Framework for Intelligent Supply Chain Operations (FRISCO) assessment approach, is recommended to be applied as proposed by (Küppers et al. 2015). This procedure aims to find an existing suitable distributed planning model from the state-of-the-art library of classified collaborative planning concepts presented in (Küppers 2013). If a suitable model cannot be found, a specific collaborative planning concept should be developed for the addressed spare parts supply chain. Finally, the planning of resulting collaborative model is proposed by using hybrid approaches that aim to combine the advantages of analytical methods, such as linear programming, and simulation models to deal with such scenarios with high uncertainty.

The third step is about finding an efficient solving approach to support the defined model execution. The choice will depend on the model defined in step 2. However, 18 of the 26 models listed in the state-of-the-art concept library by (Küppers 2013) are modelled as Linear Programming problems, which can be solved using the meta-heuristics or algebraic approaches. Thus, the choice will basically depend on the size of the SPSC in question and its number of decision variables and the limitations of the available software.

Then, in the fourth step, the model can be executed and a plan can be generated considering the demands forecasted by the IMS as deterministic values. Thus, in the next step, the feasibility of the generated plan shall be checked through simulation, as well as the performance of the model under an expected variability on the demand. In case of non-feasibility or bad performance under variability, the planning model must be updated. Otherwise, the model can be considered feasible and its performance can be compared to other management strategies in order to decide whether or not the model will be adopted.

3 Test Case

Regarding on the step one, the scenario used for testing was taken and adapted from (Israel 2014). It comprises a company with a factory and distribution centre (DC) located in the South of Brazil. The company, called Alpha on the original work and also in this one, provides three components of electrical actuators for five big markets in different Brazilian states (here decreased to four, due to the solving software limitations). The company also has intermediately three service centres (SC), here reduced to two. This work will consider the flow of the three products produced by Alpha Company. The clients of this supply chain are industries that buy these products as spare parts, for maintenance. In this supply chain, intelligent maintenance systems are used, which makes the demand visible for each one of the fifteen following days. Related to the data used in the test case, the demands by the three products in the four markets is presented on (Israel 2014). These values where considered for the planning phase. In the tests executed by (Zuccolotto et al. 2015) the forecast accuracy of the IMS reached 93%.

The transport time is considered equal as a time period of the model, i.e. the product to be transported will be available in the destination in the following period, one day in this case. The test case will not consider the allotment problem, as well as the transport of the spare parts will be considered as continuous. The production cost is 64.50, and the production time estimated in 6 min for the product one, 82.5 and 9 min for product two and 45 and 8 min for product three. Since the selling prices were not provided, the prices were generated assuming profit in each delivery for both organizations, since the products were transported by the cheapest route and stored for only one day. The profit margin of the production company was assumed as 70%, considering only the production and storing costs. The profit of the distributor was assumed as 20%, considering the cost of acquisition, storage and transport. Thus, the wholesale price of the products one, two and three are 301, 385 and 210 respectively, and the market prices were assumed 2938, 3238.75 and 1766.25. The high market prices are justified due to the high transportation costs, a characteristic of the high service level (focusing on the short lead time) required. The possibility of backlogging was not considered. The stock cost in the DC is 25.8 for the product one, 33 and 18 for the product two and three, and in the SCs 34.4, 44, 24 respectively. Finally, the transportation costs are presented in the Table 1.

Table 1. Transportation costs

	F			SC1			SC2		
	1	2	3	1	2	3	1	2	3
SC1	1162	1486	810	-	-	-	-	-	-
SC2	755	966	527	-	-	-	-	-	-
M1	-	-	-	0	0	0	460	488	321
M2	-	-	-	312	396	216	215	225	150
M3	-	-	-	529	676	369	430	550	300
M4	-	-	-	475	605	330	264	335	183

On the step two, the procedure proposed by (Küppers et al. 2015) was applied, and the perfect match was obtained with the model proposed by (Jung et al. 2008), which describes a negotiation model form distributor-driver supply chain, and consists in a supply chain where a distributor (called DA, or distribution agent) works and negotiates with a factory (called PA, or production agent). The planning model consists in one distribution planning model for the distribution agent and one production planning model for the production agent (Jung et al. 2008). Initially, the DA runs its planning model, considering the PA's capacity as unlimited. Then, DA deliveries the order to PA. PA executes its own planning and returns the attended orders to DA, which interprets the attended orders as a "perceived capacity" and re-executes its own planning. The procedure follows with this minimum communication exchange, and stops when PA returns to DA with all attended orders. At this point of the procedure, every parameter is considered deterministic.

In step three, the planning models were implemented and executed on the software IBM ILOG CPLEX. The planning is done as follows: first the DA model is executed considering that the PA has infinity capacity, then it generates its own plan and send the orders to the PA, the PA then executes its plan and send back to the PA the shortage. The DA interprets the shortage and considers the production capacity proportionally lower and executes its plan again, and sends a new order to the PA. The procedure continues until there's no shortage reported by the PA (considering the order by the DA, no the actual demand in the market). In the present work, the algorithm converged in the fourth iteration, with a DA profit of 14 858 193.25 money units and PA profit of 2 526 549.00 money units. Simulation suggested that the results are feasible. At the simulation models, the parameters Transportation Time and Demand, and only these ones, were considered stochastic.

In order to compare the performance of the results given by the mathematical model a simulation was created applying classical management strategies. The Naïve method was used to manage the SC's inventory. The method consists in keeping a safety inventory level, attending the maximum of the demand of the day, and ordering the same amount attended in the day after. The markets are, at first, attended by the nearest (with cheapest transport) SC, and if this one cannot attend, then the other one attends if possible. The safety inventory level was calculated by the equation $SS = z \times \sigma\_d \times \sqrt{l}$, where SS is the minimum stock to be held in the inventory, z is the number of standard deviations in the normal curve, σ_d is the standard deviation, and l is the lead time between production and distribution centre is one (since the delivery is continuous and attended within a day) and for z equals to three. This strategy is submitted to the very same demand generated to the distributed planning model.

On the simulation phase, variability was included in the demand to assess the performance of the model under uncertainty. Four scenarios were created, all of them assuming triangular distribution for the demand of each product, each day. In the first one, Scenario 1, the maximum and minimum were set to ±5% of the forecast, in Scenario 2, 3 and 4, ±10%, ±15% and ±25%.

In the second simulation model the plan generated by the planning model is used to manage the production facility and the service centre inventories. Both simulation models were created in the software AnyLogic. The results are presented in Fig. 1.

As it is possible to see, the distributed planning integrated with intelligent maintenance systems presents a bigger profit, mainly due to efficient ordering and inventory management. As expected, the efficiency of the distributed planning decreases with increasing uncertainty, but remained better than the Naïve approach even at high uncertainty levels. The performance of the Production Agent does not change with the uncertainty in the distributed planning, since the orders are agreed before the period. The performance of the Production Agent with the Naïve approach has a very small variation.

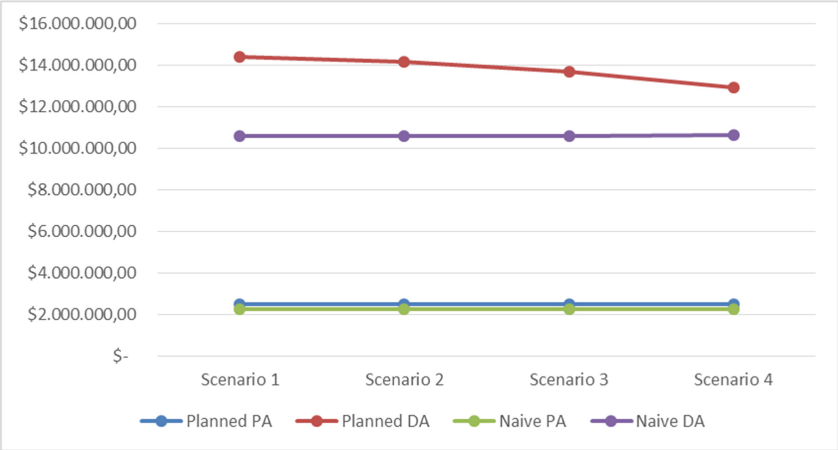

Fig. 1. Organizations' profits in different approaches and scenarios, in money units

4 Conclusions

In this paper a procedure to apply a distributed planning model in a specific collaborative spare parts supply chain was proposed, leading to better solutions in terms of overall costs for the given agents, in despite of its forecasting complexity stated by Huiskonen (2001), being the reason why usually the objective of study is usually control policies. Thus, the outcome model was applied and used as input data in a simulation model, in order to test its feasibility and performance compared to a classical management approach. The model appeared to be feasible, since its objective function was really close to the outcome of the simulation, and it also suggested to be more efficient than the Naïve approach. The framework used to find existing models and adapt them to the given supply chain coordination problem was suggested to be effective, supporting the application of this procedure.

The results of this study should be interpreted in the light of a few limitations, such as the selection of one specific supply chain, which makes the generalization to other supply chains difficult. However, this limitation is also offset by the quality of information obtained from a more in-depth study and by the analysis of a particularly innovative setting. Also, more data about the probability distribution from the forecast of the intelligent maintenance system would also help to generate more realistic results. In order to extend the present work, different classical approaches should be added to the performance comparison phase, as well as different scenarios in the simulation model.

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Measuring the Quality of B2B Logistic Services – An Industry-Specific Instrument

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Abstract. Modern service providers are confronted with increasing competitive pressures and highly individualized customer needs. Especially in the business-to-business (B2B) markets, long-term competitiveness is only possible as long as the specific requirements for the service development and provision are met. However, measuring customer satisfaction in the B2B market appears to be not as intuitive, since personal preferences are complemented by company-specific criteria and a buying center consisting of various decision makers. In this paper, we analyze existing methods for measuring service quality and test three of them for their applicability in the real-life context of the logistic domain using expert interviews. The contribution is a refined method, which uses the existing literature as a basis that is enhanced with practical input from industrial logistic service providers.

Keywords: Service quality · Industrial services · Logistics · Expert interviews

1 Introduction

In advanced economies, the service sector has continuously become prevailing during the last decades, affecting both the overall employment and the national GDP distribution. In Germany, especially industrial services like logistics create a high portion of the economic output (Eickelpasch 2012) and are now offered not only by the service providers but are also introduced by traditional manufacturers as well (Haller 2017). The increasing competitiveness leads to the need for service providers to differentiate themselves from their economic rivals. While many companies see "service quality" as their major distinction (Parasuraman et al. 1985), this is only possible if they are able to objectively measure it, which appears to be not as intuitive, since the notion of quality is an abstract concept (Karatepe et al. 2005) due to the basic characteristics of services such as immateriality and integration of the external factor. In addition, in the case of Business-to-Business (B2B) market, offered services are much more complex and individualized (Westbrook and Peterson 1998), with multiple stakeholders and supply chain partners involved, having their own perception of what makes a good service.

Typically, measuring service quality is supported by the use of instruments, consisting of quality *dimensions*, being general components of quality, and their underlying *items*, i.e. specific evaluation criteria of these dimensions (Gounaris 2005a). A first breakthrough came with the instrument called SERVQUAL, which provided

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general assistance consisting of five dimensions and 22 items for service measurement and evaluation, irrespective of the domain or individual company's characteristics (Parasuraman et al. 1988). Despite its initial acceptance and several refinements (Parasuraman et al. 1991), the instrument has been widely criticized for its seemingly general applicability and not being specific enough for certain domains or service providers (Babakus and Boller 1992; Finn et al. and Lamb 1991). Hence, numerous calls for measurements specifically designed for B2B services resulted in the introduction of new theoretical instruments, such as B2B-SERVQUAL (Vandaele and Gemmel 2004) or INDSERV (Gounaris 2005a).

However, so far, these instruments remain rather on the theoretical level with no confirmation of their usefulness and applicability in practice (Gounaris 2005b). Motivated by this research gap, the objective of this research is to analyze existing methods for measuring B2B service quality and test them for the logistic domain both from the customer and the service provider perspective by conducting a small qualitative empirical study using expert interviews. The result of the paper is a refined method, which combines the current academic best practices with practical insights, thus serving as guidance for practitioners. As for the theoretical contribution, we hereby enhance the ongoing academic discussion on the measurement of service quality in B2B markets and present further research priorities.

2 Theoretical Foundation and Research Methodology

The importance of service quality for the long-term competitiveness and sustainability of the service provider has been the center of academic attention for the past couple of decades, mostly concentrating on the B2C markets. Previous studies have identified it as the main driver of the overall customer satisfaction (Lee et al. 2000; Spreng and Mackoy 1996) and of the perceived value that the customers are getting (Hu et al. 2009), which, in turn, influence their behavioral intentions (Lai and Chen 2011) and purchase intentions (Tam 2004), as shown in Fig. 1. In addition, following the idea of Grönroos (1984), service quality emerges as a result of comparing the perceived service

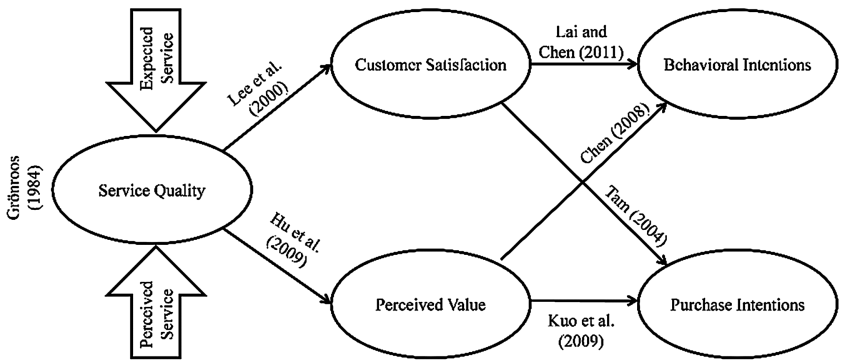

Fig. 1. The relevance of service quality for the service provider (own illustration)

and the expected service, meaning that it relies on a certain evaluation process (Philip and Hazlett 1997).

To conduct this evaluation in a structured way, several instruments have been already introduced, typically consisting of different dimensions and their corresponding items. These instruments can either provide general applicability, focusing on the overall characteristics of services or be industry-specific, concentrating on a selected domain (Cronin Jr. and Taylor 1992). Various literature reviews such as Seth et al. (2005) or Ladhari (2008) list up to 30 methods each, thus making it difficult for the practitioners to select an appropriate instrument for their own use case (i.e. "*are we asking the right questions*?"), especially due to the academic nature of methods. Therefore, we selected and empirically tested three well-established methods, which have also been previously suggested for B2B markets and logistics industry in particular (Ladhari 2008) – a universal SERVQUAL with 5 dimensions and 22 items (Parasuraman et al. 1988), its B2B extension with 8 dimensions and 29 items (Vandaele and Gemmel 2004) and an industrial model INDSERV with 4 dimensions and 22 items (Gounaris 2005b).

In order to test the applicability of these instruments in the context of logistic services, we employed methods of qualitative research, which is suitable when an in-depth access to the practitioners is needed in order to explain an emerging phenomena or test certain solutions (Yin 2013). We applied expert interviews (Flick 2014) for data collection, which followed a semi-structured interview guideline and gave the interviewees freedom to elaborate the specificity of the industry. The guiding questions addressed the notion of service quality (both from the provider and from the customer perspective) as well as based on what characteristics they select their partners. The interviews were conducted in June 2017 and lasted for 60 min each. All interview partners requested to remain anonymous.

AUTOMOBILE is a medium-sized logistics company offering international transports for automotive industry. COOLANT and BULK are family businesses offering regional transports for slaughterhouses and industrial warehousing respectively. Finally, CONSULTANT is a consultancy agency with the focus on the logistics domain. Table 1 gives an overview of the interviewed service providers.

Table 1. Organizations and Interviewees

Organization	Number of employees	Turnover per year	Position of interviewee
AUTOMOBILE	~200	~30 million	Director quality
COOLANT	~100	~20 million	Quality manager
BULK	~75	~15 million	Quality manager
CONSULTANT	~1500	~170 million	Service advisor

3 Results

When conducting expert interviews, our aim was to find out which of the dimensions and items of SERVQUAL, B2B-SERVQUAL, and INDSERV are particularly useful for the practitioners and what aspects are still missing. The deployed questionnaire comprised 17 thematic blocks, consisting of 2–3 questions each. The first question aimed at determining the overall relevance of the quality dimension for the logistics industry and the interviewed company in particular using Likert scale from 1 to 5 (5 being the highest relevance). Following the guidelines for the appropriate size of the structured interviews (Flick 2014), this first question acted as a pre-selection – only those dimensions with the relevance of 4 or 5 were analyzed further. The subsequent questions concentrated on the items – both testing the existing items from the literature and identifying new, yet unseen ones by actively asking the interviewees to reflect on their experience. With the help of the MAXQDA 12 software, the transcribed interviews were then grouped using paraphrasing (Meuser and Nagel 2002) and prepared for further analysis. (Due to the space limitations, the deployed questionnaire, coding scheme and the interviews are not presented in this paper, but can be provided upon request).

The results of the expert interviews were then clustered into three categories. The first category contained *less relevant* dimensions (i.e. those that were generally recognized as being not important) like “potential quality”, “market clout”, and “technical support”. This shows that the a priori selection of the providers and partners is not influenced by their current market share or reputation. Surprisingly, the level of the technical support is also not directly seen as an advantage – as long as the service is delivered as promised, it doesn’t matter what happens in the back office. The second category comprised dimensions, where service providers had *disagreements regarding their relevance*, which shows that even within one industry the notion of quality can be perceived differently. For example, while AUTOMOBILE and COOLANT see “tangible” or “geographical presence” as neutral for the evaluation of the service quality, BULK perceives them as essential for the customer-provider relationship, especially when certain spare parts or irregular maintenance activities are needed. Similarly, COOLANT and BULK believe that the “product offering” of services shows the competence and the adaptability of the service provider, whereas AUTOMOBILE and CONSULTANT state that only the obtained services matter. Finally, the third category contained *highly relevant* dimensions that were highlighted by all the interviewed companies and served as the base for the developed instrument, which is presented in Table 2.

Talking about the “hard process quality”, the interviewees emphasized the significance of the service provider to fully understand the demands of their customers by looking at the nuances of the contract (as most of the projects in contract logistics are highly individual one-time projects), even if it requires additional meetings and negotiations. Furthermore, with a high maturity of the industry and an overall level of competition, the proposed service needs to be monetary comparable to other providers, meaning that higher prices are to be justified by the quality delivered. Another two key dimensions for the service quality are the “output quality” and the overall “reliability”. Irrespective of the deployed techniques or IT, meeting the agreed target on time has an absolute priority and affects directly whether the provider will be chosen again in the future. It is interesting to mention that the customers also value error-free records and an accurate contract-related paperwork, since they want to be able to follow the process and participate in the value co-creation if possible. The last dimension from the existing measuring instruments is provider’s “responsiveness”, i.e. being available to the customer before, during and after the service provision. Especially in the logistics domain, where companies are intertwined in multi-staged supply chains, both the customers and providers have to be able to dynamically adjust to the short-term and long-term changing requirements.

Table 2. Dimensions and items of the modified instrument

Dimension	Item	Origin
Hard process quality	Keeps time schedules Meets deadlines Looks at details Understands customer demands	INDSERV
Output quality	Reaches objectives	INDSERV
Price	Price is competitive compared to other offers Price relates to the quality delivered	B2B-SERVQUAL
Reliability	Shows a sincere interest in solving problems Performs the service right the first time Provides its services as promised Insists on error-free records Keeps his paperwork accurately	SERVQUAL and B2B-SERVQUAL
Responsiveness	Tells exactly when services will be performed Gives prompt service Are always willing to help Are never too busy to respond to requests	SERVQUAL
Service modularity	Structured portfolio representation Combination of standardized service modules Transparency in calculations Integration in the overall supply chain	Interviews

In addition to the already existing dimensions, “service modularity” was identified as an industry-specific quality indicator both for the service offered and the service provider himself. Since many companies within the contract logistics domain position themselves as universal service providers being able to perform any possible project, the need of a structured portfolio representation where standardized service modules can be recombined with each other thus enabling the required customization seem to gain its importance, especially with the background of increased competition from smaller agile newcomers. The advantage of such a modular architecture reaches its apogee in the quotation process, where the customer benefits from an overview of what is possible and at what price, as well as the sales representative is guided by the centralized decision support when creating a plausible offer. This is also consistent with the results of our previous work that analyzed the status quo of the sales process amongst B2B service providers of wind energy and logistics based on 17 expert interviews (Lubarski and Pöppelbuß 2017), underlying the overall trend of service modularity.

4 Conclusion

In this research, we have focused on the measurement of service quality and customer satisfaction by analyzing existing academic instruments and testing them in the context of B2B logistic service providers. With the help of expert interviews involving quality managers, we were able to find an intersection between SERVQUAL, INDSERV, and B2B-SERVUQUAL enhancing it with the insights from the interviews. The developed instrument comprises of five established ("hard process quality", "output quality", "price", "reliability", "responsiveness") and a supplementary dimension ("service modularity"), being both a practical guideline for service designers or quality managers, as well as theoretical contribution to the ongoing discussion about how B2B services should be measured.

However, our research comes with certain limitations. Firstly, due to the limited resources, we were not able to test all the existing methods for service quality measurements, which may contain further useful dimensions and items, so further holistic approach is needed. Secondly, since we applied the methods of qualitative research, our sample size is too small in order to provide generalizable results. To validate our findings empirically, we call for additional research on how B2B service providers can select appropriate dimensions and items not only based on the industry but also based on further characteristics of the services offered as well as their customers' needs and their value perception.

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Integrating High-Performance Transport Modes into Synchromodal Transport Networks

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Abstract. The European Union aims to introduce synchromodal transport networks to facilitate sustainable and efficient freight transport. One fundamental opportunity of synchromodality is a modal shift towards environmentally friendly transport modes. In this respect, the present paper examines if a modal shift towards high-performance transport modes is beneficial for the concept of synchromodality. We consider the Hyperloop technology as a prime example for high-performance transport modes as it is proposed that it will be faster than air transport and more energy efficient than train transport. The results suggest that integrating the Hyperloop into synchromodal networks involves mutual benefits for both, the Hyperloop and synchromodality.

Keywords: High-performance transport modes · Synchromodality · Hyperloop

1 Introduction

Following the intentions of the European Union, the future of European freight transport is sustainable and synchromodal. The European Technology Platform ALICE has been established to develop a comprehensive strategy for logistics and supply chain management innovation in Europe. Synchromodality is one main roadmap topic that is addressed by ALICE (Zijm and Klumpp 2016). While the concepts of multimodal and intermodal transportation already received considerable attention in the past decades, synchromodality is relatively new (Dong et al. 2017). Synchromodality, also referred to as "synchronized intermodality", aims to employ multiple transport modes in a flexible, dynamic way in order to induce a modal shift towards environmentally friendly transport modes (ALICE Corridors, Hubs and Synchromodality WG2 2014; Zijm and Klumpp 2016).

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A modal shift aims for relocating freight from unimodal road transport with all its possible negative impacts towards more efficient multimodal forms of transport. Most frequently, traditional modes such as railways or waterways are associated when it comes to modal shift. However, a set of new technologies are being introduced recently in an effort to enhance the transport system's efficiency and reduce environmental impacts of transport (Diana 2010). These technologies may evolve as new transport modes that could act as efficient extension to the existing transport network. For example, the most recent idea of a "Hyperloop" has frequently been called the "fifth mode of transport" besides roads, railways, waterways and airborne traffic (Werner et al. 2016). It is stated that the Hyperloop will be faster than air transport and more energy efficient than train transport (Werner et al. 2016). Considering these outstanding properties, the Hyperloop can be defined a high-performance mode with very fast and very high throughput connections.

The Hyperloop is based on an evacuated pipeline system, and this pipeline system enables the high throughput connections. A number of similar technologies have been developed lately which are also based on a pipeline system. For example, the project *Cargo sous terrain* is in preparation in Switzerland, where an underground tube with a diameter of six meters is supposed for efficient inter-city transport (Kunze 2016). Likewise, the German *Cargocap* system involves automatically controlled vehicles that transport goods in underground tubes with a diameter of 2.8 m (Heinzemann et al. 2015). Both Cargo sous terrain and Cargocap are characterized by slow transportation speeds of roughly 30 km/h. An unsuccessful example is the underground maglev system (vacuum tube train) *Swissmetro.* Swissmetro would have connected the main cities of Switzerland with speeds up to 500 km/h (Axhausen 2013). Due to a lack of support, the project went into liquidation.

The proposed new high-performance transport modes are promising developments with the potential of complementing future transport systems. In view of the European Union's plans to realize a synchromodal network, the question arises how innovative high-performance transport modes fit into the concept of synchromodality. It is the objective of the present paper to answer this question and analyze if high-performance transport modes can be integrated into synchromodal networks, taking the example of the Hyperloop.

2 The Vision of Synchromodality

There has been criticism that a high number of similar freight transport concepts have been introduced during the last 35 years (Reis 2015). Among these concepts, we find multimodality, intermodality, combined transport, co-modality and their latest development: synchromodality. While all of the concepts mentioned target sustainability and as such the achievement of a modal shift, synchromodality stands out as it does have some important distinguishing factors (Reis 2015). Essentially, synchromodality allows for informed and flexible planning based on actual circumstances (Behdani et al. 2016). The aim is to take mode and routing decisions as late as possible in the transport planning process with the result that real-time information can be used to respond to potential incidents, e.g. bad weather conditions, strikes or congestion (ALICE Corridors, Hubs and Synchromodality WG2 2014). These last minute changes to the transportation plan are called "switching" (van Riessen et al. 2015). The possibility of switching functions as a back-up system that ensures high reliability in the transport chain.

Within the synchromodal network, the flexible planning is coordinated by a central network orchestrator, which could be one actor or an ICT platform (Buiel et al. 2015). The orchestrator matches the actual demand and supply of transport and offers integrated services. Here, information exchange between shippers, carriers and the network orchestrator is a crucial issue. Flexible, shared and comprehensive ICT platforms are needed to handle the required information (Tavasszy et al. 2015). Although this might seem complex, the implementation of such a platform has become realistic due to the rapid development of information systems in transport and logistics (ALICE Corridors, Hubs and Synchromodality WG2 2014).

From the shippers' point of view, the most elementary change in the organization of transport is the so-called "a-modal booking", or "mode-free booking". This means that when booking the transport service, the mode of transport is not yet fixed (Tavasszy et al. 2015). Instead, shippers only determine the basic requirements toward the transport service, such as costs, preferred time windows or sustainability aspects. A-modal booking is a key requirement to enable the network orchestrator to optimize and bundle the transports of all the clients. Thus, synchromodality facilitates high capacity utilization and efficiency in the network.

3 Hyperloop as a Fifth Transport Mode

Hyperloop is a novel technology for transporting goods and passengers at near supersonic speed. The idea was first presented in 2013 by Elon Musk, founder of PayPal, Tesla Motors and SpaceX (Taylor et al. 2016). As common transport modes tend to be either relatively slow or expensive, the Hyperloop seeks to offer a fast and economic "fifth" alternative besides roads, railways, waterways and airborne traffic (Werner et al. 2016). It competes particularly with high-speed rail and air transport, but the Hyperloop system is claimed to be superior regarding travel time, transport costs, energy consumption, and transport safety (van Goeverden et al. 2017). Hyperloop is a theoretical concept that has passed the conceptual stage (Werner et al. 2016). A working prototype has already been successfully tested in the Arizona desert by the company Hyperloop One. Hyperloop One plans to launch the first freight service by 2019 and to carry commercial passengers by 2021 (Gautier 2017).

The Hyperloop system works with evacuated steel tubes providing near-vacuum conditions. Inside these tubes, specific bullet-shaped capsules (so-called pods) are hovering with a speed up to 1,220 km/h between the stations. Two types of pods have been developed, one for passengers and one freight (Musk2013). The pods are propelled and levitated by a combination of permanent and electro-magnets (Decker et al. 2017). Pylons, which are placed every 30 m on average (depending on the local conditions), support the tubes (Musk 2013). It is planned that the Hyperloop will be completely powered by solar energy and it is assumed that most routes would be two to three times more energy efficient compared with air transport (Taylor et al. 2016).

A crucial factor for introducing the Hyperloop technology is definitely investment costs. The route from San Francisco to Los Angeles was the first one being proposed as a pilot corridor, which represents a distance of 560 km. Assumptions about investment costs for this corridor are highly varying. According to Musk (2013), the investment costs account for approximately € 5.3 billion whereas Hyperloop Transportation Technologies (2014) stated a best case scenario of € 6 billion and a worst case scenario of € 16 billion costs for the same relation.

Van Goeverden et al. (2017) evaluated various aspects of the performance of the Hyperloop system compared with high-speed rail and air transport. The authors concluded that the Hyperloop "has a relatively strong performance on the social and environmental performance criteria, in particular energy consumption, GHG emissions and noise" (van Goeverden et al. 2017). Further, the Hyperloop can potentially be a very safe transport mode. As major weakness of the Hyperloop technology, van Goeverden et al. (2017) determined the low capacity of the small pods, which diminishes the operational and financial performance of this new transport mode.

As mentioned above, two full-scale test tubes have already been constructed in order to test the technical features of Hyperloop in real life situations (Gautier 2017). A competition invited engineers all over the world to develop efficient pods to be tested in the pilot tubes. DP World as one of the world's largest port operators is assessing the possibility of using Hyperloop technology at Jebel Ali Port in Dubai. Their intention is to move containers from ships docked at the port to an inland container depot in Dubai which is 29 km away (Oxborrow 2016).

4 Integrating the Hyperloop into Synchromodal Networks

As the preceding chapters provided a succinct introduction of the concept of synchromodality as well as the Hyperloop system, the following paragraphs will describe how these two innovative visions go together. As will be shown there is a synergy when introducing both concepts together, which is also illustrated in Fig. 1.

The outstanding energy efficiency promised by the developers of the Hyperloop system indicates that this new transport mode might entirely comply with the objective of synchromodality to facilitate a modal shift towards environmentally friendly transport modes.

Due to the high speed provided, the Hyperloop is further capable to support the provision of a reliable back-up function within the synchromodal network. As last minute changes to the transportation plan (switching) are possible in the synchromodal network, fast and agile transport modes are needed to fulfill the reliability objectives in case of real-time switching. The Hyperloop presents a solution for that, though its applicability is restricted to specific types of cargo due to the limited capacity (for instance palletized goods or high-value goods).

As pointed out by van Goeverden et al. (2017), the limited capacity of the Hyperloop system is a potential obstacle for using the Hyperloop for transportation purposes. van

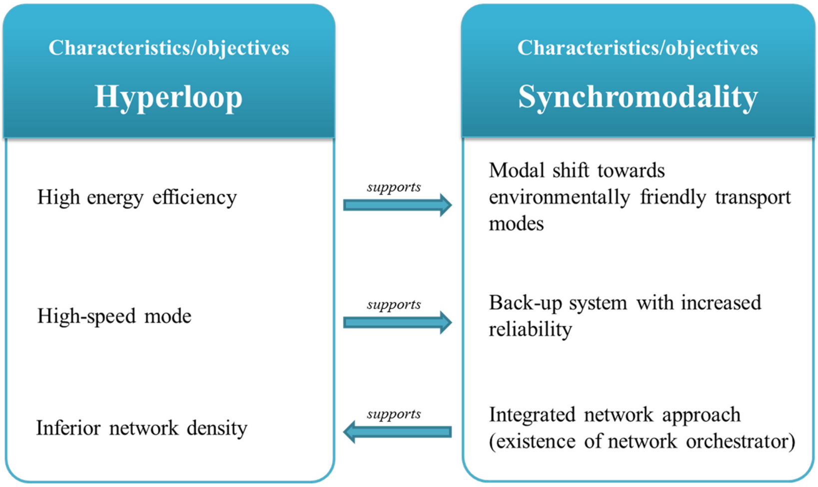

Fig. 1. Mutual benefits of integrating the Hyperloop into synchromodal networks

Goeverden et al. assume that Hyperloop applications might be limited to a "premium transport market" where there is a willingness to pay for the distinct value of Hyperloop transports, namely the high average speed provided. In a synchromodal network, this premium transport market could be characterized by those incidents and occurrences where a real-time switching is required. As an example, imagine a situation where the preferred sustainable transport mode inland waterway might not work due to bad weather conditions and there might already be a critical delay. In this case, switching to the Hyperloop could represent a reasonable solution as the Hyperloop is supposed to be immune to weather conditions (Musk 2013) and has the potential to make up for the delay.

One major drawback of the Hyperloop technology is that the network density will be expectedly inferior due to the high investment costs of constructing an Hyperloop. This means that the Hyperloop will be dependent on efficient first- and last-mile transportation with other modes of transport to provide a reliable transport service. It can be concluded that the Hyperloop system would benefit from being included into a synchromodal network since the network orchestrator provides integrated door-to-door transport solutions for the customers (Buiel et al. 2015).

5 Conclusion

The European Union encourages alternative transport solutions that contribute to greening and optimizing the transport sector (European Commission 2011). In particular, they want to develop "freight corridors optimised in terms of energy use and emissions, minimising environmental impacts, but also attractive for their reliability, limited congestion and low operating and administrative costs" (European Commission 2011). We introduced the Hyperloop as an example for so-called "high-performance transport modes" which provide a possible solution for the above described requirements set by the European Union.

At the moment, the Hyperloop technology, and also a number of other suggested high-performance transport modes are still in their infancy and there exist many unresolved questions and uncertainties that need further explanation. The Hyperloop has been taken as an example for a high-performance transport mode in this paper, but some of the conclusions also apply for similar high-performance transport technologies that are currently under development (e.g., Cargo Sous Terrain, CargoCap, ET3 - Evacuated Tube Transport Technologies or high-speed rail). It has been suggested that these technologies comprise a high potential to effectively complement future, synchromodal transportation systems, as for example their high speed and/or high throughput connections provide a relevant back-up function for the medium and long haul. There exist mutual benefits when implementing the Hyperloop technology together with synchromodal networks. Future research may analyze the characteristics of other high-performance transport technologies and elaborate some general criteria that fit to all of these technologies. It remains to be seen if the prototypes that are currently launched will demonstrate practical feasibility of the technology, such that the fifth transport mode will be available soon.

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Supplier Selection and Order Allocation with Intermodal Transportation Cost

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Abstract. In this paper, a mixed integer non-linear program (MINLP) is proposed for the single item supplier selection, economic lot-sizing, and order allocation problem considering inventory holding, ordering, transportation, and item cost under quantity discount. The proposed MINLP determines the optimal economic lot-size, the allocation of order quantities among suppliers, and the number of trucks. In the proposed MINLP model lead time, the capacity of the supplier and truck, and demand of the product are incorporated as constraints. In order to understand the effect of transportation cost in the selection of suppliers and allocation of order quantities, the model is solved twice with and without the transportation cost function. Finally, the MINLP is solved in AIMMS (Advanced Interactive Multidimensional Modeling System) using its outer approximation algorithm to select the best supplier, to determine the economic lot-size, the corresponding order quantities and number of trucks needed to meet the demand.

Keywords: Supplier selection · Economic lot-sizing · Order allocation
Mixed integer non-linear programming

1 Introduction

In today's very competitive global market, companies strive to optimize their business functions and the entire supply chain. Sourcing decision or supplier selection is one supply chain function which plays an important role in achieving organizational competitiveness since raw material and component parts constitute the major cost of the product in some cases up to 70% (Ghodsypour and Brien 1998). Because of the challenges buyers face, the supplier selection problem has gained wide attention both from practitioners in industries and academicians. The supplier selection decision includes the selection of the right supplier(s) and the order quantities among the

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selected suppliers (Weber and Current 1993). However, recently, researchers do also integrate the carrier selection decision as part of the supplier selection problem (Liao and Rittscher 2007). The holistic approach of determining which supplier(s) be selected, how much should be ordered from the selected supplier(s), and which carrier should be used for transportation helped to avoid a suboptimal solution which might result from solving the three decisions independently (Choudhary and Shankar 2013; Mendoza and Ventura 2009). Moreover, the supplier selection problem could also be made to include the decision of the economic lot-size (economic order quantity), which is the amount of order at a time, when inventory costs are included in the cost function. However, only a few papers do consider the integrated decision of lot-sizing in the supplier selection decision (Pazhani et al. 2016). According to Ghodsypour and Brien (1998), there are two types of supplier selection problems: single sourcing and multiple sourcing suppliers selection problems. In the single sourcing, the supplier can satisfy the demand of the buyer in terms of quantity, delivery speed, and quality. Whereas, in the case of the multiple sourcing, no single supplier can fulfill the demand in terms of all the buyer's requirement. In this case, the buyer has to make a decision in selecting suppliers and allocate orders among them. In this paper, a MINLP model is developed for the integrated multiple sourcing problem for a single item involving, lot-sizing, order allocation, and transportation mode selection decisions. The cost function of the proposed model includes the inventory holding, ordering, transportation, and item cost, while lead time, the capacity of supplier, and truck are considered as constraints.

2 Literature Review

A considerable amount of literature is available for the multiple sourcing supplier selection and order allocation problem. Supplier selection is a typical multi-objective or a multi-criteria decision problem, where cost, quality, delivery performance, and geographic location are the most commonly used criteria (Kahraman et al. 2003; Mendoza 2007; Weber et al. 1991; Zhang and Zhang 2011). An extensive literature review for the multi-criteria supplier selection problem and proposed models to solve the problem can be found in (De Boer et al. 2001; Degraeve et al. 2000; Weber et al. 1991). Unlike Weber et al. (1991) and Degraeve et al. (2000), De Boer et al. (2001) review the methods used for both the final stage and the stages prior to the final stage; namely, decision methods for problem definition and formulation of criteria, for pre-qualification of suitable suppliers, and for the final choice-phase. In extending the previous review they provided a comprehensive framework for detailing the methods and models used in the supplier evaluation and selection. Since this paper is concerned with studies that integrate the supplier selection, lot-sizing, order allocation, and transportation mode selection, we will concentrate the review on these specific studies which also include quantity discounts.

Hong et al. (2005) developed a mixed integer linear program (MILP) with maximizing the revenue as an objective function while finding the optimal number of suppliers and meeting the demand of the customer. Rajan et al. (2010) also developed a MILP for the multi-product multi-supplier supplier selection problem for an agricultural equipment retailer. Ghodsypour and O'Brien (2001) formulated the sourcing problem as mixed integer non-linear programming to find the optimum number of suppliers and order quantity that minimizes the total cost of logistics. In their proposed model, the transportation cost is not explicitly modeled though it is mentioned. Karpak et al. (2001) proposed a goal programming formulation of the supplier evaluation and selection problem setting quality, cost, and delivery performance as the goals. The goal of their model is to find the right order quantity while meeting both demand and supply constraints. Narasimhan et al. (2006) formulated a multi-objective programming with minimum order size, maximum available supply, stipulated price, quality, and promised delivery-performance levels, using as criteria to evaluate the suppliers' performance. The authors recommended the use of and used AHP to generate the relative weights of the five criteria. As it is the case with others, their model determines the optimal suppliers and the optimal order quantity. Wadhwa and Ravindran (2007) also developed a multi-objective formulation of the supplier evaluation and selection problem with the objective of minimizing price, lead time, and rejection. They proposed three different solution approaches and compared the result of each approach to determine the best approach. The solution approaches used in their research are weighted objective, goal programming, and compromise programming method. Recently, Mendoza and Ventura (2013) included transportation cost in their mixed integer non-linear program formulation to determine the economic lot-size with demand and capacity of suppliers incorporated as constraints.

In these various research, the case of capacity constrained multi-sourcing, supplier selection, economic lot-sizing, and order allocation problem with intermodal freight cost has not been adequately addressed in the literature. Hence, the contribution of this research is the integration of intermodal transportation cost in modeling the supplier selection, economic lot-sizing, and order allocation problem under quantity discount.

3 Model Development

We consider the problem of selecting suppliers, determine the economic order quantity, and allocating orders among suppliers for a single item where suppliers are capacity constrained and offer an all-units quantity discount. In developing the model, the following notations are used.

Notations

Indices:

- i *the set of suppliers* $i = 1, 2, 3, \ldots, I$
- k *the set of price break points* $k = 1, 2, 3, \ldots, K$
- j *the set of alternative transportation modes* $j = 1, 2$

Parameters:

- C_{ik} the unit cost of the item from supplier i at the k^{th} discount interval
- S_i *the ordering cost of the item from supplier i*
- U_{ij} *Unit transportation cost from supplier i using transportation mode j*
- F_j *Transportation cost per full truck load per km from the intermodal terminal of transportation mode j* to the warehouse of the buyer

- B_j *distance between the destination point of transportation mode j* to the warehouse of the buyer
- CAP_i *Capacity of supplier i*
- *T Cap Truck load capacity*
- n_i *number of trucks per order required to transport* Q_i.
- L_{ij} *the lead time for acquiring the item from supplier i using transportation mode j*
- *L the maximum lead time the buyer allow for the item to be delivered*
- *D Demand for the item*
- $[q_{i,k-1}, q_{ik}]$ is the lower and upper bound k^{th} quantity offers

Decision Variables:

- Q_i *Economic Ordered Quantity*(EOQ)*of the item from supplier i*
- d_i *the total amount of the item to be purchased from supplier i*, $d_i \in [q_{i,k-1}, q_{ik}]$
- X_i *is a binary variable, its value set equal to* 1 *if supplier i is used and* 0 *otherwise*
- Y_{ik} *is a binary variable; its value set equal to* 1 *if the orered quantity is in the* k^{th}*interval; and* 0 *otherwise*
- T_{ij} *is a binary variable; its value set equal to* 1 *if transportation mode j is used to transport from supplier i; and* 0 *otherwise*

Objective Function
Minimize Cost

$$\begin{aligned} Z_1 = & \sum_{i=1}^{I}\sum_{k=1}^{K}\frac{hC_{ik}Q_i d_i X_i Y_{ik}}{2D} + \sum_{i=1}^{I} S_i r_i X_i \\ & + \sum_{i=1}^{I}\sum_{j=1}^{J}\left(n_i * B_j F_j + U_{ij}Q_i\right) r_i X_i T_{ij} \\ & + \sum_{i=1}^{I}\sum_{k=1}^{K} C_{ik} d_i X_i Y_{ik} \end{aligned} \quad (1)$$

Model constraints

$$\sum_{i=1}^{I} d_i X_i \geq D \quad (2)$$

$$d_i \leq CAP_i, \quad \forall i \quad (3)$$

$$\sum_{i=1}^{I} L_{ij} d_i T_{ij} \leq LD, \quad \forall j \quad (4)$$

$$\sum_{j=1}^{2} T_{ij} - X_i \geq 0, \quad \forall i \quad (5)$$

$$Q_i - n_i * T\,Cap \leq 0, \quad \forall i \tag{6}$$

$$q_{i,k-1} Y_k \leq d_i \leq q_{ik} Y_{ik}, \quad \forall i \tag{7}$$

$$r_i Q_i = d_i \tag{8}$$

$$X_i, Y_{ik}, and\, T_{ij} \in (0, 1) \tag{9}$$

$$n_i, Q_{i,}, d_i, r_i \in Integer \tag{10}$$

The objective (1) is to minimize cost, which includes the inventory holding, the ordering, the intermodal transportation, and the item costs respectively. The constraints considered in our model are as follows. In Eq. (2), the sum total amount ordered from each supplier should satisfy the demand of the product. In Eq. (3), the allocated order from each supplier should not exceed the periodic capacity of the supplier. In Eq. (4), the aggregate lead time, which is the sum of the product of the lead time of a supplier using transportation mode j with the allocated order to the supplier, should not exceed the product of the allowable lead time stipulated by the buyer with the demand of the product. Equation (5) restricts the selection of one of the transportation modes. Equation (6) states that the capacity of the total number of trucks used to transport the order from supplier i should be greater than or equal to the economic order quantity from the supplier. Equation (7) introduces the all units discount restriction offers of all suppliers. Equation (8) ensures that the number of orders multiplied by the EOQ from a supplier should equal the allocated order quantity to the supplier. In Eq. (9), the supplier selection, quantity discount offer interval, and the mode of transportation selection variables are binary. Equation (10), states that the number of trucks, the EOQ, the allocated order quantity, and the number of orders made to each supplier are all integer values. The next section presents a numerical example to show the applicability of the proposed model and compare the result with the result of other two methods commonly used in practice.

4 Numerical Illustration

In this section, a numerical example is presented to demonstrate the applicability and effectiveness of the proposed model for selecting suppliers and determining the economic order quantity, total order quantity, and the number of trucks. The following tables provide the data used in the numerical illustration. In case of international suppliers being selected to supply the item, trucks are used to transport the item from either of the destination of the ports. The distance from the seaport and the airport to the central warehouse of the buyer is 884 km and 50 km respectively, with transportation cost per truck per km at 40 Birr (Ethiopian currency) for all distances greater than 100 km and 100 Birr otherwise (Table 1).

Table 1. Input parameters

		Discount offers		Unit transportation cost			
		Lower bound	Upper bound	Unit cost	Sea	Air	Setup cost
Suppliers	1	0	20	16.9			1,000
		21	60	16.4			
	2	0	15	8.98	0.41	6.53	5,000
		16	45	8.5			
	3	0	25	12.62	0.84	9.37	5,000
		26	80	12			
	Demand	130					

The results in Table 2 show the optimal lot-size and the order quantities when considering the inter-modal transportation cost is (60, 0, and 70) from supplier 1, 2, and 3 respectively. If the decision maker is to use the least unit cost approach without considering inventory, setup, and transportation costs in his supplier selection and order allocation process, the optimal value would have been (5, 45, and 80). That is, in the least unit cost approach, the decision maker first allocates the order quantity up to the capacity of the supplier, then the left over will be assigned to the next least unit cost supplier up until the demand is met. Comparing the result of the proposed model (Table 2) and the least unit cost approach (Table 3), the optimal values from the proposed model could save 20,264.15 Birr. Consequently, there is a significant saving when using the proposed model.

Table 2. Optimal values using proposed model

Suppliers	1	2	3
EOQ	60	0	70
Order quantity	60	0	70
No. of orders	1	0	1
No. of trucks	0	0	3
Total cost	23,593.4		

Table 3. Optimal values using the least unit cost approach

Suppliers	1	2	3
EOQ	5	45	80
Order quantity	5	0	70
No. of orders	1	45	1
No. of trucks	0	2	4
Total cost	43,857.6		

In addition to performing a comparison between the least unit cost method and the proposed method, we also solved the problem without incorporating the inter-modal transportation cost to see the effect on the supplier selection and order allocation decision. Table 4 presents the results obtained by solving the problem without the consideration of the transportation cost function. The result shows that both the EOQ and the order quantities from supplier 1, 2, and 3 respectively are (50, 0, and 80) with the corresponding total cost of 7,893.27. However, since the optimal values are obtained by excluding the transportation cost function, the actual cost including the transportation at these optimal values is 28,643.08. This clearly shows that the consideration of the transportation cost in the supplier selection and order allocation could have an impact on the both selection and order allocation decisions. Table 5 presents a comparison of the costs obtained using the proposed model with and without transportation cost function and the least unit cost approach.

Table 4. Optimal values without incorporating the transportation cost function

Suppliers	1	2	3
EOQ	50	0	80
Order quantity	50	0	80
No. of orders	1	0	1
Total cost	7,893.3		

Table 5. Cost comparison of the different methods

	Proposed model		
	With transportation cost model	Without transportation cost model	Least unit cost approach
Inventory cost	113.31	113.27	92.64
Ordering cost	6000	6000	11000
Transportation cost	15656.09	20749.82	31337.91
Item cost	1824	1780	1427
Total cost	23,593.4	28,643.1	43,857.6

5 Conclusion

The selection of suppliers, lot-sizing, and allocation of orders among the selected suppliers is an important logistic function for buyers. The problem becomes more difficult when suppliers offer discount and transportation costs are included in the selection problem. The main contribution of this paper is the incorporation of the inter-modal transportation cost for determining the best supplier, the economic order quantity, and the total order quantity among suppliers. Our proposed model incorporates and investigates the impact of the inter-modal transportation cost in the supplier selection and order allocation process. The numerical results show that the modeling and consideration of the inter-modal transportation cost are essential as it has an impact on the selection and allocation decision. The model of this paper has the potential to be expanded to include multiple items and the case of dynamic demand. Moreover, future research may also consider the case of multiple products, multiple sourcing, and multiple warehouses under all-units quantity discount or other types of discount environment such as incremental or business volume discount.

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Mathematical Modeling for Integrating Production-Routing-Inventory Perishable Goods: A Case Study of Blood Products in Iranian Hospitals

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Abstract. In this study, a robust mathematical model for the integrated problem of production, inventory, and routing of uncertain perishable goods is presented in a network including a producer and a group of retailers in which transfer among retailers is for controlling the uncertainty of customer demands. Since the mentioned problem is NP-Hard, an innovative solution algorithm is suggested for it that leads us to the best solution with the best change in the vehicle routes in every stage of search. Finally, the suggested algorithm is done on the available data in the literature and a real case study and the results show high efficiency of this algorithm regarding time and quality of answers.

Keywords: Integrating production · Routing-inventory · Perishable goods

1 Introduction and Literature Review

Programming production and controlling inventory of perishable goods such as foods, dairy products, drugs, and blood products is very complex due to their short life span. Loss and shortage are the main challenges of managing perishable products that the correct management of production can decrease them to a large extent, but it cannot prevent them completely (Gunpinar and Centeno 2015).

Consider a two-level production chain consisting of a producer and some retailers with the producer having the job of producing and distributing a perishable product to the retailers. Even if the producer can manage the production rate properly, there will be shortage and excess for each retailer, because the retailers' demands are random, so transferring goods from the excess state retailers to the shortage state ones can decrease system expenses in shortage, loss and transportation. For this purpose, this study aims at managing these transfers along with managing production and inventory of perishable products (Coelho and Laporte 2014).

Coelho and Laporte (2014) studied replenishment, delivery, and management of perishable goods inventory. In this study, the expenses of maintenance and the price of selling goods in different ages was not the same, so retailers could sell these goods according to: early sale of older products, early sale of fresh products, and optimized sale.

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Farahani et al. (2012); Seyedhosseini and Ghoreyshi (2014); Zu et al. (2014) used an integrated model and Chen et al. (2009) used a non-linear programming model for production timing and vehicle routing to deliver foods by taking time windows into account and considering customers' demands as a probability. The aim was determining optimized production rate, the beginning of production, and vehicle routes by maximizing the producer expected benefits.

Civelek et al. (2015) presented an innovative replenishment for blood platelets with the purpose of minimizing the expenses of maintaining inventory, loss, shortage, and replacement. They filled inventory with fresh goods in constant rates and fresh goods are maintained for future use by limiting some replacements. The results showed better functioning especially when providing platelets is restricted.

Duan and Liao (2013) presented old inventory ratio (OIR). This policy just uses information about age. In comparison with order policy without considering age and EWA policy extended by Broekmeulen and van Donselaar (2009) with regard to the limitations of maximum permitted shortage under controlling centralized and decentralized inventory, The results show that centralized control on the platelets supply chain decreases expiration rate expected by the system.

Based on the review article done by Adulyasak et al. (2015) about production-routing, no studies are done on the robust optimization of this problem. Therefore, we continue reviewing the studies done on robust inventory-routing.

Solyalı et al. (2012) modeled robust routing-inventory problem under uncertain demands using Bertsimas and Sim's method. Also, they extended branch and cutting algorithm. Huang and Lin (2010) studied multi-products routing and inventory problem under uncertain demands and expanded ant cloning algorithm to solve it. Lefever et al. (2015) studied the problem of robust inventory-routing by the time of different trip. They used simulation of Mount Karlo for improving solutions. Sokol and Papageorgiou (2015) presented a robust model and a two-stage solution-marine routing with chance trip time and time windows. The first stage was making robust routes and the next used a multi-scenario innovative construction. Also, Lowalekara and Ravi (2017) showed the application of TOC thought in blood bank environment. Dillon et al. (2017) presented a two-stage chance-programming model for managing inventory in blood supply chain.

Considering literature review, in the studies done on production management and distribution of perishable products, the producer is responsible for providing retailers' demands and in none of these studies, transfer among retailers is considered as a strategy for checking uncertain demands. Also, most of the studies done on production management and distribution of blood products have presented a replenishment policy (production) for blood center and the issue of routing to the hospitals is not taken into account (hospitals are as retailers with the job of providing patients' demands). Transfer among hospitals is just seen in Lang's study (2010) and without taking into account production, delivery routes of blood products, and simulation problems. Some studies have suggested innovations for replenishing blood products in hospitals and among them, just Hemmelmayr et al. (2009) have studied routing for distributing blood products to the hospitals. This study presents an integrated issue of production-inventory and routing. And it considers not just production and inventory management and distribution planning, but also transfer among retailers to control demand uncertainty. Presenting an innovative solution on a case study about blood transfer services in Tehran is the part added to other related studies.

2 Problem Statement and Modeling

This part presents a robust mathematical model for the integrated problem of production, inventory, and routing perishable products in a two-level supply chain including a producer and a group of retailers in a limited time span. The producer faces production restrictions in each period and should decide about the amount of production at the beginning of each period. Also, this study supposes that there is a vehicle with limited capacity that traverses a route for delivering the perishable products to a group of retailers from the producers at the beginning of each period. Since retailers face different demand scenarios, transfer among retailers and direct delivery from producers to the retailers (generally transfer) is possible after each scenario in the period. The mentioned problem is presented with three time periods and six retailers is Fig. 1. Other suppositions are: (1) Producer and retailers' inventory at the beginning of the first period is clear for each age groups. (2) Retailer's capacity is limited. (3) Maximum production is definite for each period. (4) Product age is fixed and definite. (5) FIFO policy is used for satisfying customers' demands. Then, after defining sets and indices, parameters and variables, the issue will be modeled in certain conditions. Moreover, a brief explanation of the robust conditions and finally the robust orbit of the problem under investigation will be presented.

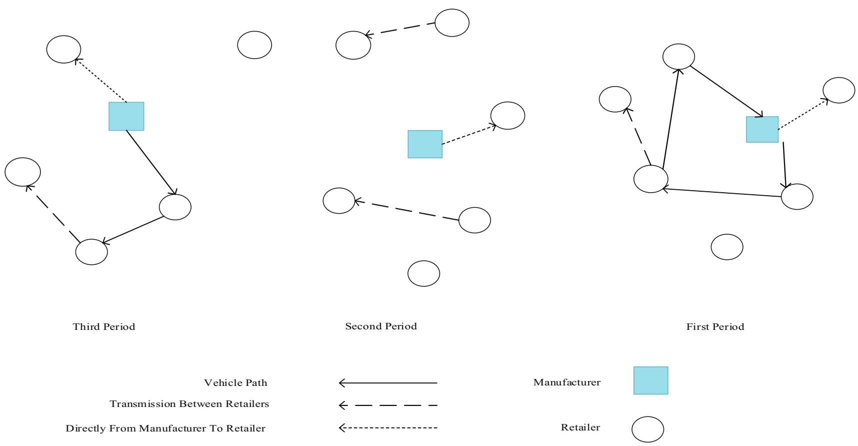

Fig. 1. Description study problem

2.1 Sets and Indices

V: Set n producer and retailer $i, j \in \{0, 1, 2, \ldots, n\}$
V': Set n retailer $i, j \in \{0, 1, 2, \ldots, n\}$
T: Set τ $t \in \{0, 1, 2, \ldots, \tau\}$

G: Set of G, H, the age of perishable products $G\ g,\ g' \in \{0,\ 1,\ 2, \ldots, H\}$
S: Set of scenario $S\ s,\ s' \in \{0,\ 1,\ 2, \ldots, \Omega\}$.

2.2 Parameters

h_i: The expense of maintenance at the nth retailer and producer
PC: Production expense for each unit of perishable product
c_{ij}: Transportation expense of vehicle between nodes i and j
b_{ij}: Transfer expense between node i and j
ω: Wight inventory for balance between (shortage expense)
BB^t: Maximum production rate in producer in period tth
de_i^t: Retailer's demand at period t
$de_i^{t,s}$: Realization under scenario S
$I_i^{0,g}$: Initial inventory of the first period with age g in ith retailer and producer
Q: Capacity of vehicle
C_i: Capacity of maintaining ith retailer
ML: Maximum loss
λ: Allocated weight to purpose function variance
p_s: Probability of scenario Sth.

2.3 Variables

$I_i^{t,g}$: Inventory level in producer and retailer with age g at the end of period t
$I_i^{t,g,s}$: Realization under scenario S
$x_{i,j}^t$: 1 if node i is visited after node j in period t, otherwise 0
$q_i^{t,g}$: The amount of perishable product delivered to retailer i with age g at period t
$w_{ij}^{t,g}$: The amount of perishable product transferred from i to j with age g at period t
$w_{ij}^{t,g,s}$: Realization under scenario S
$\delta_i^{t,s}$: Realization of perishable product demand in retailer ith under scenario S
$d_i^{t,g}$: Some of the perishable product demand in ith retailer provided from age g in period t
$d_i^{t,g,s}$: Realization under scenario S
vv_i^t: Auxiliary variable for deleting sub circle
$l_i^{t,g}$: Auxiliary variable for employing FIFO policy, 1 if a product with age g at period t is sold by retailer i, and 0 if it is not sold
$l_i^{t,g,s}$: Realization under scenario S.

2.4 Mathematical Model of the Problem in Certain Conditions

In certain conditions, producer is certain of the extent of retailers' demands and decide based on full information about production rate, delivery to the retailers, and transfer rate among retailers in a way that system expenses decrease according to the restrictions.

$$\min \sum_{i \in V} \sum_{t \in T} \sum_{g \in G} h_i I_{i,t}^g + \sum_{i \in V} \sum_{j \in V} \sum_{t \in T} c_{ij} x_{ij}^t + \sum_{i \in V} \sum_{j \in V'} \sum_{t \in T} \sum_{g \in G} b_{ij} w_{ij}^{t,g} + PC \sum_{t \in T} F^t \tag{1}$$

$$I_0^{t,g} = I_0^{t-1,g-1} - \sum_{i \in V'} q_i^{t,g} - \sum_{i \in V'} w_{0,i}^{t,g} \quad g = 2, 3, \ldots, H, \ t \in T \tag{2}$$

$$I_0^{t,g} = F^t - \sum_{i \in V'} q_i^{t,g} - \sum_{i \in V'} w_{0,i}^{t,g} \ g = 1, \ t \in T \tag{3}$$

$$I_i^{t,g} = I_i^{t-1,g-1} + q_i^{t,g} + \sum\nolimits_{j \in V} w_{j,i}^{t,g} - \sum\nolimits_{j \in V'} w_{i,j}^{t,g} - d_i^{t,g} \ i \in V', \ g = 2, 3, \ldots, H, \ t \in T \tag{4}$$

$$I_i^{t,g} = q_i^{t,g} + \sum_{j \in V} w_{j,i}^{t,g} - \sum_{j \in V'} w_{i,j}^{t,g} - d_i^{t,g} \ g = 1, \ i \in V', \ t \in T \tag{5}$$

$$\sum_{t \in T} \sum_{i \in V} I_i^{t,g} \leq ML \quad g = H \tag{6}$$

$$F^t \leq BB^t \quad t \in T \tag{7}$$

$$de_i^t = \sum_{g \in G} d_i^{t,g} \quad i \in V' \ t \in T \tag{8}$$

$$de_i^{t,g} \leq C_i l_i^{t,g} \quad i \in V' \ t \in T \ g \in G \tag{9}$$

$$l_i^{t,g-1} \leq l_i^{t,g} \quad i \in V', \ t \in T, \ g = 2, 3, \ldots, H \tag{10}$$

$$C_i(1 - l_i^{t,g-1}) \geq \sum_{g'=g} \begin{pmatrix} I_i^{t-1,g'-1} + q_i^{t,g'} + \\ \sum_{i \in V} w_{j,i}^{t,g'} - \sum_{i \in V} w_{i,j}^{t,g'} \end{pmatrix} - de_i^t + 1 \quad i \in V', \ t \in T, \ g = 2, 3, \ldots, H \tag{11}$$

$$\sum_{g \in G} I_i^{t,g} \leq C_i \quad i \in V' \ t \in T \tag{12}$$

$$q_i^{t,g} \leq C_i \sum_{j \in V} x_{i,j}^t \quad t \in T, \ i \in V', \ t \in T, \ g \in G \tag{13}$$

$$\sum_{g \in G} q_i^{t,g} \le C_i \sum_{g=1}^{H-1} I_i^{t-1,g} \quad i \in V' \; t \in T \tag{14}$$

$$\sum_{g \in G} \sum_{i \in V'} q_i^{t,g} \le Q \quad t \in T \tag{15}$$

$$\sum_{j \in V} x_{i,j}^t = \sum_{j \in V} x_{ji}^t \quad t \in T, \; i \in V' \tag{16}$$

$$vv_i^t - vv_j^t + Qx_{ij}^t \le Q - \sum_{g \in G} q_J^{t,g} \quad t \in T, \; j \in V' \tag{17}$$

$$\sum_{g \in G} q_J^{t,g} \le vv_i^t \le Q \quad i \in V' \tag{18}$$

$$\sum_{i \in V} x_{i,0}^t \quad t \in T \tag{19}$$

$$x_{ij}^t \in \{0, 1\} \quad i, j \in V \; i \ne j, \; t \in T \tag{20}$$

$$I_i^{t,g} \ge 0 \quad t \in T, \; g \in G, \; i \in V \tag{21}$$

$$w_{ij}^{t,g} \ge 0 \quad t \in T, \; g \in G, \; i \in V, \; j \in V' \tag{22}$$

$$d_i^{t,g} \ge 0 \quad t \in T, \; g \in G, \; i \in V' \tag{23}$$

$$vv_i^t \ge 0 \quad t \in T \tag{24}$$

$$F^t \ge 0 \quad t \in T \tag{25}$$

$$q_i^{t,g} \ge 0 \quad t \in T, \; g \in G, \; i \in V' \tag{26}$$

Purpose function (1) decreases inventory, routing, transfer and production expenses. Restriction 2 updates producer inventory level for age 2 and above. While restriction 3 shows producer inventory level for age 1 and above and t is based on production rate. Restrictions 4 and 5 indicate retailers' inventory level for age 2 and above and age 1 and above respectively. Restriction 6 restricts the number of losses, and restriction 7 shows production restriction. Restriction 8 states that demand can be provided by products with different ages. Restrictions 9 to 11 are used for applying FIFO policy to provide retailers' demands. Restriction 9 states that when the demand of a product with age g is satisfied, the auxiliary variables related to it $\left(l_i^{t,g}\right)$ will be 1, and restriction 10 states that auxiliary variable related to age $g - 1$ will be 1 only if the auxiliary variable related to product g is 1. In other words, inventory of product age $g - 1$ is used for satisfying demands when inventory of product age g is not enough for satisfying demand. Finally, restriction 11 is used for preventing the auxiliary variables to be 1 and states that if available inventory of product age g and above is enough for satisfying demands, the inventory of age $g - 1$ should not be used for satisfying demands (right side positive restriction makes the auxiliary variable of product age $g - 1$ zero). Restriction 12 states the restriction of retailers' capacity for keeping perishable products. Restriction 13 states that in the case of visiting retailers, the vehicle will deliver the product to them and restriction 14 restricts delivery rate to the capacity available to the retailers. Restriction 15 shows the restriction of vehicle capacity. Restriction 16 is the restriction of forming circle and restrictions 17, 18 are the restriction of deleting sub circle. Restriction 19 states that a vehicle is available. Restriction 20, 26 show the kind of variables.

2.5 Case Study

In this study, distributing platelets from Tehran blood center to 70 social security hospitals is studied. Expenses such as transportation, maintenance and production are based on real data. Also, data such as demand, inventory of the beginning of the first period, production rate maximum, vehicle capacity, and hospitals are produced according to the capacity of beds in hospitals and it is explained in the following part:

- Vehicle capacity: 35% of the sum of the number of beds in hospitals.
- Capacity of each hospital: 70% of hospital beds capacity.
- Demand of each hospital: 4% to 8% of hospital beds capacity for the first scenario, 10% to 14% of hospital beds capacity for the second scenario, 16% to 20% of hospital beds capacity for the third scenario, which are chosen randomly.
- Maximum Production: between 8 to 20% of the sum of hospital beds capacity chosen randomly.
- Inventory of the period beginning in blood center: between 5 to 10% of hospital beds capacity chosen randomly in a way that inventory from the age group 3 is 8% of the total inventory and from group age 2 is 2% of the total inventory.
- Inventory of the period beginning in blood center: between 5 to 10% of hospital beds capacity chosen randomly in a way that inventory from the age group 3 is 6% of the total inventory and from group age 2 is 4% of the total inventory.

2.6 Results

In this part, for evaluating model function in terms of time, solution quality, a case study on distributing platelets from Tehran blood center was used. In addition, we can use this case study about producers of other perishable products such as Pegah, Amol, etc. Companies to investigate the problem. In addition, algorithm is run on a set of data about inventory – routing problem with transfer and the policy of replenishing orders. For solving the robust model exactly, current network problem, the first and the second local search models of GAMS 24.1 software are used with CPLEX Solver 12.6. All computations are run in a computer system with processor having features core I5, 2.6 GHz and 6 GB RAM (Fig. 2).

Regarding what is mentioned above, this part compares the expenses, inventory, production rate, shortage rate, and loss rate in 2 states of transfer and non-transfer among 70 hospitals. Therefore, the shortage expense is 70000 Toman (Iran's currency). As Figs. 3, 4 show, expenses and shortage rate in the permitted state of transfer are less than those in the forbidden state. Also the results show that the loss rate is the same in two states and has not exceeded the maximum planned loss, in other words, transfers have not decreased losses and applying FIFO policy for consumption and optimization policy for non-loss production in all time periods except period 1 is investigated in 2 states (Tables 1, 2, 3 and 4).

Table 1. Results obtained from solving the presented problem for 10 hospitals

Shortage expense	Upper limit	Lower limit	Time	Improvement percentage
10000	10498915	10498915	6	0.00
20000	19407783.8	19268563.2	1800	−0.72
30000	23176596.5	22822872.2	1800	−1.53
40000	25297174.8	24902265.6	1800	−1.56
50000	27256975.5	26922317.8	1800	−1.23
60000	2926719.1	28895692.6	1800	−1.27
70000	30741983.9	30102944.1	1800	−2.08
80000	31504630.4	30938759.4	1800	−1.08
90000	32172909.9	31686411.1	1800	−1.51
100000	33043059.9	32342479.4	1800	−2.12

Table 2. Results obtained from solving the presented problem for 30 hospitals

Shortage expense	Upper limit	Lower limit	Time	Improvement percentage
10000	58310450	55862433	3600	−4.38
20000	356163891.5	101107520.9	3600	−252.26
30000	413980891.5	114479711.2	3600	−261.62
40000	471797891.5	125076176.1	3600	277.21
50000	529614891.5	13564716.4	3600	−290.43
60000	587431891.5	144509195.7	3600	−306.50
70000	645248891.5	147901701.2	3600	−336.27
80000	703065891.5	147983004	3600	−375.10
90000	760882891.5	148014915.1	3600	−414.06
100000	818699891.5	148005079.9	3600	−453.16

Table 3. Results obtained from solving the presented problem for 70 hospitals

Shortage expense	Upper limit	Lower limit	Time	Improvement percentage
10000	30245611	30119610.4	1800	−0.42
20000	58109010.9	55504800.5	1800	−4.69
30000	75717901.5	64322108.8	1800	−17.72
40000	84112509.7	69621019.4	1800	20.81
50000	100443380	75016819.4	1800	−33.89
60000	102762642	79922062.1	1800	−28.58
70000	96960051.7	82784377.1	1800	−17.12
80000	97981519.1	846591166.8	1800	−15.74
90000	112373605	86650124.4	1800	−29.69
100000	104332262.8	88614925.2	1800	−17.74

Table 4. Results obtained from solving the presented

Shortage expense	Upper limit	Lower limit	Time	Improvement percentage
10	26236722.1	25838122	1620.60	−1.54
20	50393762.5	48533183.6	1642.9	−3.83
30	86303849.4	71721501.4	1800	−20.33
40	116726432.9	89769065.6	3600	−30.03
50	353676986.1	100813206.4	3600	−250.82
60	441841206.6	113310995.3	3600	−289.94
70	534519747.4	126858725.3	3600	−321.35

Table 5. Comparison between results of the innovative algorithm and ALNS algorithm on IRPT-ML

Problem size	Suggested algorithm		Ivanov and Rozhkov approach		Improvement percent
	Answer	Time	Answer	Time	
10	403.42	5.18	403.42	2.27	0
20	1547.29	15.37	1547.29	8.75	0
30	1831	31.82	1830.64	16.21	0.02
40	1999.05	52.68	1999.05	26.88	0
50	2482.82	77.15	2481.82	29.37	0.04
60	3238.33	137.53	3206.33	35.21	0.99
70	3304.26	260.65	3252.92	14.46	1.55

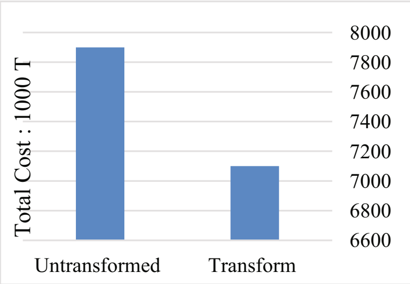

Fig. 2. Comparing total expense in transfer and non-transfer state among retailers

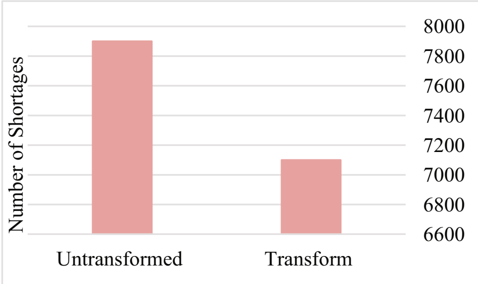

Fig. 3. Comparing shortage amount in transfer and non-transfer state among retailers

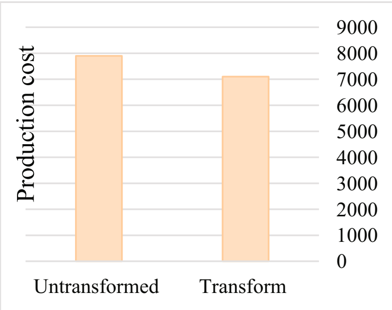

Fig. 4. Comparing production rate in transfer and non-transfer state among retailers

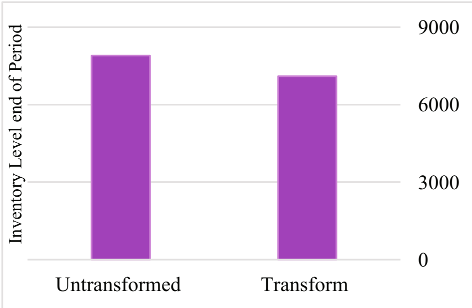

Fig. 5. Comparing inventory level of the end of first period in transfer and non-transfer state among retailers

According to Fig. 5, production rate is more in non-transfer state among retailers. In other words, a retailer facing extra products can transfer product to a retailer facing shortage and prevents extra production and expense. In addition, the inventory level of the period end is more in producer and retailers in non-transfer state that causes more expenses of maintaining inventory (Fig. 5). According to the mentioned cases, transfer among retailers decreases extra expenses, total expenses, and shortage in retailers. A comparison of the results obtained from innovative algorithm and previous research such as Ivanov and Rozhkov (2017) on these examples is provided in Table 5. As you see in this table, most of the answers obtained by suggested algorithm are improved (improvement percent in the last column is calculated as the difference between the answer obtained by the suggested model divided by the answer of Ivanov and Rozhkov (2017) algorithm multiplied by 100), especially when the duration for solving suggested algorithm is less than the duration for solving Ivanov and Rozhkov's algorithm.

3 Conclusion

In this study, the integrated mathematical problem of production-inventory and routing was studied under the uncertainty of demand for perishable goods in a network including a producer, and groups of retailers. This study takes into account not only production management, but also inventory and distribution planning, FIFO policy for retailers' consumption, and transfer among retailers for the purpose of controlling the uncertainty of customers' demands. The function of suggested problem on a case study was studied about the blood transfer services in Tehran. Since the duration of solution by the exact algorithm of branch and limit was high for the case study and the answers were undesirable. Also, the suggested model was run on the available data in the literature and reached to the conclusion that the suggested algorithm is more efficient regarding duration and quality of answers. Then, there was a comparison between the two states of transfer and non-transfer production, shortage, inventory, and expenses. In addition the results obtained from innovative algorithm compared with previous research such as Ivanov and Rozhkov (2017) demonstrated that most of the answers obtained by suggested algorithm are developed especially in terms of duration for solving the problem.

Regarding the mentioned innovation of this study in the second part, this study can be expanded by considering the transfer of non-consumed products to the producers from the retailers, the routes of transfer among retailers in a time span and the time for delivering the perishable food to the retailers.

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Maritime Logistics

Improving Logistics Efficiency in Offshore Wind Farms Construction

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Abstract. The increasing construction of offshore wind farms and their expected improved profitability call for a better efficiency in offshore logistics. Based on some existing principles from optimizing production techniques, this paper proposes an *ad hoc* model to measure and improve efficiency for logistics during offshore wind farms construction.

Keywords: Offshore wind construction · Offshore logistics Offshore Logistics Efficiency · Continuous improvement

1 Introduction

Main challenge for the offshore wind industry is profitability. The Levelized Cost Of Electricity (LCOE) is an indicator for the profitability or the competitiveness of an energy source. LCOE corresponds to the sum of expenses divided by electrical energy produced over lifetime of the plant. For offshore wind, it used to be substantially higher (0.13 $/kWh median) than the other common energy sources: onshore wind (0.07 $/kWh median), hydropower (0.07 $/kWh median), biopower (0.08 $/kWh median), natural gas combined cycle (0.05 $/kWh median), coal (0.07 $/kWh median) and nuclear (0.08 $/kWh median) (National Renewable Energy Laboratory 2015). According to Poulsen and Bay Hasager (2016), logistics may conservatively amount to 18% of LCOE for offshore wind farms. According to Myhr *et al.* (2014), depending on type of bottom-fixed turbines considered, installation of wind turbine could represent between 7 and 9% of LCOE cost breakdown over life cycle. Offshore wind industry sees a need to improve such part of life cycle costs by optimizing installation techniques and planning with improved planning and logistics tools, new organizational and management tools as well as innovative business models (Megavind 2010). Moreover, a high number of offshore wind farms are under construction in the world (2.56 GW in 2016) or in pre-construction (8.13 GW in 2016) (4C Offshore 2016). Furthermore, increasing distances from the coast (Poulsen and Bay Hasager 2016) and rising sizes of wind turbines (Berger 2016) are making the subject even more relevant.

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We see a need that researchers and practitioners investigate deeper on how to optimize logistics during offshore wind turbine installation in particular. If this objective can be reached, the wind turbine providers could potentially improve their installation costs and achieve better LCOE.

2 Offshore Logistics Efficiency

For the particular case of offshore wind farms construction, a specific definition for offshore logistics is proposed: main vessel(s) that transport and install wind turbine components between base port and wind farm location and support vessels that transport material and technicians to complete wind turbine construction.

In order to measure efficiency, it is necessary to measure it at the bottleneck of the process. Goldratt and Cox (2016) define bottleneck as any resource whose capacity is equal to or less than the demand placed upon it. During installation phase, floating cranes and installation vessels are only available to a limited extent and might be the bottleneck resources (Lange *et al*. 2012). However, bottlenecks identification in offshore wind construction process need further research.

Lambert (2008) explains that in order to be proactive, triggers and signals must identify tasks that were not performed as planned. This implies to have a measurement system of the performance in place during execution.

Overall equipment effectiveness (OEE) concept has been elaborated by Seiichi Nakajima to evaluate how effectively a manufacturing operation is utilized (Hansen 2005). This is part of the Total Productive Maintenance (TPM) (Nakajima 1982) system and nowadays broadly applied in manufacturing sector, such as automotive industry.

OEE is the ratio of the Valuable Operating Time to Planned Production Time:

$$OEE = \frac{ValuableOperatingTime}{PlannedProductionTime} \quad (1)$$

Valuable Operating Time corresponds to manufacturing only good parts at the maximum theoretical speed with no downtimes.

However, monitoring only OEE is not sufficient to understand what can be the possible wastes or losses in the production. In order to analyze deeper, effectiveness losses have been divided in three categories: downtime losses (breakdowns and product changeover), speed losses (running at reduced speed and minor stops), and defect losses (defects in process and reduced yield). It can be noted that schedule losses are not included. This is a strategic and planning matter and hence not considered in effectiveness losses.

Moreover, in particular case of offshore logistics, unlike the manufacturing sector, defect losses may not be considered relevant; it is then suggested to focus on downtime and speed losses of the logistics spread, in particular during planned operations. These inefficiencies are crucial to evaluate as when such waste occurs, it does not only impact vessel spread chartering costs, but also directly resources associated with the vessel spread (i.e. technicians, material, bunker…) and other dependant activities on the critical path (i.e. base port, chain of activities related to commissioning and trial test). Such inefficiencies impact on overall project is also a vital indication for decision making during construction of the wind farm. As the industry is still young, it consequently lacks such evaluation and does not use a recognized methodology to actively measure and monitor efficiency offshore. In order to close this gap, this paper proposes an *ad hoc* Offshore Logistics Efficiency (OLE) measurement model (Fig. 1).

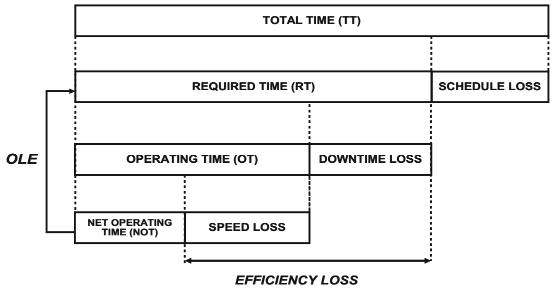

Fig. 1. Proposed OLE measurement model for offshore logistics

Unit to be used for Total Time (TT), Required Time (RT), Schedule Loss, Operating Time (OT), Downtime Loss, Net Operating Time (NOT) and Speed Loss is time unit. Offshore Logistics Efficiency (OLE) is unit less or can be expressed in percent.

Total Time (TT) is the period duration to be analyzed. TT can be as short as one weather window and up to the total cumulated project duration.

Schedule Loss is the time when the equipment is not used per the plan, as example: if the vessel is planned to work on a 10 h shift per day, there is 14 h of Schedule Loss for this day.

Required Time (RT) is the difference between TT and Schedule Loss. This is in most cases a matter of planning.

Downtimes Losses are events that stop operations, as example: lifting equipment break down, engine breakdown, electrical failure…

Operating Time (OT) is the difference between RT and Downtime Loss.

Speed Losses are situations that prevent operations to reach reference pace, as example: longer time than expected to torque a component (5 h instead of expected 3 h, in that case, there are 2 h of Speed Loss).

Net Operating Time (NOT) is the difference between OT and Speed Loss.

Proposed Offshore Logistics Efficiency (OLE) performance indicator is the ratio between the Net Operating Time and Required Time:

$$OLE = \frac{Net\ Operating\ Time}{Required\ Time} = \frac{Required\ Time - Downtime\ Loss - Speed\ Loss}{Required\ Time} \quad (2)$$

The higher are Downtime and Speed Losses, the lower NOT is, hence, the lower efficiency is. The lower are Downtimes and Speed Losses, the higher NOT is, hence, the higher efficiency is. An OLE ratio of 100% would be considered perfect efficiency. For installation vessel, if we consider a reference pace of 0.60 turbine installed per day, preliminary studies estimate that OLE can be as low as 30%, waiting on weather contributing up to 75% to Losses.

For support vessels, if we consider an ideal number of 12 technicians transfers every 2 h between vessel and turbine, OLE range can vary between a few percents and 80%, depending on type of vessel and season. Again, main contributor to Losses is usually waiting on weather.

3 Improving Offshore Logistics Efficiency

When offshore logistics efficiency performance indicator and related measurement system are defined, inefficiencies can be identified and tracked: intent is to consistently measure Downtimes and Speed Losses activities in order to find inefficiencies root causes, eliminate them and then tend to maximize NOT. Practically, it is suggested to collect information from Daily Progress Reports (DPR) which are broadly used in offshore wind industry. DPR are usually covering 24 h per day. It is proposed to fill them in using predefined sections in accordance with model presented in Fig. 1. It is recommended to also add at least a comment area to give some chance to express issues directly from the field. A technical tool is necessary to collect automatically DPR information. The tool should be able to sum-up the different type of inefficiencies on a selected period and sort them in Pareto graphs. Pareto states that, for most of the time, roughly 80% of the effects come from 20% of the causes. Main causes of inefficiencies can be prioritized and associated corrective or preventive actions can be implemented according to the Pareto order. Plan, Do, Check, Act (PDCA) or Deming Circle concept (1986) can be applied to control and implement continuous improvement of the processes. This improvement process can provide results only if properly animated and managed by appropriate personnel at a suitable frequency. It is proposed to fill-in DPR and review the quality of data from the field on a daily basis. This can be taken care of by a responsible on the offshore vessel and reviewed by a measurement responsible in the back office. It is then suggested to review on a weekly basis results using technical tool that collects data with personnel from the field and back office responsible of the operations. The purpose would be to review the most important inefficiencies of the week and identify actions to reduce the inefficiencies. Moreover, review of actions in progress and their results is necessary. Finally, on a monthly basis, a review at higher management level should be conducted to support the process, present improvements and agree on targets.

4 Conclusion

Based on some existing principles from optimizing production techniques, this paper consequently suggests an *ad hoc* model to measure offshore logistics efficiency during offshore wind farms construction and a way to calculate it (Eq. 2). First assessment foreshadows there is room to improve installation and support vessels efficiency. Offshore Logistics Efficiency performance indicator needs to be monitored and a system for continuous improvement has to be implemented.

A continued research agenda should consequently have the following ingredients:

– Identify more closely bottlenecks during offshore wind farms construction.
– Propose a tool to automatically collect relevant information to identify inefficiencies and sort them to find improvement actions.
– Apply this proposed model on a case study, evaluate the impact of the different inefficiencies and propose some actions for further improvement in the offshore wind industry construction.
– Conduct sensitivity analysis in order to evaluate the confidence in the model and results founds.

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Integrating Ship Scheduling and Berth Allocation for Container Seaports with Channel Access

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Abstract. In this talk we discuss the discrete berth allocation problem under channel access restrictions given by a river or sea gate through which calling vessels have to transit. We further outline an optimization concept for scheduling vessel movements in the channel related with the well known flowshop machine scheduling problem.

1 Introduction

Shipping channels are often a constraint to port capacity due to the significant capital cost and environmental impact of channel dredging. Capacity impacts of channel operations are most significant in tidally restricted ports, where deep draft vessels are only able to move through the channel during narrow windows around high-tide in order to maintain sufficient under-keel clearance. Channels are often narrow which constrains the capability of vessels passing in opposing directions. There has been much research to-date around berth allocation and sequencing, but in channel constrained ports the value of existing approaches can be limited.

In this paper we present an approach to optimize the scheduling of channel movements and furthermore, to integrate the channel scheduling and berth allocation/sequencing problems. In particular we argue that the problem can be viewed as a no-wait bidirectional flow-shop with parallel machines and time window constraints. Benchmark problems from the literature for berth allocation/sequencing have been modified to incorporate a range of channel configurations and used as test cases for the proposed model.

2 Related Work

Due to the strong growth of global trade and maritime transportation, the berth allocation problem (BAP) occurring in container ports is studied intensively since two decades, see [2–4] for recent overviews.

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Investigating port operations under tidal conditions and channel restrictions, however, is a relatively new field of research. In [1] authors consider a BAP for a tidal bulk port in Brazil with stock level constraints. The problem is modeled as a transportation problem with given stock-level constraints taking the role of consumer demands. [5] present a MIP model to maximize the throughput of a bulk port in Australia. Based on an accurate consideration of the time-varying water depth, a ship schedule is generated from a set of so as to maximize the total draft of ships handled during a single high-tide period. In [9] authors present a discrete BAP incorporating water-depth and tidal constraints to minimize the total turnover time of ships. The planning horizon is split into the current tide period, and a second period capturing a number of subsequent tides. As the tide changes periodically, the problem is solved on a rolling time basis updating the schedule after every tidal change.

To get insight into the impact of channel capacity restrictions on port operations, [7] consider a seaport which is connected with an outer anchorage by a tide-independent one-way channel. A ship scheduling model is presented to minimize the total weighted waiting time of ships before passing the channel. A more sophisticated optimization model is presented by [6]. It addresses the scheduling of ship traffic along a set of waterways connecting a port with the open sea. A capacity constraint is included in the model which limits the total width of ships being in a waterway at a same time. A simulated annealing algorithm is proposed which comes up with good results compared with greedy heuristics like FCFS for a real scenario in the Yangtze Delta with up to 60 ships.

In this paper we develop an advanced mixed-integer linear model for scheduling ships movements in a port channel. The model captures the physical structure of a channel as done by [8], but is not restricted to the geometry of a thoroughfare channel.

3 Modeling Approach

We consider a channel connecting an anchorage in the open sea with a set of inner berths where ships are loaded and unloaded. A channel is represented by a line of channel segments which are used to model inbound and outbound movements of ships as well as their handling at a berth. These kinds of operations are jointly referred to as segment transits. A segment transit time represents the duration needed by a ship to travel a segment of a certain length either inbound or outbound, or to handle the ship at a berth. We assume that all transit times are fixed and known in advance. We further assume that all ships travelling a segment in the same direction are not permitted to overtake. We distinguish between channel segments where passing of opposing ships is allowed or not allowed. Note that the channel model described captures important challenges faced in ship channel traffic.

The problem of scheduling a set of ship movements in the channel model can be viewed as a flowshop type machine scheduling problem. Here, ship movements correspond to jobs, channel segments correspond to machines, and channel segment transits correspond to operations. Since ships cannot stop between consecutive segment transits, no-wait constraints must hold between most consecutive operations of a ship movement. An exception to this includes segment transits representing berth occupations. Here, a ship is allowed to wait after service. However, waiting at a berth to start the outbound travel through the channel possibly blocks succeeding ships. The described problem is referred to as the Channel Scheduling Problem (ChSP). It is defined as follows. Given a channel model and a set of ship movements together with a destination berth and the arrival time for each ship, find a schedule which respects the channel restrictions and which minimizes the total waiting time of all ships. The ChSP is formulated similar to a disjunctive program for a machine scheduling problem.

The described modeling approach allows for numerous practical extensions which are quite easy to implement including the consideration of tidal constraints and the incorporation of the BAP leading to the berth allocation problem with channel restrictions (BAP-CR). In this problem, the last channel segment is viewed as the destination port for the ships. At the port a set of discrete berths is available, with each capable to handle each of the ships, but the handling time can vary for a ship at the different berths.

4 Results

Computational experiments have been performed to understand the advantages in solution quality achievable through solving the MIP models derived for the ChSP and the BAP-CR compared to heuristics, and to determine the key factors influencing required computational effort and the practical limits on problem size for our modeling approach. It was found that both problems and their particular formulation were computationally challenging for practical sized problem instances. However, the benefit of incorporating channel scheduling into berth allocation was demonstrated with a notable proportion of problem instances resulting in changes to the optimal berth allocation when channel conflict constraints are considered.

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Revenue Management and Freight Rate Coordination in the Container Shipping Industry

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Abstract. Freight rates in the container shipping industry are quite volatile. They are published regularly based on certain indexes and make a daily rate bargaining impossible. Carriers as well as customers agree long term freight rates to achieve longer term planning security. However, customers have the market power to enforce a published rate if it is lower than the contracted rate. We report about an approach that supports the shipping company to determine contracted freight rates under the consideration of this "unfair" customer behavior using segmentation-based pricing methods from revenue management.

1 Introduction

The global container vessel fleet forms the backbone of international cargo transportation. Its success is based on a high degree of standardization of the complete transportation process. The container shipping industry has to deal with structural challenges. Among them, the fluctuation of the achievable revenues per TEU is quite important (volatile rates). Reference rates are published and updated regularly. This market price-transparency challenges the rate agreement between shippers and their customers. In this article, we focus on the determination of longer term rates (fixed rates) under the consideration that short term rate reductions must be considered. We apply market segmentation and prize discrimination techniques from revenue management (RM). RM has been applied already in the liner shipping industry Wang et al. (2015), Zurheide (2015) or Zurheide and Fischer (2015). We describe the underlying decision problem (Sect. 2) and derive a mathematical model (Sect. 3). The model validity is checked (Sect. 4).

2 Rate Coordination Problem

A liner shipping company operates one-directional relation between an origin (loading) port and a destination (unloading) port. It provides the capacity of C_p TEUs for loading in the origin port within period p. All periods are collected in the set $\mathcal{P}$ and all customers form the set $\mathcal{C}$. In period p customer c provides at

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most D_{cp} containers. Each customer c pays the so-called *effective rate* er_{cp} per container loaded for shipment in period p to the shipping line. We assume that the number $PF_{cp}(x)$ of loaded containers for customer c in period p depends on the currently applied rate x (price-market-function). The total revenue sum gained by the shipping company received from customer c in period p is then $PF_{cp}(er_{cp}) \cdot er_{cp}$.

An important information for the determination of the effective rate er_{cp} is provided by container rate indexes like the Shanghai Containerized Freight Index (http://en.sse.net.cn/indices/scfinew.jsp). They are regularly published and represent a reference price. We call this rate the short term rate (STR) s_p known to and equal for each customer c but updated every period p. The STR-values are volatile. In order to hedge the risk of quite high STRs, customers as well as shipping lines agrees so called fixed rates (FR) with the intention to give both market partners a well-defined base for there financial planning. For each customer c an individual fixed rate FR_c is contracted. Obviously, the actual future s_p-values are not known but we assume that a reliable forecast exists. We distinguish three different situations now for the calculation of the effective rate er_{cp}. If s_p exceeds f_c then customer c exploits the FR. The effective rate er_{cp} equals f_c (first case). If the STR falls below the agreed FR in period p, we have to inspect the difference $f_c - s_p$. If this difference is less than $\alpha \cdot f_c$ then the customer accepts the higher contracted rate to avoid stressful re-negotiations with the shipper (second case). The effective rate er_{cp} equals again f_c. Finally, if $f_c - s_t$ reaches or exceeds $\alpha \cdot f_c$ then the customer switches to the daily rate even it is necessary to conduct stressful re-negotiations with the shipper (third case). Now, er_{cp} equals s_p.

The Rate Coordination Problem (RCP) comprises the determination of the fixed rates for all customers so that the total sum of revenues gained from all customers over all periods is maximal. The provided limited capacity is respected in each period and customers have the market power to overrule the FRs if the STRs fall significantly below the FR-value. Solving this optimization problem requires the assignment of contingents of the total shipping capacity to the customers according to their willingness to pay. It is an extension of the expectation maximization model discussed in the context of revenue management (Klein and Steinhardt 2008). The major difference compared to the aforementioned setup is that the effective rate is not a problem parameter but must be determined during the solving of the decision task.

3 Mathematical Model

$$\max \quad \sum_{c \in C} \sum_{p \in P} PF_{cp}(er_{cp}) \cdot er_{cp} \tag{1}$$

$$PF_{cp}(er_{cp}) \leq D_{cp} \ \forall c \in \mathcal{C}, p \in \mathcal{P} \tag{2}$$

$$\sum_{c \in \mathcal{C}} PF_{cp}(er_{cp}) \leq C_p \ \forall p \in \mathcal{P} \tag{3}$$

$$(1-\alpha)\cdot f_c - s_p \leq y_{cp}\cdot \mathcal{M}\ \forall c\in\mathcal{C}, p\in\mathcal{P} \tag{4}$$
$$(1-\alpha)\cdot f_c - s_p \geq -z_{cp}\cdot \mathcal{M}\ \forall c\in\mathcal{C}, p\in\mathcal{P} \tag{5}$$
$$y_{cp} + z_{cp} \leq 1\ \forall c\in\mathcal{C}, p\in\mathcal{P} \tag{6}$$
$$er_{cp} \leq d_p + z_{cp}\cdot \mathcal{M}\ \forall c\in\mathcal{C}, p\in\mathcal{P} \tag{7}$$
$$er_{cp} \leq f_c + y_{cp}\cdot \mathcal{M}\ \forall c\in\mathcal{C}, p\in\mathcal{P} \tag{8}$$

The continuous non-negative decision variable f_c stores the fixed rate determined for customer $c \in \mathcal{C}$. The effective rate associated with customer c in period p is stored in er_{cp}. The binary decision variable y_{cp} becomes 1 in case that $f_c - s_p \geq \alpha \cdot f_c$. Similarly, the binary decision variable z_{ct} becomes 1 in case that $f_c - s_p \leq \alpha \cdot f_c$. The planning goal represents the maximization of the revenues collected from all customers (1). The number of allocated containers is limited by the number of containers D_{cp} provided by the customers within each period (2). The overall liner capacity is respected in each period (3). Constraint (4) ensures that the indicator y_{cp} is 1 if the FR is significantly higher than the STR. Similarly, constraint (5) enforces z_{cp} to become 1 in case that the FR is accepted by the customer. At most one of these two decision variables is allowed to be 1 (6). The maximal applicable effective rate is bounded by (7) as well as (8).

$$\sum_{r\in\mathcal{R}} y_{rcp} = 1\ \forall c\in\mathcal{C}, p\in\mathcal{P} \tag{9}$$
$$q_{cp} = \sum_{r\in\mathcal{R}} r\cdot y_{rcp}\ \forall c\in\mathcal{C}, p\in\mathcal{P} \tag{10}$$
$$er_{cp} = \sum_{r\in\mathcal{R}} \bar{P}_{rcp}\cdot y_{rcp}\ \forall c\in\mathcal{C}, p\in\mathcal{P} \tag{11}$$
$$q_{cp} \leq D_{cp}\ \forall c\in\mathcal{C}, p\in\mathcal{P} \tag{12}$$
$$\sum_{c\in\mathcal{C}} q_{cp} \leq C_p\ \forall p\in\mathcal{P} \tag{13}$$
$$REV_{cp} = \sum_{r\in\mathcal{R}} r\cdot \bar{P}_{rcp}\cdot y_{rcp}\ \forall c\in\mathcal{C}, p\in\mathcal{P} \tag{14}$$
$$\max \quad \sum_{c\in C}\sum_{p\in P} REV_{cp} \tag{15}$$

Obviously, the model (1)–(8) is not linear in the general situation. Let R^{max} denote the largest number of containers demanded by any customer in any period and the set $\mathcal{R}$ is defined by $\mathcal{R} := \{0, \ldots, R^{max}\}$.

In the here considered application we can achieve a model reformulation based on the discretization of the number of containers $q_{cp} \in \mathcal{R}$. This is a reasonable simplification since the number of containers shipped for each customer in each period is an integer number. We introduce the binary decision variables y_{icp} ($i \in \mathcal{R}, c \in \mathcal{C}, p \in \mathcal{P}$). For each ordered pair (c, p) the decision variable set

$\{y_0, y_1, \cdots, y_{R^{max}}\}$ forms a *special ordered set of type 1 (SOS-1)*, i.e. its sum equals 1. First, we ensure that the y_{rcp}-variables form an SOS-1 (9). Next, we identify the indicator variable y_{rcp} that represents the value of q_{cp} (10). Using these indicator variables, we can now identify the profit $R\bar{E}V_{cp}$ earned from customer c in period p. The two constraints (2) as well as (3) are adjusted to the new nomenclature by (12) and (13). Let $\bar{P}_{rcp}$ refer to the profit that can be realized per container if r containers are accepted from customer c in period p. The decision variable family REV_{cp} is introduced to store the sum of revenues earned in period p from customer c (14). If we replace the objective function (1) by the linear function (15) then the resulting comprehensive model (4)–(15) is a mixed-integer linear program. We can use commercial solver software like CPLEX to identify optimal model solutions.

4 Computational Model Verification

In order to evaluate the proposed decision model we have set up an artificial evaluation scenario. It consists of three customers and ten shipping periods. At the beginning of each period, the recent SRT is published. Here we assume that the SRT-evolution is $s_1 = 520$, $s_2 = 480$, $s_3 = 470$, $s_4 = 500$, $s_5 = 510$, $s_6 = 470$, $s_7 = 490$, $s_8 = 510$, $s_9 = 530$ and $s_10 = 480$ (solid lines in Fig. 1). Customer 1 has a maximal demand of 750TEU per period, customer 2 wants to send at most 1000TEU in a period whereas customer 3 provides at most 1250TEU. The demand of customer 1 (customer 2, customer 3) decreases by one TEU if the effective rate is increased by 1.33 EUR (0.90 EUR, 0.64 EUR). If the effective rate reaches 1000EUR (900EUR, 800EUR) then customer 1 (customer 2, customer 3) will not place any shipment order. We parametrize the proposed model for a situation where the shipping line provides sufficient capacity ($C_p = 3000$ TEU) but also for the situation with scarce capacity ($C_p = 1400$ TEU). For both settings, we evaluate the α-values 0% and 5%.

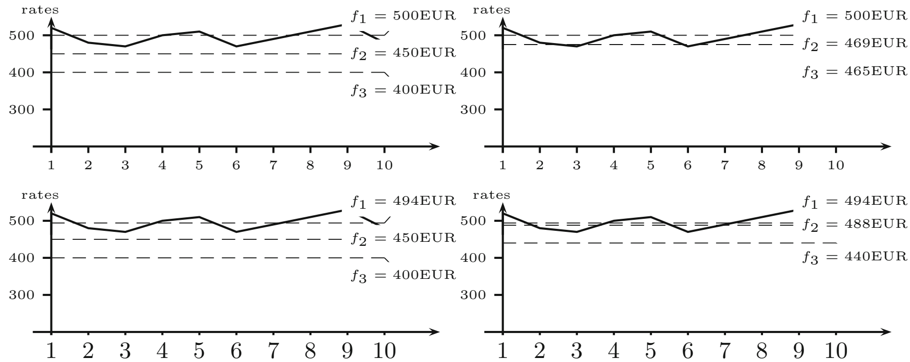

Fig. 1. Investigated STR-sequence and optimal FRs for $\alpha = 0$ (top-left: $C_p = 3000$, top-right: $C_p = 1400$) as well as $\alpha = 5\%$ (bottom-left: $C_p = 3000$, bottom-right: $C_p = 1400$)

Table 1. Achieved revenue sums as well as numbers of accepted containers

α	C_p	Total revenue	#TEU
0	3000	6'622'998	15083
	1400	6'552'972	13856
5%	3000	6'624'753	15045
	1400	6'583'712	13998

The two upper plots in Fig. 1 show the determined fixed rates for the $\alpha = 0$ scenarios. In case that enough capacity is available (left plot) the optimal FRs can be determined individually for each customer since there is no competition for the available capacity. The FRs are significantly below the SRTs in order to attract as much TEU as possible. If the capacity is reduced to 1400 TEU (right plots in Fig. 1) then the FRs for customers 2 as well as 3 are increased. Now, less TEUs are allocated for customers 2 and 3 so that the first customer who has the highest willingness to pay remains its originally allocated capacity portion. However, we observe a reduction of the overall sum of revenues from 6.62 Mio EUR to 6.55 Mio EUR accompanied by a decrease of accepted TEU from 15083 TEU down to 13856 TEU (Table 1). In case that the customers are willing to accept larger differences between the fixed rate and the recent SRT ($\alpha = 5\%$) then the optimal fixed rates are adapted (lower plot in Fig. 1). For the customer 1 (with the highest willingness to pay), the rate is reduced slightly down to 494 EUR independently of the available capacity. As a result, the total sum of collected revenues is increased compared to the $\alpha = 0$-cases although the number of accepted TEU is slightly reduced in the case with sufficient capacity. If the capacity is short then the rates of the two remaining customers are significantly raised. Compared to the $\alpha = 0$-case with short capacity both the revenue sum and the number of accepted TEU increase.

5 Summary and Outlook

We have reported the modeling of an important decision problem in the container shipping business. The validity of the proposed model has been demonstrated.

An important issue to be included into the calculation model are the bunker costs. In contrast to other "prominent" applications of revenue-based capacity allocations (like the airline industry), we observe a significantly higher portion of variable costs depending on the final vessel payload. Furthermore, the dynamic behavior of the market must be considered in order to make such a pricing approach applicable in the container shipping industry.

In the next research steps it is necessary to investigate the impacts of changing profit functions as well as of varying capacities. Furthermore, the opportunity to bargain about an adjustment of the fixed rate should be analyzed.

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Conducting Safety Inspections of Container Gantry Cranes Using Unmanned Aerial Vehicles

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Abstract. Port facilities operate in a highly competitive environment and maintain several supply chains simultaneously. The performance and interaction of these supply chains are vital to the national logistics infrastructure as well as the hinterland with its connected services. Both aspects – competitiveness and dependency – make it vital for ports to maintain a structured and detailed inspection and maintenance schedule. This paper analyses the innovative approach of using unmanned aerial vehicles (UAV) for inspection works. It argues that such technology enables costs reductions and increased operative benefits via high definition image generation at the same time and providing a valuable support to maritime safety operations.

Keywords: Port safety · Unmanned aerial vehicles · Drones · Inspection

1 Introduction

Drone systems have significantly risen in terms of availability and operability in civil industrial areas over the past decade. They are briefly differentiated in remotely operated vehicles (ROV) with operation areas on land and under water and unmanned aerial vehicles (UAV) for aerial operations. It should be noted that other types and descriptions exists among various sources that are not subject to this paper. UAV in general can be classified by size, payload (e.g. for camera and sensor systems) and flight time. Depending on the construction of the system, different capabilities of these factors arise. A basic classification for example differentiates fixed wing UAVs (mostly for large area operations) and multi rotor UAV (for dedicated operations in narrow areas). While this paper introduces the use of UAV into port inspections on narrow areas it focusses on multi rotor systems.

Port facilities represent a nation's key logistic infrastructure facilitating and maintaining the trade of goods being the key driver of modern globalization. 74% of goods entering or leaving Europe go by sea and ports generate employment of around 3 million (direct and indirect) workers across the 22 EU maritime member states (European Commission 2015). In 2016 around 70.12 million TEU were handled in the fifteen largest container ports within the EU (Notteboom 2017). Maintaining permanent port operations is vital to the infrastructure of a region. Key aspect of this permanent

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operation lies in the identification and prevention of malfunction and attrition of cargo handling equipment in the beforehand of accidents or breakdowns.

The number of industrially produced UAV system types has risen from 655 to 2,059 from 2005–2015 (RPAS Yearbook 2015). Given the fact of customization and individual upgrades on UAVs, it is likely that the actual number of types on the market exceeds the above presented values. The global UAV market value is valued at $4.2 billion in 2017 TEAL Group (2007–2015) while the European market accounts for approx. $234 million (Verdantix 2017). The numbers indicate a considerable gap between the two markets indicating that unmanned systems in Europe may face a significant growth potential in the future. The value of the global five years market opportunity til 2020 is estimated at additional $100 billion (Goldman Sachs 2017). This trend can only be realized and its benefits can only be exploited, if unmanned systems find growing application in innovative industrial settings – such as port inspections.

2 Methodology and Literature Review

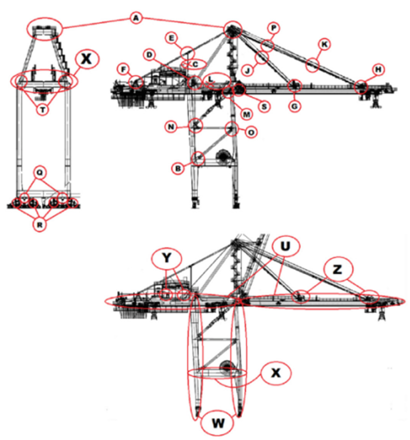
The analysis of innovative approaches in academic research is often accompanied by an initial scarcity of literature that also applies to this article's research area. Gantry crane inspection has been analyzed by different studies. Kopnov (1999) addresses the fatigue life prediction of the metalwork of cranes. From a maintenance planning point of view contributions were provided towards safety and efficiency improvement (Cook 1999), optimal inspection periods (Baek et al. 2009) and the design of intelligent monitoring systems (Xu et al. 2009). The remote aspect of inspection and maintenance maritime related platforms was introduced by Kyrkjebø et al. (2009). Unmanned aerial vehicle inspection opportunities in general were analyzed by Metni and Hamel (2007), Irizarry et al. (2012) and Hallermann and Morgenthal (2012 and 2014). Initial studies of unmanned systems within the maritime sector evaluated the operations of remotely operated vehicles (ROV) among different Japanese disaster sites (Osumi 2014) or described the use of an ROV at the 2012 wreck of the *Costa Concordia* off Tuscany (Alotta et al. 2015). Stein (2018) provides initial frameworks of unmanned system usages in port operations from a security based point of view using qualitative methods based on grounded theory.

It is the aim of this paper to add another perspective towards the integration of unmanned systems in port operations (as introduced by Stein 2018) by conducting action research on the approach of unmanned gantry crane inspections. The method of action research originated in the work of Lewin (1946) and was initially adapted on industrial research by Coch and French (1948). Action research gathers data from the applied experiments that is contextually embedded and interpreted. The aim is to contribute both to practical concerns of a problematic situation and to the goals of science within a mutually acceptable framework (Karlsson 2009). Following Coghlan and Brannick (2005) knowledge is generated via repetitive cycles of diagnosing and action -planning, -taking and evaluating whereas the research must be recoverable (Checkland and Holwell 1998). The following research represents the initial action research cycles towards the identification of a possible and beneficial implementation of unmanned crane inspections in ports.

3 Scenario and Framework

The overall research question is whether it is possible to conduct unmanned container gantry crane inspections while identifying treats and benefits of such operations. Additionally frameworks of best practice and operational planning are introduced in order to maintain the recoverability of this paper's research to other crane and port structures. The research scenario is located in a container port facility in Hamburg (Germany) using different multi-rotor drones among different test flights between July and November 2017. The inspection object is a container gantry crane build by ZPMC with a total height of around 85 m and a boom length of around 80 m for container payloads of up to 120t.

In Germany, port operators are obliged to conduct repetitive safety checks on container cranes according to principle 309-001 of the German Social Accident Insurance standard (DGUV). This goes in line with the European directives 98/37/EG and 2006/42/EG (both determining basics of health and safety standards for machineries) and directive 2009/104/EG (use of work equipment). Those norms are further assisted by ISO 9927-5:2017 (inspection of gantry cranes) and ISO 17096:2015 (safety of gantry cranes) standards (Graphic 1).



Graphic 1. Container gantry crane inspection plan. Source: Stein conferred with operator (2018)

Additional suggestions are provided by the international labor association (ILO) code of practice for safety and health in ports. Given the high container turnover and the severe consequences of breakdowns, container port operator shortened inspection cycles to semiannually or even quarterly within their operational frameworks. The scenario follows the original inspection plan of the port operator that includes 26 components with 85 inspection areas consisting of a total of 287 inspection points. Around 43% of all components, areas and inspection points are frequently inspected by professional industrial climbers while the remaining 57% are conducted by port staff. Both operations obtain a certain safety risk and economic burden in terms of both external and internal costs. This paper argues that the combination of manned and unmanned inspection contains economic and safety benefits while the following approaches intent to clear the path for proper academic evaluation. The following steps represent first action research cycles dealing with the initial research questions:

(1) Can UAVs produce inspection relevant optical content?
(2) Which procedures assist a proper risk management?
(3) Which factors affect a UAV inspection operation in ports?

The aspect of UAV delivering proper content that is useful for inspection purposes was tested in July 2017. The UAV delivered promising results despite low light conditions and occurring rain as provided in the appendix of this paper. Additional flights were conducted in October and November 2017 under conditions displayed in Table 1.

Table 1. Test flight conditions

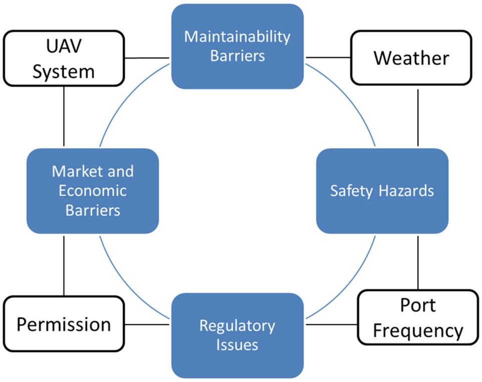
Test flight	Temperature (min-max)	Windspeed	Light	Rain	Sun
July 25th 2017	16–21 °C	17 km/h	Heavy clouds	Light	None
October 26th 2017	10–12 °C	17 km/h	Cloudy	None	None
November 6th 2017	4–10 °C	6 km/h	Light clouds	None	Yes

Source: Stein (2018)

This paper argues that the multitude of 287 inspection points per gantry crane require a strict path plan and coordination among UAV pilots and the port inspection department. This aspect is critical to identify and categorize inspection outcomes as well as maintain a safe operation parallel to surrounding port's routine business. It concludes that such risk management and path planning procedures require 3D models of the gantry cranes where components and inspection angles can be planned for accordingly. The initial efforts of a 3D model are displayed in Graphic 2, were the first 25 m height of the crane were 3D modelled. While initially intended to assist in path planning of the UAV pilot, the generated 3D model provides a valuable ground for fully unmanned flight operations in a later stage of the project.

Graphic 2. Initial processing of a 3D crane model. Source: Stein (2018)

When conducting unmanned inspections in ports, certain barriers must be considered and accounted for as structures in Graphic 3. Stein (2018) already pointed out major barriers of unmanned system usages in ports from a security perspective based on intensive literature research. The following framework concludes the main barriers of safety related UAV inspection operations in port facilities. In order to clear the path for innovative services, one must understand and mitigate risks and barriers that might arise from and during those operations.



Graphic 3. UAV inspection barriers. Source: Stein (2018)

The maintainability of inspection operations is mainly affected by two aspects – the UAV system and the weather. While rain reduces the quality of the inspection pictures and constitutes a certain danger to the UAV system, wind either requires larger and more powerful UAV systems or endangers the whole operation. The safety aspect of wind conditions is manifested in the fact that GPS positioning during an UAV flight can get lost due to external factors such as signal disturbances to the controlling unit. In such cases the UAV will drift with the wind that, based on the intensity, direction and UAV position, can lead to a total loss and safety issues. The frequency of the port must also be considered in terms of that the gantry crane must be out of service and must be accessible meaning the berth must be idle. This aspect determines the regulatory issue of a UAV operation likewise to the local regulations of unmanned flights in general based on the country and state where the port is located. The decision towards the size of the UAV system affects the operability towards weather conditions and the payload of camera systems likewise to the price of the whole system. Together with the cost of permissions, prices reflect the economic aspect of the operation that is crucial to any UAV operations in ports. The aspect of 3D modelling for path planning accounts both for safety hazards and economic barriers as it mitigates operational risks and shortens operational procedures via enhanced communication approaches.

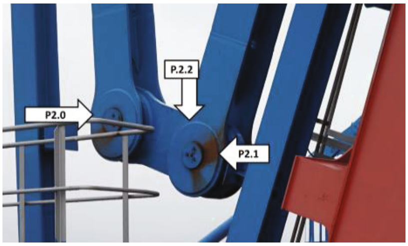
Even if barriers of unmanned inspections services are present and must be accounted for, the overall benefit generated by such innovative services truly outlines the challenges. If ports intend to remain innovative and cost efficient, the consideration towards unmanned services for dedicated operations such as crane inspection clearly remains beneficial. Future academic and applied contributions will most likely further enhance this topic while this contribution began laying the path.

4 Conclusion

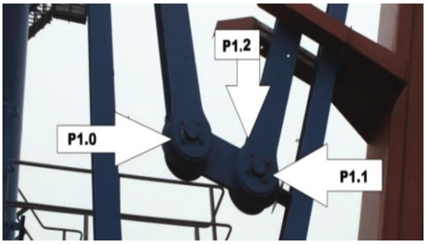
Unmanned aerial vehicles have significantly evolved over the past ten years, providing cost effective operability in various industrial settings. Europe has especially huge potentials in terms of market growth and usability of unmanned systems while the whole global industry is expected to grow significantly in the upcoming future. Ports operate in a highly competitive market while being of central importance to a nation's transport infrastructure. The need for better and more efficient innovative approaches therefore is given under both aspects economically and safety related. This paper argues that UAV can provide such services with regard to gantry crane inspections while providing initial qualitative contributions as a basis for further (and currently ongoing) research. In order to integrate innovative unmanned operations in existing structures, risks must be identified and accounted for. This paper positively answers the question towards a general usability of UAV services in gantry crane inspections. It furthermore presents an initial risk assessment framework. Additionally and in line with accepted academic frameworks, it identifies and quantifies inspection points and efforts. The concept of 3D modelling for risk mitigation and enhanced communication is introduced in this context. This evaluation reflects an initial stage of the ongoing research approaches of innovative unmanned port operations. It provides a valuable contribution to the so far scars literature on unmanned maritime and logistics topic and acts as a solid basis for future research.

Appendix

(See Graphics 4 and 5).

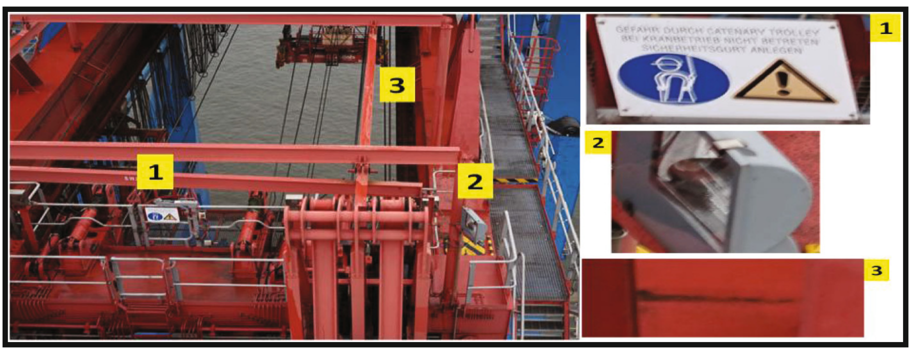


UAV picture Point P (left side)
Source: Stein (2018)



climber picture point P (right side)

Graphic 4. Comparison UAV picture and industrial climber. Source: Stein (2018)



Graphic 5. Examples of a UAV inspection test flight. Source: Stein (2018)

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Dispatching Strategies of Drayage Trucks at Seaport Container Terminals with Truck Appointment System

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Abstract. Implementing a truck appointment system at container terminals is a successful method to smoothen peaks in truck arrivals and thereby reduce truck waiting times and congestion in the port area. In spite of extensive literature on its impact on container terminal productivity, other stakeholders in the port drayage network have been studied only occasionally. This paper aims to analyze different strategies of time window selection for port drayage companies considering different company sizes and competitor' strategies. The analysis is done by means of a discrete event simulation model. The results show that an early booking of appointments at container terminals is beneficial for the success rate of trucking companies. Furthermore, it is highlighted that the truck turn time of small-sized companies in this network is higher than the one of large-sized companies.

1 Motivation for Truck Appointment Systems

Due to the increasing amount of world seaborne trade by more than 41% in millions of tons loaded between 2005 and 2015 (United Nations Conference on Trade and Development 2017) and the rising ship dimensions severe challenges for container terminals and ports have occurred. One of these challenges is the high truck congestion at terminal gates due to peaks in truck arrivals before and after the berthing of large vessels. Often, these queues lead to heavy traffic in the whole port area and to long waiting times and delays for all transports. Port drayage truck drivers are especially affected by these waiting times. As they are mainly owner operators, the lowered numbers of finished orders per day endanger their financial independence. Furthermore, the waiting times often occur with running engines and thereby cause higher greenhouse gas emissions.

To overcome these challenges, many ports and terminals try to smoothen the peaks in truck arrivals. One successful solution is the implementation of a truck appointment system (TAS). A TAS is a vehicle booking system in which truck drivers can reserve specific time windows during the working hours of the TAS operator in which they have to arrive for loading or unloading. Penalties can

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be defined for late arrivals or no-shows of trucks as well as for too long waiting times at the terminal gates. In 2002, the ports of Los Angeles and Long Beach implemented the first TAS worldwide (Giuliano and O'Brien 2007). Today, many different TAS are operating in ports around the world, e.g. Vancouver, Sydney and Southampton (Huynh et al. 2016). Extensive research has been done on methods to optimize TAS in relation to terminal performance (Guan and Liu 2009, Zehendner and Feillet 2014) and to a lesser extent on the impact of TAS on trucking companies. Inter alia, Namboothiri and Erera (2008) developed an optimization-based scheduling framework for selecting time windows at container terminals with TAS as well as an algorithm for finding optimal truck routes. Shiri and Huynh (2016) implemented a mathematic model to solve the drayage scheduling problem with time windows for TAS at container terminals.

Port drayage often accounts for a considerable part of the overall transportation cost in the maritime supply chain and for a high percentage of truck arrivals at container terminals (Harrison et al. 2007), (Shiri and Huynh 2016). It is defined as "truck pickup from or delivery to a seaport, with the trip origin and destination in the same urban area" (Huynh et al. 2011) and mainly serves as short distance transportation from one container terminal to other terminals, empty container depots, freight stations, customs stations and vice versa. Due to this, a drayage truck driver manages several transports per day. The main challenge for drayage companies is the dispatching of different transports while minimizing waiting times and empty trips and respecting the opening hours of the logistics nodes. The introduction of a TAS at container terminals causes new constraints and a higher complexity in the dispatching process. A comprehensive overview of research papers on TAS and port drayage can be found in Lange et al. (2017). Few publications consider the fact that the impact of TAS on drayage companies can vary. To mitigate this research gap, this paper focusses on the impact of TAS on drayage companies considering different drayage company sizes and dispatching strategies in relation to competitors.

2 A Simulation Study Based on the Example of the Port of Hamburg

In this paper, the dispatching process is divided into two parts: (1) selecting time windows at container terminals for specific transport orders and (2) the vehicle routing for all trucks in the fleet and all orders. For both parts one workday with a given number of orders, based on a normal distribution developed on the example of the port of Hamburg, is considered.

In part (1), visual basic is used to generate a given amount of orders. Every order consists of source and drain, which are based on probability distributions found by examining data from a middle-sized drayage company in the port of Hamburg. Opening hours for each source and drain have to be considered. If the sources and/or drains are container terminals, a time window has to be selected. This process is determined by three parameters: trucking company size, selection horizon (72, 48 or 24 h in advance) and the competitors' selection horizons.

First, for each order the possible time windows fitting the constraints, e.g. opening and closing hours of source and/or drain, are prioritized by their probability to be successfully chosen starting with the lowest. The probability is developed based on a distribution of truck arrivals of the port of Hamburg and the chosen selection horizon of the considered trucking company and the competitors. Second, the prioritized time windows are checked for the number of already booked appointments. If this number reaches a specific limit, no further appointments are available in this time window. Starting with the time window with the highest priority, the systems tries to book the appointment based on a random number. The list of all orders, the opening and closing times of the stations and the selected appointment times for the container terminals serve as input for the simulation model and is generated anew for each simulation run.

In part (2), the vehicle routing is done in a discrete event simulation model, which is implemented in Tecnomatix Plant Simulation version 13.1. Because the routing for a truck is adjusted continuously, it is called a dynamic vehicle routing. Orders are assigned to trucks at the shift starts, after a break or when an order is completed or cancelled. All unallocated orders are prioritized by their urgency. The urgency is derived from the opening and closing hours respectively the appointment times of source and drain, the necessary trip duration considering the traffic at the current time of day and the expected waiting times. In the next step, a nearest neighbor algorithm is used for all orders with the highest priority. The order with the shortest travelling distance between current location of the truck and source is selected. The travelling time of the truck and the turn time at the container terminal or station depend on the time of day as well as on the probability for unplanned events. Missed time windows or arrivals after the closing time of stations are possible. If the truck arrives at the terminal less than 60 min after the end of his time window, the successful handling depends on the capacity of the terminal. If no capacity is left or the trucks arrive after more than 60 min the order is cancelled. These orders are documented and punished with a penalty time illustrating the time necessary to return the container to the company's depot. Trucks reaching a container terminal more than one hour in advance have to wait until 60 min prior to their time window. If capacity is free at this point, they can proceed to the terminal handling facilities. Else they have to wait until their time window starts. All capacity evaluations are based on a distribution gained from the port of Hamburg.

3 Simulation Results

First, to display and analyze the impact of different appointment selection horizons the company size is kept stable at a big-sized level with 60 trucks. In average 776,64 orders are generated per simulation run for a big-sized company. In Fig. 1 the success rates of three possible selection horizons of appointment times at container terminals under consideration of the competitors' selection horizons are presented.

It is prominent that the success rates are, contrary to the expectations, very similar in all scenarios. To evaluate the reasons for this result, the number of

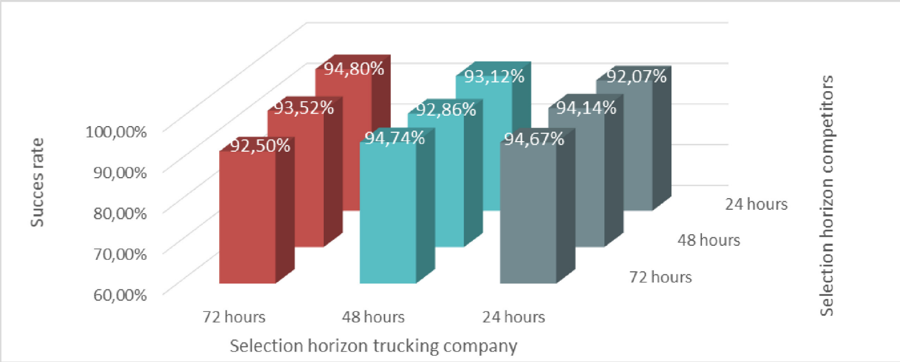

Fig. 1. Success rates of selections horizons

selectable orders per truck is analyzed. It is highest in the scenarios where the trucking company has a long selection horizon and lowest for the ones with a short horizon. Therefore, more studies are conducted for two of the scenarios - 72 h selection horizon for both trucking company and competitors and 24 h selection horizon for the trucking company and 72 h for the competitors.

If the number of trucks is increased to 70, the 72–72-h scenario has a success rate of 98.29% against a rate of 95.75% for the 24–72-h scenario. In conclusion, the long selection horizon has a positive impact on the success rate of trucking companies. Nevertheless, if the trucking company has a high percentage of non terminal transports, also a late selection horizon is feasible. Second, in Fig. 2 the impact of the company size on the truck turn time is displayed. The average truck turn time for one transport is higher for a small-sized company as for a big-sized one. This is due to the fact that a more flexible dispatching is possible with more orders and therefore, the probability for a follow-up order in close proximity of the current location is higher.

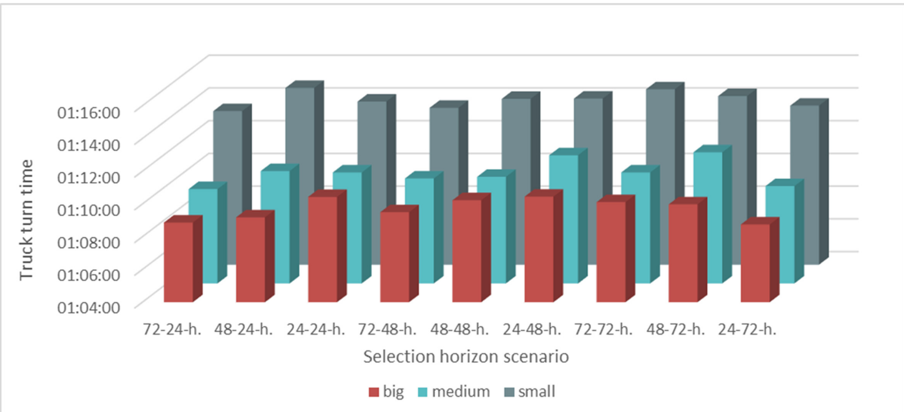

Fig. 2. Truck turn time depending on company size and selection scenario

4 Conclusion and Outlook

The simulation study shows a first starting point for the analysis of impact factors between different stakeholders in the port drayage network. Especially the dependencies between different trucking companies and their appointment time selection horizons are evaluated. The results emphasize the importance of an appropriate booking strategie for trucking companies in relation to the company size. For small-sized company an early and well planned booking process is vital to remain competitive with larger-sized companies. Future research aims at including more stakeholders, as empty depots and freight stations, in the port drayage network and analyze, how they are affected by a TAS at container terminals.

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Simulation-Based Analysis of Dispatching Methods on Seaport Container Terminals

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Abstract. Efficient dispatching of vehicles and transport orders between the quayside and the yard of container terminals is an important challenge for terminal operators. Despite the large amount of literature in this field, there is no systematic approach investigating the effects of terminal characteristics on the performance of different dispatching methods. This simulation study aims to close that research gap for the case of different dynamic dispatching methods.

1 Introduction to Dispatching on Container Terminals

Container terminals are logistic nodes in the maritime supply chain between sea transport and the hinterland. Increasing cargo volumes and larger vessels lead to the necessity to optimize terminal operations regarding speed and efficiency. There are several types of terminal systems. The most used system on container terminals worldwide is the RTG/TT-system which runs as follows: Quay cranes (QC) discharge containers from a vessel and put them down on an available terminal tractor (TT). The TT transports the container from the quayside to the yard. In the yard area, a Rubber-Tired Gantry Crane (RTG) lifts the container from the TT and puts it down in the storage area. The loading process runs the other way round.

Thereby, the term horizontal transport refers to the interface between quayside and yard. It is an important process to allow for an efficient service to vessels. Regarding horizontal transport, there are three main decision problems: first, which vehicle type to choose; second, how many vehicles to buy; and third, how to route and dispatch the vehicles. This paper focuses on the last one, and especially on the dispatching problem.

Dispatching aims to find an efficient assignment (and sometimes sequence) of transport orders and vehicles for a defined time horizon (ad hoc, minutes, hours) to serve the QC continuously and to minimize the driven distances of vehicles. Thereby, dynamic and static dispatching can be distinguished. The dynamic approach triggers the assignment at certain events, e.g. if a transport order is completed and a vehicle is available. This approach is very flexible but also myopic. On the contrary, the static approach (often also called scheduling) generates a long-term plan based on estimates for arrival and operation times. The plan can be optimized using mathematical methods. However, it is highly

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dependent on the quality of the time estimates. As container terminal processes are quite stochastic, this study focuses on dynamic dispatching methods. Specifically, the research question is, whether certain terminal characteristics affect the performance of a dispatching method and if yes, which ones. Therefore, a simulation study is conducted to approach that question.

The following section presents the state of the art of dispatching on container terminals. Then, the simulation model and the design of experiments are presented. Finally, the simulation results are discussed and conclusions derived.

2 Literature Review

A number of publications analyze dispatching methods on container terminals. Dynamic dispatching methods like "nearest vehicle" or "least capacity usage" are investigated by e.g. Grunow et al. (2006), Koster et al. (2004), and Tao and Qiu (2015). Briskorn et al. (2006) or Choe et al. (2016), for example, analyze methods using a look ahead horizon (e.g. latest arrival time at the QC). Corman et al. (2016), He et al. (2015), and Ng et al. (2007), inter alia, formulate a mathematical model and either solve it exactly or by using heuristics such as genetic algorithms or tabu search. For a detailed analysis of the existing literature see Schwientek et al. (2017).

The respective publications usually develop an own dispatching method or compare a few methods for a specific terminal. Several authors vary a number of terminal characteristics within the scope of the sensitivity analysis (see e.g. Böse et al. (2000), Grunow et al. (2006), Klerides and Hadjiconstantinou (2011), Zeng et al. (2009)). Zeng et al. (2009) and Liu and Ioannou (2002) show that the number of available vehicles influences the dispatching method performance ranking. However, the interrelations between terminal characteristics and dispatching method performance are not investigated systematically.

3 Simulation Study

The simulation study bases on a reference terminal that is implemented in Tecnomatix Plant Simulation 12 using modified data of a real terminal. Both terminal characteristics and dispatching methods are varied to investigate the effects of the respective combinations on the efficiency of the horizontal transport.

The simulation model reflects a typical RTG/TT-terminal. It focuses on the horizontal transport area framed by the quayside and the yard area. The simulated terminal has a capacity of 1,600,000 TEU (Twenty-foot Equivalent Unit), the quay length is 800 m. Eight QC are installed. The yard comprises 20 blocks (6×28 TEU) parallel to the quay wall. For every yard block, there is a RTG available. There is a maximum of 48 TT (six per QC) on the terminal. Three different vessel types arrive at the terminal with approximately 500–3,500 containers for discharging and loading. Output parameters are the QC productivity as well as the distances driven by the TT.

The choice of dispatching methods and terminal characteristics bases on a preceding literature analysis (see Schwientek et al. (2017)). The chosen dispatching methods showed a good performance in comparison to others in earlier studies. Accordingly, terminal characteristics were chosen that were identified to influence the dispatching method performance ranking or that appear to be possibly relevant.

Three different dynamic dispatching methods are investigated: distance-based, inventory-based and time-based. The distance-based method showed in several cases a good performance compared to other methods. This method aims to minimize the driven distances of the TT by assigning the nearest transport order. The inventory-based method is a dispatching method referring to Briskorn et al. (2006) that was evaluated positively in several other publications. Thereby, an available vehicle is assigned to a transport order that belongs to the QC with the smallest inventory. The inventory of a QC is understood as the number of transport orders that is already assigned to this specific QC. The time-based dispatching method chooses the longest waiting transport order for a vehicle.

Six terminal characteristics are evaluated in this study regarding their influence on the performance of dispatching methods:

1. Number of TT (values: 24, 32, 40, 48)
2. Speed of TT (values: 20 km/h, 30 km/h, 40 km/h)
3. Capacity usage of the quayside (values: 50%, 63%, 75%, 88%, 100%)
4. Vessel size (values: only small vessels, typical size distribution, only large vessels)
5. Yard block assignment to containers (values: random, close to QC, three defined blocks)
6. Stochasticity of operation times (values: no, normal, high).

4 Simulation Results

Table 1 shows the results of the simulation experiments. It displays the mean values of all respective simulation runs for the distance per container in meter and the QC productivity in moves/hour. The distance-based method leads on average to 5% less distance driven by the TT. On the contrary, the inventory-based method leads on average to a 8% higher QC productivity. These results are plausible as the distance-based method focuses on the TT and the inventory-based method aims to avoid waiting times for the QC. The time-based method performs similar to the inventory-based method.

The evaluated terminal characteristics rarely influence the performance ranking of the dispatching methods. This means that if the value of one of the evaluated characteristics changes, the method performance ranking does not change. However, as Fig. 1 shows, the results are nevertheless interesting. For example, the distance-based method leads to shorter distances, especially if only few TT are available or if the capacity usage is high. On the contrary, this leads at the same time to a reduced QC productivity. Both cases (less TT or high usage)

Table 1. Performance of evaluated dispatching methods

Method	Distance per container	QC productivity
Distance-based	**1076**	24.5
Inventory-based	1133	**26.5**
Time-based	1130	26.1

imply that there are more transport orders to be executed by less TT. Therefore, a TT has a larger number of transport orders to choose from, but some transport orders have to wait longer and so does the QC.

A variation of the TT speed shows in the simulation results no impact on the driven distances or the QC productivity. The yard block assignment of containers to storage places influences the absolute performance of the dispatching methods, but not the ranking. This is also the case for the stochasticity of the operation times of QC and RTG. If the arriving vessels are rather small, the time-based method performs slightly better than the inventory-based method in terms of QC productivity.

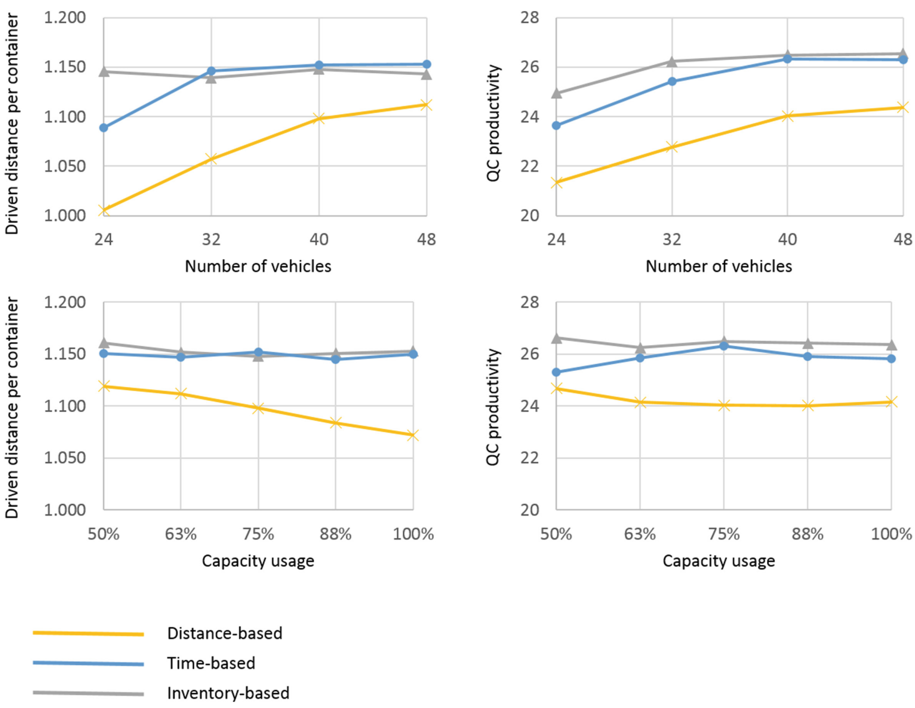

Fig. 1. Influence of number of TT and terminal capacity usage on driven distances and QC productivity

5 Conclusion and Future Research

This simulation study shows a first start to evaluate the interrelations between container terminal characteristics and dispatching method performance depending on different performance criteria. Especially the choice of the performance criteria influences the choice of the dispatching method. Future research aims to systematically extend this study by further characteristics, dispatching methods and performance criteria.

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Port Call Optimization by Estimating Ships' Time of Arrival

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Abstract. Ships' estimated arrival times command an optimized port call and thus the heartbeat of every sea port. Various factors influence the waiting times of vessels at anchorage. Occupied berths or tide dependencies are just some of the factors leading to long waiting times before entering the port. Terminal operators cannot allocate the berths efficiently and hinterland transports cannot plan ahead due to the often times incorrect information regarding vessels' time of arrival. To reduce these problems with regard to an optimized port call, a prediction model for the maritime traffic situation in the German North and Baltic Sea is developed to determine future ship positions and, in particular, arrival times. Within this paper, the accelerated research project as well as its benefits for port call optimization are presented.

1 Introduction

8719 sea-going vessels called the port of Hamburg in 2016 (Port of Hamburg Marketing 2017). In an increasingly globalized world, the shipping market is subject to an intense competitive pressure: Ports fight for sea cargo, but emissions and costs have to be reduced. The pressure for maximum efficiency while sailing, in vessel usage or in the time vessels spend in the port rises. Long waiting times at anchorage cause higher costs for shipowners and delays lead to long waiting periods (Port of Rotterdam 2017).

Unknown times of arrival lead to planning uncertainties for pilots, tugs, terminal operators and many other shore-based stakeholders. A non-automated information exchange leads to laborious, error-prone and time-consuming communication processes between the ship and the different maritime stakeholders (Pahl and Voß 2017). Nevertheless, it should be mentioned that some maritime stakeholders, such as liner shipping companies berthing at their own terminal, are not affected by the aforementioned issues. A statistical analysis from October 2015 stated, that the Direct Berth Rate (DBR) of the port of Hamburg was 9.38%, representing that more than 90% of the arriving vessels have to be at anchor before entering the port of Hamburg. In comparison, the DBR of the port of Felixstowe was 72% and the DBR of the port of Rotterdam was 70% (World Maritime News 2015).

Within this paper, the potential of an optimized port call should be discussed by means of an automated estimation of the time of arrival. This paper

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commences with an overview of the collaborative research project VESTVIND[1]. The objective, concept and model are presented within Sect. 2. Possible effects of the VESTVIND project on an optimized port call can be found in the Sect. 3. Finally, the paper concludes by a summary of results and an outlook.

2 The VESTVIND Project

Aiming to develop an algorithm to forecast maritime traffic, especially estimating ships' time of arrival in the German sea ports, VESTVIND is a collaborative research project of Fraunhofer CML and TRENZ AG, partly funded by the IFB[2]. The project aims at estimating ships' arrival and departure times at all major German ports with an automated calculation in real-time. The estimated values are visualized within a web application (Real-ETA 2017).

2.1 VESTVIND's Concept and Model Parameters

Many factors influence the movement of a vessel. Traffic separation schemes lead to strict route keeping within the fairway, harsh weather situations lead to the choice of another shipping route, actual wind or current conditions or strict restrictions regarding emissions lead to speed regulations during the voyage of a ship. Within the VESTVIND project, the ship parameters length, breadth, draught and geographical position of a trip as well as the environmental data wind, current, sea state and water depth will be considered for the purpose of predicting near-coast maritime traffic (Scheidweiler et al. 2016).

Ship movement data is gathered from the Automatic Identification System (AIS), which has been introduced by the International Maritime Organization in 2004 (IMO 2004). Efficiency and security of maritime traffic could be increased by the automated exchange of position, speed, course and many other variables from ship to ship or ship to base-station (ITU 2014). To investigate the influences of the environmental data on ship movements, the data is projected onto a predefined $n \times m-$dimensional grid with a grid-with of $a \times a$ metres. Given a ship position $(\varphi, \lambda) \in \mathbb{R}^2$ received from the AIS, the corresponding grid point (x_i, y_j) for $i = 1, ..., n$ and $j = 1, ..., m$ is given by

$$x_i = \frac{\lambda \cdot 1862 \cdot 60}{a} \text{ and } y_j = \frac{\varphi \cdot 1852 \cdot 60 \cdot \cos\left(\lambda \cdot \frac{\pi}{180}\right)}{a}.$$

The aggregation of ship movement and environmental data is used to forecast the time of arrival as described in the next section.

2.2 VESTVIND's Methodology

The prediction of the time of arrival of a specified ship in a specified port is based on four steps, which are described in the sections below.

[1] Vessel Traffic - Vorhersage Informationsdienst (Vessel Traffic Prediction Information Service).

[2] Investitionsförderbank.

Generation of Trips. By means of the voyage data of the AIS, historical trips representing a complete voyage from berth to berth are generated for each ship to use the historical trip data for forecasting the standard shipping route as well as the speed later on. A trip $T = \{t_1, ..., t_n | t_i \in \mathbb{N}\}$ contains $t_i \in \mathbb{T}$ trip segments for $i = 1, ..., n$. The dynamic position data of two AIS messages from a specified ship whose time difference $\Delta_t \in \mathbb{R}_{>0}$ is less than 15 min is combined to the same trip segment, given that the vessel is making speed. If Δ_t is larger than 15 min, a new trip segment is generated consisting of a start and end position. Finally, the segments t_i are combined to a trip T: By using of polygons representing the ports of the North and Baltic Sea, intersections of the start and/or end position of a trip segment with the ports are determined.

Classification of Ships. Due to the lack of ship model data or shipping company policies within the AIS database, ships are classified according to their length, breadth and draught differences. It is assumed that "similar" ships move on similar routes and have the similar speed distributions on this routes. Given a trip T_i of a vessel i with $m_i \in \mathbb{N}, l_i, b_i, d_i \in \mathbb{R}$ representing the MMSI, length, breadth and draught of a vessel and t_i representing the current time stamp and the parameters $m_s \in \mathbb{N}, l_s, b_s, d_s \in \mathbb{R}$ and time t_s of ships with same destination and $t_i > t_s \, \forall \, s$, ships are classified by their similarity. The similarity factor $r_s \in \mathbb{R}$ is given by

$$r_s := r_{start} + f_m - f_l|l_i - l_s| - f_b|b_i - b_s| - d \cdot f_d|d_i - d_s|$$

with $f_m = 5$ if $m_s = m_i$ and $f_m = 0$ if $m_s \neq m_i$ and $r_{start} = 100 + f_m$, if $m_i = m_s$ and $r_{start} = 100$ else. The factor d is used to weight the influence of the draught differences with $d = 2$ if $d_i - d_s > 0$ and $d = 1$ else and the factors f_l, f_b and $f_d \in \mathbb{N}$ are used to weight the differences accordingly. The algorithm is then based on a subset of all ships with ranking factor $r_s > c$ given a threshold c. After extracting the subset of similar ships, the ships are classified according to their speeds compared to the actual speed of the ship, which ETA has to be predicted, as well as the differences regarding the maximum speed. Finally, the best fitting trips are extracted.

Standard Shipping Routes. Standard routes are used to assign weather forecasts. Given the historical grid points g_i of the subset of best fitting ships and trips, the crossings of each position are counted for all trips $T \in \mathbb{N}$ with $G_i := \sum_{i=1}^{T} g_i$. Given a predefined threshold g_c a grid point G_i is assigned to the standard shipping route if $G_i > g_c$.

Estimated Time of Arrival (ETA). A multi-layer artificial neural network, which consists of one input layer, two hidden layers and one output layer (cf. Fig. 1), is used to predict the time of arrival of a specified vessel. Since the statistical correlation between the dependent and independent variables is unknown, multivariate regression techniques cannot be applied. Artificial neural networks are used to model the unknown relationship between the speed over ground and the environmental parameters as well as the static vessel data.

The input parameters $x_1, ..., x_6 \in \mathbb{R}$ represent the wind speed and direction, current speed and direction, water level, significant wave height and an area indicator x_7 with $x_7 = 0$ if the ship is moving in open sea and $x_7 = 0$ else. The output parameter $y \in \mathbb{R}_{>0}$ is defined as the travel time to the destination which should be computed using the trained neural network. Before training the network, the input and output data is normalized within the interval $[-1, 1]$ (Abramowski 2008). Because of the differentiability, which is needed for the gradient descent within backpropagation used to recalculate the weight, the tanh-function is used as an activation function for training the network. Additionally, neurons of each layer are connected with constant values to improve the effectiveness of the learning process (Shanmuganthan and Samarasinghe 2016). After training the network, the ETA will be calculated by addition of the current time stamp and the denormalized travel time, which is computed by the weather forecasts as well as the area indicators at the predicted standard route through the network.

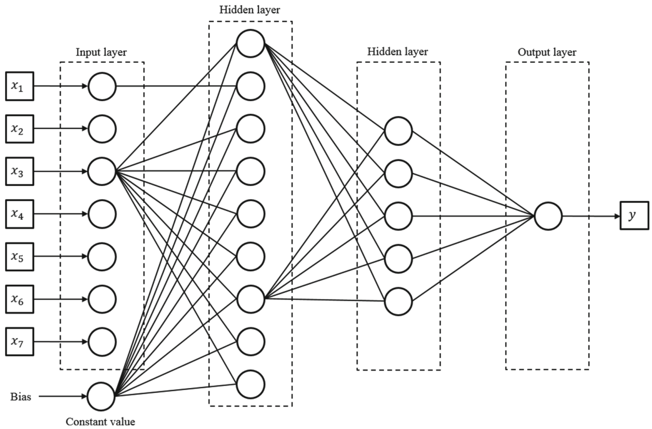

Fig. 1. Structure of the artificial neural network used for ETA calculation. For reasons of clarity, only a subset of connections is displayed. Based on Abramowski (2008).

3 VESTVIND's Effects on Port Call Optimization

In order to plan and optimize the allocation and usage of berths as effectively as possible, terminal operators need detailed information about vessels' time of arrival and possible delays to recalculate berth allocations. Due to manual inputs of the ETA in the AIS, this information is often incorrect or missing. A study from 2003 placed that 49% of the AIS transmissions "showed obvious errors in the field of [...] ETA" (Harathi-Mokthari et al. 2008). In addition, the ETA is not updated automatically, so that the ports do not receive any information about delayed or premature arrivals (Harathi-Mokthari et al. 2008). By providing an automated ETA, a first concrete step forward on the path towards an automated information exchange in maritime traffic and improvements of operational processes in ports (Haraldson 2015), (Burmeister et al. 2012) and the maritime logistic chain (Jahn et al. 2017) can be achieved.

The optimization of port calls comprises an efficient use of ports' infrastructure and resources. Receiving an updated ETA, the port can quickly respond to changes, rapidly adjust the berth plan and control the hinterland transport. Despite existing port constraints like tug, pilot, berth and crane facilities, a more efficient and coordinated planning of a high number on ever-larger vessels calling the port will be possible. Pilots and tugs can better plan and optimize their operations by not requesting them too early or too late, thus reducing expensive waiting times. Dock bookings can be postponed in advance, which leads to considerable cost savings for the ship owners. Since tidal and water levels are taken into account within the algorithm, the speed can be throttled in advance to reduce waiting times at anchorage for reaching the flood wave. This leads to considerable fuel and emission reductions of the ship.

4 Conclusion and Outlook

This paper has presented a concept for forecasting ships' time of arrival in the German seaports with regards to port call optimization. Artificial neural network modelling is a widely used technique in many big data problems and complex systems. From the first internal verifications of the algorithm on the basis of historical AIS and environmental data of the year 2016, it can be concluded that the developed algorithm performs according to its previously defined forecast quality: On average, the predictions were within the specified accuracy window (forecast for the next 24 h with an accuracy of ± 1 h). However, artificial neural networks also have its limitations, since many parameters like human factors influencing ships' speed and travel time are omitted. Taking into account additional input parameters, such as lock capacities, traffic service regulations and traffic densities, the prediction quality of the algorithm will increase. Thus, the developed algorithm is a good basis but also requires further enhancement.

Taken as a whole, the ETA-algorithm contributes to the optimization of port calls in various ways: the waiting times of ships at anchorage can be minimized, waiting times of pilots at pilot points can be reduced, berths can be allocated more efficiently, waiting times for the hinterland transport can be shortened and fuel costs and emissions can be reduced. With an optimized port call a further step towards the digitalization of the maritime logistic chain can be achieved. A system that provides the ETAs using the proposed algorithm should mainly be operated by terminal and port operators as well as by port authorities. In addition, it is desirable to establish a network of all European ports to better coordinate and optimize the port call.

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Sub-Sahara African from Seaports and Their Influence on Pharmaceutical Chains

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Abstract. The problems of congestion in the seaports of the sub-Saharan region are phenomenon that are interrelated to delays in the delivery of goods. Causes can be missing process transparency or rather a mismanagement of agencies or inadequate communication and cooperation between the actors. Temperature sensitive goods like pharmaceutical products can serve as an example. More than 90% of pharmaceutical products used in the sub-Saharan region arrive via sea route and are further transported towards the inland or neighbouring landlocked countries (Therrien 2014, Schumann and Streit-Juotsa 2014). Additionally, more than 80% of external trade of these regions' countries is channelled through the ports (Njinkeu et al. 2008). Despite the extensive goods transactions in the ports, the freight's logistics to rural regions and the hinterland is subject to difficult conditions. This paper aims to show the significance of the ports of Douala for the development of the region but also discusses the impact of congested ports for the logistics of pharmaceutical products. The lack of transparency in processes of sea ports will be considered just like the overall logistical activities between sea port and hinterland.

Keywords: Maritime transport · Port congestion · Logistics · Seaport logistics Transport · Hinterland · Pharmaceutical logistics · sub-Saharan-Africa

1 Introduction

In the worldwide trade, the maritime way is the most used transport mode for goods. With little waiting time in the port and good transporting possibilities and conditions, most countries can profit efficient and effective from the trade of goods. In the last decades, the maritime traffic was subject to significant developments and is defined by a big growth in the segment of container traffic. To profit from economies of scale, shipping companies invested in the growing market of container vessels. This trend towards bigger vessels will pressure the development of better port facilities and strengthen the resulting improvement of port productivity (Caschili and Medda 2013, OECD/ITF 2015). In the countries south of Sahara, freight still spends an unusual long time in the ports before being processed further. This poses a serious obstacle to a successful integration of sub-Saharan economies into the worldwide trade networks

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(Gidado 2015). A World Bank study by the title "Why Cargo Dwell Time Matters in Trade", which analysed six sea ports of the sub-Saharan region – Durban, Douala, Lomé, Tema, Mombasa, and Dar es Salam – shows that among those only the port of Durban meets the international standard (four days). The study additionally shows that the average waiting time of freight of ca. 20 days is usually a result of delay in transaction and storage time. Half of this time could be used to transport the freight goods from the ports to the hinterland ("Global Ranking 2016"). Even though ca. 90% of freight volume in sub-Sahara Africa is transported in containers on trucks towards the hinterland, the coordination of logistics processes on the last mile is paid little attention. The example of the sea port of Douala shows long-lasting controls and a significantly long freight goods time in the port (World Bank 2012, 2015).

2 Literature Review and Objective

Most solutions for overstrained seaports examine the optimisation of truck costs. In his article Chang (Chang 2009) presents the complexity of congestion problems in the port and introduces a method to optimise the truck costs. In this model (among other factors) the varying capacity of trucks in the different seasons is analysed. Additionally a sensitivity analysis was conducted to determine which alternative of optimisation would provide the highest increase in efficiency and cost efficiency. In other scientific articles the concept of variations in the period of revolution of ships and freight was examined vis-à-vis the capacity of the port and the relative efficiency. Active influencing factors were identified which cause the port congestions in African sea ports. The results of the concept suggest that a combination of mismanagement and bad regulation of capacities cause the overload problems in the sea ports of the sub-Saharan region. As a solution, an improvement of regulating mechanisms is recommended to increase the efficiency and capacities in the ports (Gidago 2015).

Other scientific research discusses the concept of port attractiveness. It explores the impact of macroeconomic, socioeconomic and infrastructural variability on the different economic and financial possibilities on the African continent (Caschili and Medda 2013). It focuses to a greater extent on the costs caused by port congestions (storage and customs costs).

World Bank has also financed research projects, for example "Les Port Maritimes en Afrique de l'Ouest et du centre – Les defits à relevées" (World Bank 2007). A different study published in 2011 gives attention to the infrastructure of Cameroon as a perspective for the continent (World Bank 2011). Furthermore, an article published in 2011 called "Determinants of a regional port-centric logistics hub: The case of East – Africa" by Haralambides et al., analyses and identifies the criteria of economic potential on the basis of the logistical costs of alternative hub-port-locations in the seaports of East-Africa (Haralambides et al. 2011).

Literature review showed that a transparent description of the logistical processes in the port itself and the hinterland should be carried out, nor the impact of congestion problems on temperature sensitive freight goods such as pharmaceuticals should be examined. In reference to the state of science, this paper aims to show the challenges of sea port logistics in the sub-Saharan region with example of the sea ports of Cameroon (e.g. sea port of Douala). Additionally the problem of congestion of the port through unavailable capacities (e.g. physical, technical, and infrastructural), which strongly influences the qualitative and quantitative goods movements for the hinterland is analyzed. The approximate analysis of overall activities (coordination and communication between the sea port actors), which are connected to the sea port logistics and support the pharmaceutical provision in the follow-up logistics (last mile) is a component of the project. It can further the attention for logistical requirements of temperature sensitive goods in the region.

3 Port Congestion and Challenge for the Sea Port Logistics

World Bank's working document from 2015 titled "Cameroon Economic Update" evaluates the performance of the sea port in Douala: the long waiting times of the vessel and the freight goods in the port of Douala – from arrival to docking or delivering of the goods to importers – is caused by bad port management. A worse performing port reduces the trade volume of a port and therefore weakens its competitive ability (Schumann-Bölsche et al. 2015, Global Ranking 2016). The trade and traffic advancement are important instruments for market integration and the performance or rather efficiency of a port, to lower trade business costs and therefore reduce the margin between the national and the international prices, benefiting costumer and producer (Njinkeu et al. 2008). The current infrastructural standard in this sea port does not meet the requirements of international sea traffic: originally, the normal workload capacity of freight goods in Douala's sea port was set to five to six million tons. In 2015 it received 11 million tons of freight goods (Ministere des travaux publics 2016). This shows a doubling of capacities necessary with only little actual change in infrastructure. The constantly growing amount of freight goods in this port was already detected seven years ago. On the one hand, this development shows the big importance of the port for the region and the neighbouring countries. On the other hand it shows – with almost unchanged physical and technical capacities that potential for improvement exists in the management of this port. The development of the sub-Saharan region furthermore requires investments in transport and other areas. The countries of the Sub-Saharan region have limitations such as remoteness, size, fragmentation, transport logistics and weaker capacity to use financial and other services. Their markets are smaller and more fragile. Weak infrastructure, a low entrepreneurial base, and a lack of support at national and regional level does not help enhance productivity. This undermines the development of regional and global value chains along with competitiveness. (AfDB et al. 2014).

Additionally to the waiting time in the port, the transport times for the hinterland and for the remote regions are calculated. The long delays in the port are connected to missing transparency in various areas – e.g. the time for customs declaration (from unloading of the ship to registration of customs), the time for declaration (from declaration assessment to payment of customs fees), and the time needed to receive a permission of departure (from registration payment to issuing of permission of departure). Thereafter the follow-up logistics takes over, which is defined by processes of good movement from leaving of the port area to the delivery to the final consumer. The effectivity of the follow-up processes depends on the requirements of multimodal traffic operators. The official traffic and transport regulations and the legal safety of economic actors in the sub-Saharan countries is not always given.

4 Influence of Port Congestion on the Pharmaceutical Logistics in the Sub-Saharan Region

In the countries of the sub-Saharan region approx. 46% of people live in rural areas. Despite this big population, the access to and the mobility in these regions is challenging. The health facilities are on average 30 to 50 km from most inhabited areas. Additionally, the streets are not usable under bad weather conditions and therefore the supply of the region with necessary goods like pharmaceuticals is severely limited (UN 2015, Gwilliam 2011).

The World Health Organisation (WHO) demands in its “Guide for good storage practices for pharmaceuticals” the control and record keeping of critical parameters like temperature and humidity. The integrity and quality of pharmaceuticals to the final customer can only be provided, if regulations regarding the storage and transport/handling are met. The recommended practice is not limited to pharmaceutic manufacturers, but stretches to importers, third party logistics, and retailers. Especially in developing countries these guidelines can often not be realised, since the cold chain is interrupted often (Schumann and Streit-Juotsa 2014, Schön et al. 2014, Schöpperle 2013). The missing keeping of the official requirements to storage and transport can partially be explained through the precarious condition of infrastructure, but also through limited knowledge of the employees in the handling of pharma products (Specht and Hunkel 2010). In the international comparison (“Global Ranking 2016”) of the Logistics Performance Index of 160 countries, Cameroon takes place 148. The temperature determinations must be observed during transport, handling, and storage. The WHO regulations are to be distinguished four temperature range:

Deep frozen:	15°C to 0°C	Cool:	+8°C to +15°C
Cold:	+2°C to +8°C	Room temperature:	+15°C to +25°C

Through storage in to high temperature or humidity, pharmaceuticals verifiable lose effectiveness. Due to cost factors some of the pharmaceuticals are shipped through the maritime traffic and stored in non-refrigerated containers. In the sea port of Douala, pharmaceutical containers (no refrigerated containers) are stored for one to four weeks, while the customs handling takes place (Schumann and Streit-Juotsa 2014). From a climate perspective, high temperatures (above 35 °C) and humidity are not unusual in the dry season of the sub-Saharan region. The long waiting time of goods at the port due to the delay in customs clearance procedures and the lack of port infrastructure means that restrictions on movements of goods flow occur both in the port itself and in the last mile or in the hinterland. Further consequences include reduced quality of the end products, reinforced by unsuitable transport and logistics infrastructure. These facts dictate that the cold chain for temperature sensitive goods cannot be maintained and therefore the logistics cannot fulfil their complete function. To improve the logistical activities in the supply chain, the following options exist: A transparent representation of the logistics processes in order to clearly define tasks and responsibilities in the processes. All actors involved in the process can thus be assigned and supported by coordination and communication measures. Regarding the cold chain problem in the drug supply chain, appropriate measures can be defined after careful observation.

5 Summary

In national just like in global context, in both of which the sea traffic and port sector in the sub-Saharan region is present, there are multiple long-term developments necessary in different areas. The size of ships, especially container ships will continue to grow. This needs to lead to effective and efficient implementation or configuration of port infrastructure in the region. An easement of transport movement between sea port and hinterland is necessary to improve the state of traffic in the country. This calls for transparent description of the logistical processes in the port and the follow-up, to reach improvement and innovation possibilities. Which measures need to be developed in short-, middle- and long-term to provide the quantitative and qualitative flow of goods between port and hinterland? The solution will not only positively influence the attractiveness of shipping companies but will lead to an improvement of the living situation of people in the affected countries. Despite the variability of the logistical development backlog in the countries of the sub-Saharan region, a concept will be designed that tries to adapt to the heterogeneity of the countries. This way, simple or modern technologies can be applied in transport, handling, and storage, to ensure the quality of the goods at the end of the chain. Further research is needed to improve logistical conditions in the region.

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Global Value Chains and Supply Chain Trade: How Organizations Create Sustainable Business Models

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Abstract. To take a lead in the digital revolution, if not at least in order to follow it, organizations comprehensively review their business models. Falling transport costs and decreasing costs for information exchange have propelled the emergence of global value chains and with it supply chain trade. Whereas the former have enabled firms to move production of goods away from the places of consumption, the latter drive production being split up into individual tasks performed at different locations worldwide. Now, digitalization drives a third wave with considerable impact on the future commercial sustainability of business models in manufacturing, trade and, last but not least, logistics. This paper will use Baldwin's concept of the Two Unbundlings to explain globalization from a historical perspective and assess the implications of this development on the logistics industry, which benefited in past, but must now be on the lookout to meet the changing needs of their trading and manufacturing clients.

Keywords: Globalization · Digitalization · Innovation · Value chains
Supply chain trade · Unbundlings · Logistics service providers

1 A Historical Perspective with Current Value: How Globalization Shapes (Logistics) Business Models

The demand for logistics services is derived demand. The shape and volume of logistics services is dependent on decisions made in manufacturing or trading companies. Logisticians need to understand the drivers that shape the industries they are serving. One of those drivers has been globalization. In two waves, following a reduction in transport costs and the costs for exchanging information, global trade thrived, and with it the logistics industry.

The first wave of reduced transport costs facilitated the exchange of raw materials and finished goods. Falling transport costs have enabled firms to move production of goods away from the places of consumption. The second wave led to the emergence of supply chain trade (Baldwin 2006: p. 23). Lower costs of information exchange split production into individual tasks performed at different locations worldwide. As such,

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semi-finished items are moved around several times before being assembled into the finished good.

The paper takes on a historical perspective to explain the nature of trade in the context of globalization. It will use Baldwin's concept of the Two Unbundlings to explain globalization, and the emergence of supply chain trade that both benefited and got facilitated by the logistics industry. It will argue how two waves of globalization have shaped global value chains and a new paradigm of "task-by-task" competition. Now, digitalization is ushering in a third wave bringing new challenges. The use of renewed near-shoring and of additive manufacturing techniques are just two examples. Digitalization brings down manufacturing costs and shape business models once again.

2 The Two Waves of Globalization: From a Surplus Economy to Global Supply Chain Trade

Although trade has been around since at least 3,000 BC, nothing has had a so lasting impact on it than the introduction of hydrocarbons as fuel in shipping and rail at the beginning of the Industrial Revolution and the dramatic fall in the costs for information exchange around the world (Bernstein 2008; Vries 2012: p. 7, 28). In former times it took ages to move goods around in horse-drawn carriages or even on foot. It took ages to move information around by word-of-mouth instead of regular postal services, the telegraph, or even telephone and not to mention today's email. These constraints let production and consumption bundle together. In a village economy, everything what was consumed, was produced locally. Only the surplus, if any, could be traded and exchanged for other goods (Vries 2012: p. 8, 20). During and after the Middle Age, international trade focused on raw material and precious items, such as silver (Findlay/ O'Rourke 2007).

The emergence of cheaper transport and information exchange changed all this. Taking on full steam from the early 1700 s onwards, with the commercial use of the first steam engine and lasting until c.1960, the first wave of globalization unbundled production and consumption. In one nation, raw materials could be grown and harvested, whereas in others these got transformed into finished goods. These finished goods were then consumed in even a third nation (Baldwin 2012: p. 1).

In this, what Baldwin calls the "First Unbundling", the costs of moving goods around decreased. The costs of moving information, and thus of moving ideas around, were still prohibitively expensive, leading to high coordination costs. Thus, production still used to be vertically integrated due to high costs of coordination. (Baldwin 2006: p. 7). Clusters of economic activities emerged. The concentrations of the textile industry in England or the steel industry in the German Rhine-Ruhr area are two examples. In these clusters, national teams of ideas and workers battled for supremacy on global consumption markets (Baldwin 2012: p. 2; Vries 2012: p. 15).

Since the early 1990s globalization has changed face again. The Internet has lowered the costs of moving ideas. A second unbundling has seen production falling apart itself. The decrease in coordination costs enabled firms to deploy production activities in different locations around the world and coordinate them centrally. As a result, goods travel the world no longer in raw or finished form, but as semi-finished items (Baldwin 2006: p. 23).

3 The Concept of "Task-by-Task" Competition: A New Paradigm!

The unbundlings have profound impacts on the competitive strategies of firms, and as such, on the logistics industry. During the first wave of globalization, firms competed on a "company-by-company" basis. The second unbundling forged supply chain trades: Those appear when production is disaggregated on to task- or activity-level (Baldwin 2012: p. 1).

Christopher gets this on the point: "There has been a dramatic shift away from the predominantly 'local for local' manufacturing and marketing strategy of the past. Now, through offshore sourcing, manufacturing and assembly, supply chains extend from one side of the globe to the other." (Christopher 2011).

Competition on the activity-level, or on a "task-by-task" level, requires firms to reconsider the performance of each task in terms of its place, method and timing. Firms follow a new paradigm of business competitiveness: "the task [is, sic.] the identifier, rather than the sector. There [is, sic.] competition between the same tasks being performed in different nations" (Baldwin 2006: p. 23).

Firms are seeking arbitrage of using low-cost environments for carrying out simple production processes with final assembly of the product in high-wage countries; a fact that is reflected in the plummeting shares of manufacturing in the G7-countries in the 1980s and 1990s; and the resulting increase in a handful of developing nations (Baldwin 2011: p. 2) as well as a steep increase in containerization (UNCTAD 2016).

Driven further by consumption in the Western world (Ferguson 2011), task-by-task competition has formed entire industries of offshoring services and value-added logistics which in turn facilitated trade further (Veenstra 2015: p. 12). It has benefitted freight forwarders, shipping lines and third-party logistics service providers offering transportation, warehousing and light manufacturing services in all but the remotest locations around the world.

4 Conclusions from the New Paradigm: Seeking Competitiveness Through a Rearrangement of Organizational Processes

The new paradigm in the wake of the second unbundling requires a completely new set of corporate competitive thinking. Task-by-task competition requires a review of the underlying business models of a firm. Firms need to ask what is the combination of processes that determines the firm's value chain. For firms, there is an opportunity to rearrange processes and concentrate on those where they cannot be replaced by competitors. A rearrangement needs a corresponding review of the revenue model. Focusing on existing and stable processes that are merely optimized does not sustain competitive advantage; there are still tasks which might be offshored and which might endanger the firm's competitiveness.

A one-sided focus on efficiency gains risks a loss of the uniqueness of a firm. Traditional optimization tools neglect the individual composition of activities in each organization. Best example is the implementation of supposedly powerful ERP-software solutions. More often than not, these require the rewriting of existing processes to the needs of the system, rather than the needs of firm's source of competiveness and, thus, its commercial sustainability.

A good example is the automotive industry. A brand in the industry no longer stands for a particular sort of hardware that offers a certain benefit to the consumer, but a distinct combination of services plus hardware, for example a ride sharing business delivered with cars of a certain make.

Logistics must be aware that new paradigm is not about incremental productivity increases. It is all about a radical rearrangement of business processes. The industry must be aware that their clients seek to formulate resilient business cases that will for sure look different from today's.

5 Implications on Global Value Chains from Digitalization

The requirement of new thinking does not end here. As logistics is derived demand, we need to understand the wider implications of corporate digitalization understood as an opportunity to lower manufacturing costs. Following the second unbundling, on a strategic level, in many sectors radical rearrangements of processes take place, not only an optimization of existing tasks.

Lowering the manufacturing costs driven by digitalization will change the face of supply chain trade further. There will be other forms of derived demand driven by digitalization. At first sight, digitalization is a logical consequence of the human quest to optimize processes. However, this is a far too short-terministic approach: what happens, if there is a re-arrangement of tasks coupled with the opportunities of digitalization?

This combination might allow firms to integrate and relocate production closer to the centers of demand. The rise of labor costs in Asia, in particular China, gradually eats away the manufacturing cost advantage over developed markets. It limits the arbitrage opportunities of unbundling production activities and moving tasks to lower-wage environments.

The eroding of the Asian labor cost advantages for US-American and European companies can have two implications. First, in accordance with the "tasks-by-task" paradigm, activities might be relocated to other, more advantageous locations. In future, central Asia or Africa might play a role here. In terms of Asia, this might entail keeping it in Asia and betting on future economic expansion in this region, or relocating to US or Europe. Second, the recent example of Adidas' new "Speedfactory" to be located in high-wage Germany is a prime example. It will use robots and novel production techniques such as additive manufacturing. Avoiding ordering semi-finished items from suppliers that will be assembled into a new pair of shoes, the factory will again vertically integrate production from raw material stage, such as plastics, fibers and other basic substances using highly automated machines and additive manufacturing techniques (Economist 2017).

This regionalization of supply chains, whereby shippers gain the benefits of using less fuel, saving costs and reducing emissions, results in less long-haul transport and more short-haul carriage (Millar 2017).

The logistics industry, benefited in past from a second wave of globalization, must now be on the lookout to meet the changing needs of their trading and manufacturing clients in order not to be washed away by the upcoming third wave.

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Security in Maritime Logistics – Learning by Gaming

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Abstract. In maritime supply chains several measures are in place in order to mitigate different security risks. Future managers for security in supply chains need to be trained to select appropriate measures on different security related risks. This paper describes one practical approach to train personnel on security risks, mitigation measures and mechanisms between these two interacting themes. In detail, the approach follows the game based learning (GBL) concept.

Keywords: Maritime security · Security mitigation measures · Serious games

1 Introduction

Maritime supply chains use the concept of intermodal transports which lead to waiting times in intermodal terminals where a container could be accessible for criminals. In addition, truck transports are also endangered at public parking areas while the driver is at rest or even absent from truck. Consequently, there are risks of cargo theft and insertion of contraband for the purpose of smuggle. Maritime supply chains are also endangered by modern piracy. In addition there is still the fear of terrorist attacks on supply chains.

In order to control these security risks several mitigation measures have been developed. These measures are capable to lower the probability and/or to reduce the consequences of risks.

To support the decision process future managers for security in supply chains need to be trained. Students in the field of supply chain security have to learn these risks and corresponding mitigation measures. Instead of a classical lecture it was concluded to let the students experience these dependencies. Consequently, a serious game in the field of supply chain security was developed.

2 Serious Games – Game Based Learning

Serious games allow students to experience situations which are too costly and/or hazardous in the real world. (Charsky and Mims 2008) stated that games are a valuable

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instructional method and strategy for teaching a wide variety of content. According to different studies about game based learning (GBL) students reported more interest in games than in classical lectures (Tobias and Fletcher 2011).

Business simulations are commonly used in management education (Keys and Wolfe 1990). The well-known Beer Game was developed in early 1960's (Forrester 1961) and is still used in management education to teach the bullwhip effect.

In order to enable students to experience the dependency between risks and measures in the field of supply chain security a first version of the Supply Chain Security Game (SCSG) has been developed. Players should play the game to get a broader understanding of risk management and to experience which measure could be used against which security risk. The SCSG is a board game which also describes the usage of different transport modes in order to cover different risks for different transport modes.

The following sections describe the background of the game and some examples of risks and mitigation measures which have been implemented.

3 Background of the Supply Chain Security Game

Each player acts as a supply chain manager who has to organise the whole transport from a source to a destination warehouse. Depending on the actual transport order each player has to decide which mitigation measures should be used in order to decrease the likelihood and/or the consequences of the security risks.

3.1 Supply Chain Security Risks

Different kinds of security related risks are used in the game. In order to decrease the complexity, the game is a limited representation of the real world setting. In detail, only selected risks and measures are used and are also simplified.

As mentioned in (Europol 2009) transports are endangered by the risk cargo theft. According to (FreightWatch 2013) criminals try to steal cargo from a truck which is parked in unsecured parking areas. Another scenario is theft in a warehouse where burglars try to steal goods out of a warehouse. Goods can be smuggled in legal shipping containers, for example bribed employees of a warehouse hide drugs in regular containers. Another risk is maritime piracy – the International Maritime Organization describes in (IMO 2013) different incidents in this field, like hijacking and robbery. In addition, the game also covers different scenarios in the field of terrorism. These scenarios were derived from a study of (DNV Consulting 2005) which describes possible attacks on terminals, tunnels and bridges. The game also takes the contrary relationship of low likelihood and severe consequences of terroristic attacks into account.

3.2 Mitigation Measures

Players of the game have the opportunity to invest in ten different independent measures, for example: secure parking of trucks, route planning by using the Incident Information

Service of the TAPA (TAPA 2017), training of personnel and Container Security Devices (McKinney and Radford 2014).

4 Model of the Supply Chain Security Game

During the development process of the SCSG a domain model was created in order to model all objects and their associations of the game. Figure 1 illustrates a simplified diagram of the domain model.

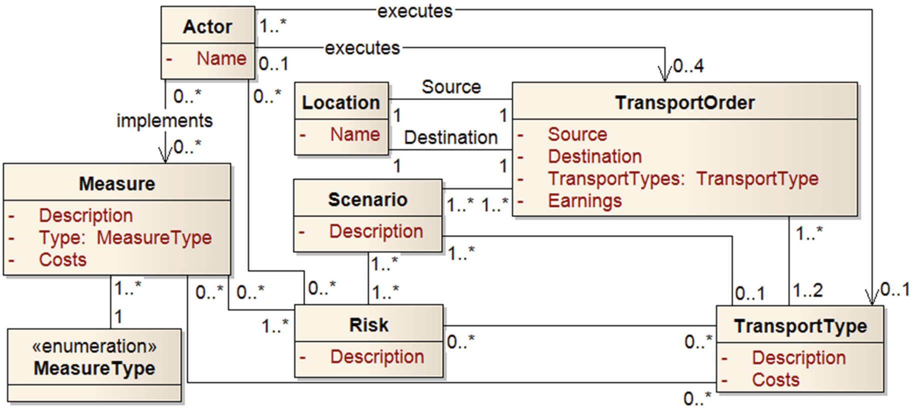

Fig. 1. Domain model of the Supply Chain Security Game

The class 'Actor', describes roles of supply chain actors (e.g. carrier and freight forwarder). Each player acts as a logistic service provider and has to fulfil 'Transport Orders'. These 'Transport Orders' describe a start and destination location of the transport and the earnings for its fulfilment. In addition, depending on the terminals, the pre- and post-carriage can be carried out by truck or train. Therefore, different costs have to be applied.

Each risk is linked to one-to-many scenarios. For example, the risk of theft offers a variety of modi operandi (e.g. theft in warehouse) which are modelled as scenarios. These scenarios are associated with the 'Transport Type' in order to model the link (i.e. theft of cargo from a truck) to a transport type (i.e. truck). In order to cope with risks-scenarios the actors can use mitigation measures. Therefore, in the model each measure is linked to at least one risk. In detail, the model enables measures which mitigate one risk only and measures which are capable to be used for different risks. In contrast, there are risks which cannot be mitigated by measures which are controlled by the players. In example, the players are unable to mitigate the risk of a terroristic attack on a terminal, because the players are not controlling the terminals and are unable to implement the measure 'ISPS Code' (International Ship and Port Facility Security Code).

On the basis of the domain model the game was implemented and tested in several iterations. Afterwards the first release was used in lectures.

5 Description of the Supply Chain Security Game

Aim of the game for each player is to fulfil transport orders and to maximize capital. The game is played in rounds, during a turn the player can continue the transport and can play event cards. The board game consists of the gaming board, different dices, gaming pieces, money and different card sets. Figure 2 shows the gaming board including container terminals, warehouses, pirate areas and transport routes.

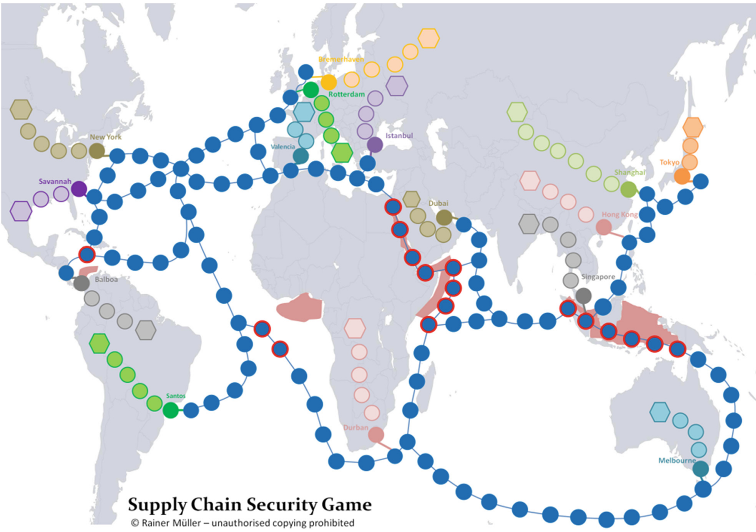

Fig. 2. Supply Chain Security Game board

Transport order cards describe a transport from a source to a destination warehouse which has to be fulfilled by a player.

Each player also has his own deck of measure cards. Each measure card gives a concise explanation of the measure and the price. Depending on the transport order and its configuration each player has to select appropriate measures.

Most important cards of the game are the event cards which are describing different events, mainly risk scenarios. Each scenario describes the risk and also which measure can mitigate the likelihood and/or consequence to which extent. Players can use these cards in order to attack other players with the described risk. The attacked player tries to defend against the attack by the usage of his measures. Depending on the selection of the measures the attack may be averted or the attacked player has to suffer the consequences shown on the card.

6 Conclusion

The first version of the described game was played by several groups of students. In order to get first insight into the effectiveness of the learning process of the game a small feedback survey and a short discussion was carried out. By now, the results so far are promising. Most students concluded that they got a very good insight into the topic of supply chain security. Students also stated that playing the SCSG was more motivating than a classical lecture.

Due to the iterative development of the game next versions will be improved, i.e. reduction of the complexity of the rules. In addition, it is planned to extend the evaluation process by a short exam in order to access the learning outcome by playing the game.

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How Blockchain Could Be Implemented for Exchanging Documentation in the Shipping Industry

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Abstract. The purpose of this study is to investigate the conditions under which blockchain technology can be adopted and the design criteria that are needed for exchanging shipping documentation in containerized shipping. To alleviate the impact of current documentation exchange mechanisms on supply chain efficiency in the maritime industry, this study aims at presenting guidelines for leveraging blockchain technology as a solution for exchanging documentation in the shipping industry. We conduct semi-structured interviews with representatives from business, IT, and public institutions. This qualitative data is analyzed through a theoretical framework comprising transaction cost economics, diffusion of innovation and design theory. Based on the theoretical model and stakeholder analysis, a set of eight design principles are proposed for the successful implementation of blockchain. These are (1) Immutability, (2) Decentralization, (3) Security, (4) Privacy, (5) Compatibility, (6) Scalability, (7) Inclusiveness and (8) Territoriality. Furthermore, the study investigates four potential approaches for the implementation phase affecting the likelihood of adoption by industry stakeholders. The exploratory approach and generic framework provides the groundwork and inspiration for further research in supply chain management and the emerging field of blockchain technology.

Keywords: Blockchain · Distributed ledger technology · Shipping Digitization · Supply chain management · Documentation exchange Maritime logistics

1 Introduction

The invention of the ISO standard for shipping containers in 1960 marked the beginning of a new era in global trade (Levinson 2006). Until then cargo had been moved in nets as break bulk. Adopting containers as a standard unit made it possible to increase utilization rates. Containers could be stacked efficiently on ships, and even on trucks and trains for further intermodal transportation. It allowed all transportation providers to focus on the transportation of 'grey boxes' rather than on which products they moved. The innovation was effectively that the entire industry could agree on one standard size and shape (Bernhofen et al. 2013). Today, the maritime industry needs to

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undergo a similar transformation. Digitization is one of the biggest trends in the 21st century, which opens the possibility for 'containerization' of documentation.

However, the majority of stakeholders in the shipping industry operate with extensive manual handling of documents, including the Bill of Lading, Customs declarations, and the Certificate of Origin. The physical supply chain in international transportation has undergone a thorough process of streamlining and standardization. However, inter-organizational information sharing systems are outdated and manual processes still prevail in large parts of the supply chain. As authorities, often do not have all information readily available, containers stand still almost half of the time of their journey (Jensen et al. 2014). This way, the current *modus operandi* causes a redundant built-in-slack leading to a multitude of problems that drive costs in international trade. The lack of coordination and information sharing results in little transparency and a general lack of trust between the parties involved. For authorities, the lack or inaccuracy of information poses a security risk and an increased workload. Similarly, the inaccuracy of information and delays also affects operational aspects along the supply chain. Many of these challenges point to issues of governance and business processes for inter-firm coordination that do not properly account for the complexity in the supply chain of international trade. The multitude of different actors in the supply chain, their relationships, different regulations, and the cost of information inherently contribute to supply chain barriers, which impede global trade. Therefore, the transportation industry is in dire need cut costs by improving its inter-organizational processes, such as achieving industry-wide digitization of documentation exchanges. The digitization trend of the 21st century delivers the solutions but equally, poses numerous new challenges.

One potential solution that has surged in media popularity is blockchain technology. It has been credited for its revolutionary innovation and versatility. The technology might have profound impacts on society as a whole, but also for the field of supply chain management. However, there is a significant level of technological uncertainty concerning blockchain. Furthermore, nobody knows the required organizational conditions for the technology to reach industry wide adoption necessary to harness its full potential. To compensate for the identified gap, we formulate the following research question: Under which organizational adoption conditions can blockchain be adopted and what are the design criteria for the implementation of blockchain in the exchange of shipping documentation?

We apply a choice of theories to shed light on the various aspects that constitute the adoption of a blockchain based solution. For this, we seek to apply a framework covering various conditions, which combine design, economic and strategic characteristics, to arrive at a blockchain based system that may be adopted successfully by the shipping industry. Based on the array of problems described above and the research gap identified, we thus contribute with a new documentation-sharing paradigm by conducting an exploratory investigation. Moreover, we contribute with an initial understanding about how this system may have to be designed in order to be implemented in the industry.

2 Methodology: Qualitative Case Studies

The empirical evidence for our study stems from 20 interviews with 31 respondents in seven countries. These are split into 10 Skype interviews (primarily used for other geographies) and 10 face-to-face interviews. The geographical scope includes Denmark and India, UK, USA, Norway, The Netherlands, and Germany. We interviewed a total of 20 different companies, which consist of Multinational Enterprises (MNEs), Small and Medium-sized Enterprises (SMEs), public organizations and non-governmental organizations (NGOs). The MNEs are comprised of major carriers, IT vendors and freight forwarders. The SMEs consist of start-ups, start-up facilitators, consultancies, NGOs and freight forwarders. Public organizations include academics and EU project consortia. The period of interviews started in the beginning of January 2017 to the end of March 2017. The identities of the majority of our respondents are anonymised according to agreements made with them.

The interviews were conducted in three stages. First, we aimed at getting an understanding of the maritime industry and evaluate the business case of introducing a block chain based system to tackle the lack, inaccuracy, and inefficiency of sharing information. During this initial phase of the interviews, the scope and direction of our research was refined. Secondly, we interviewed different supply chain actors and their respective interests concerning information sharing along the supply chain. To evaluate potential conflicts of interest we aimed at gaining an understanding of what drivers and barriers to collaboration and sharing of data in the industry might be. During this phase, it became apparent that there have been previous attempts to facilitate sharing of information that often failed or their impact had been negligible on a wider scale. This is believed to be caused by the complexity and geographic scope of the industry. Moreover, interest in the technology was widely received, but a lack of understanding prevailed. Thirdly, we focused the interviews on discerning of how such a system would be adopted by the industry. For this, we inquired about incentivisation, business models and the willingness to test and adopt a blockchain based solution. This was also based on gaining an understanding of what conditions and incentives would make different supply chain actors adopt the solution considering current market trends and technological capabilities.

3 Findings and Conclusion

The overall goal of the paper was to assess how blockchain can be an adoptable solution for exchanging shipping information. Until today it has remained difficult for shipping stakeholders to ascertain that a given digital piece of information is the truth, or the single valid version, which is important when title to shipped goods are handed over amongst independent supply chain actors across national and judicial borders. The finding is that blockchain technology can be adopted for exchanging shipping documentation if designed to solve the inherent challenges of transitioning to digital documentation without jeopardizing the value proposition of the stakeholders involved. There is strong evidence that the ‘containerization’ of shipping documentation will have a profound impact on the industry that could provide a competitive advantage to those that can digitize this flow in a structured and simplified manner.

This paper set out to find the conditions under which a blockchain based system would be adoptable for exchanging shipping documentation. Through our case interviews with the stakeholders we found that these conditions are digitization, dematerialization of documents, streamlining the flow, interoperability, regulation reconcilable, cost reduction, removing reliance on central entities, increased supply chain visibility and encryption to facilitate privacy.

Our study demonstrates that blockchain facilitates the possibility to cut costs and advance global trade as transaction costs are reduced. The reason why blockchain is so decisive is that it has the potential to redefine the way digital information is exchanged, thanks to immutability which is absent in other information technology systems. Therefore, maritime stakeholders should understand that a blockchain based system will lead to considerable operational improvements and cost savings. Changing the status quo would reduce transportation and lead times, resulting in a profound impact on supply chain performance and a wide variety of performance measures within the field. A proof of concept performed by IBM and Mærsk demonstrates a 15% cost saving enabled by IBM's Blockchain technology Hyperledger (Forbes 2017).

Having determined that blockchain can fulfil the prior conditions, we have set forth eight design principles to address the conditions needed to persuade the intended stakeholders. These are immutability, decentralisation, security, privacy, compatibility, scalability, inclusiveness and territoriality.

Our proposed design principles for a blockchain based system are crucial for stakeholders' ability to reap the benefits of this transformation without risking a loss of bargaining power. Particularly those at the centre of the supply chain, such as carriers and forwarders, will see vast gains through digitization, whereas smaller entities further up- and downstream need additional incentives to join. Reallocation of benefits might thus be necessary to contemplate when introducing a blockchain based system. Most importantly, our research finds that blockchain will have profound implications for authorities. The proposed solution would offer compelling advantages, which could streamline operations while making it more complex to conduct fraudulent commerce. When it comes to the 'containerization' of shipping documentation and a second revolution in maritime shipping, we argue that blockchain technology has the potential to transform the industry for advancing international trade in the 21st century. Ultimately, "No matter what the context, there's a strong possibility that blockchain will affect your business. The very big question is when" (Iansiti and Lakhani 2017).

Having fully applied our theoretical framework, we critically assess the degree to which the chosen theories account for all factors influencing adoption of the system. We argue that Everett Rogers' (2003) model for diffusion of innovations is missing the element that the expected approach of implementation has an impact on the likelihood of adoption. This is supported by the argument that prior attempts have failed to reach industry-wide adoption, despite technological brilliance and fulfilment of conditions set by the industry at the time.

To substantiate the findings, four non-mutually exclusive approaches to implementation with varying expected effects on adoption are discussed to elaborate on this criticism. Literature suggests that a bottom-up rather than top-down approach should be the most attractive for far-reaching adoption. Therefore, we hypothesize that to account for the complexity of the industry, a public-private partnership creating an open and collaborative ecosystem approach is a condition for achieving industry-wide adoption. Gathering evidence to support the validation of this hypothesis requires further investigation by academia.

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Analysis of the Choice Behavior for Container Transport Services in the Maritime Hinterland

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Abstract. The handling of the growing container volume is facilitated by standardization and digitalization. This, in turn, makes container transport services offered by actors of the maritime transport chain hard to differentiate. Additionally, ports are faced with fierce competition and the connectivity to the hinterland becomes crucial for their competiveness. Hence, for ports it is necessary to understand the choice behavior of decision-makers in the maritime hinterland to remain competitive. Therefore, a discrete choice model is developed to investigate the preferences of shippers and forwarders for transport services in the maritime hinterland. Transport services are evaluated regarding transport costs, transit time, frequency and IT services by shippers and forwarders operating in South-West Germany. Unsurprisingly, the results reveal that costs, time and frequency are highly important for both decision-makers. However, IT services require a differentiated consideration. Shippers prefer tracking and tracing, whereas forwarders prefer no IT services and reject the introduction of an eMarketplace, which indicates the perceived threat to their business model.

Keywords: Choice behavior · Container transport · Port · Hinterland IT services

1 Introduction and Research Background

The worldwide container port throughput increased from 88 million TEU in 1990 to approximately 691 million TEU in 2016 (Notteboom et al. 2017). Hence, in maritime transportation effective and efficient processes are needed to deal with the enormous amount of containers. From a technological perspective, continuous improvements in automatization and digitalization enhance container handling. Port authorities, terminal operators and carriers are investing in information technology (IT) (e.g. port community systems, automated guided vehicles) to prevent congestion and improve services. However, in the maritime hinterland the progress of digitalization is lagging behind (Harris et al. 2015). The challenges and reasons for the slow progress are: low degree of horizontal cooperation due to fierce competition, complex operative coordination due to uncertainties in the transport process and small investment potential due to low margins (Van der Horst and Van der Lugt 2011). Since the hinterland connectivity becomes crucial for the port competitiveness, actors (e.g. port authorities) intensify investments into the hinterland to increase market shares and differentiate services

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(Acciaro and McKinnon 2013). Thus, the knowledge about the choice behavior of shippers and forwarders in the hinterland can generate competitive advantages for ports.

Research on the port choice behavior is mainly conducted by using surveys or case studies (Flodén et al. 2017). Besides transport costs and transit time, the hinterland connectivity (De Langen 2007) and IT services (Yuen et al. 2012) are ranked as highly important. A second stream in research is the application of discrete choice models (DCM) using selected factors to derive utility values from the stated preferences. In a systematic literature review Culliane and Toy (2000) define the most relevant factors of transport services: transport costs, transit time, frequency, punctuality and additional transport services. Especially the first four are applied in various research studies using DCM (Feo et al. 2011; Arencibia et al. 2015). However, the influence of IT services as additional transport service on the choice behavior remains a research gap.

The research aim of the paper at hand is to analyze, if IT services influence the choice behavior of shippers and forwarders for container transport services in the maritime hinterland. Therefore, a DCM is developed and sent to shippers and forwarders organizing hinterland transportation in South-West Germany. This region is selected because of the high yearly container volume and export quotas (ISL 2015). Additionally, the port choice behavior is not clearly predetermined by distance as it is in e.g. North-East Germany, where ports of northern Germany are clearly favored because of lower lead times and costs. The remainder of the paper is structured as follows. In the next section the research design is described. Then the results are presented. Subsequently, the paper ends with the conclusions.

2 Research Design

In accordance to the approach of Arencibia et al. (2015) the scenario, attributes and levels of the DCM were discussed and validated in face-to-face interviews with managers from a port and an intermodal operator responsible for hinterland connections in South-West Germany. The DCM starts with a short description of the methodology and scenario as well as the definition of the attributes and levels (see Table 1). In the scenario the transport source is defined in the center of the considered region, 50 km away from the next trimodal hinterland terminal and, in turn, 600 km away from the port. The intermodal operator provided data regarding transport costs, transit times and frequencies for the considered region and distances to derive the levels of the attributes. The transport costs (in €/shipment) contain hinterland transport, storage and transshipment costs. The levels are average values for transport sources in South-West Germany using intermodal transport (barge and rail) to the four biggest ports of the north range (Rotterdam, Hamburg, Antwerp and Bremerhaven). The same applies to transit time containing average values of short (15 h) and long (20 h) rail and average barge (40 h) transports. For the attribute frequency the levels comprise the number of weekly rail and barge departures from hinterland terminals considering low (2 times/week), average (3 times/week) and high frequented (5 times/week) relations. The first level of IT services contains no additional service. Level two and three are selected based on the categorization of Harris et al. (2015) using eMarketplace (an integrated booking platform aligning transport supply and demand) and tracking and tracing (an application for location and status information of containers).

Table 1. Attributes and levels of the DCM

Attributes	Levels		
Transport costs	450 €	480 €	550 €
Transit time	15 h	20 h	40 h
Frequency	2 times/week	3 times/week	5 times/week
IT services	none	eMarketplace	Tracking and tracing

For the DCM the software QuestionPro and a stepwise disclosure format is chosen. The DCM is based on a multi-nominal logit model, which is the mostly used model due to simplicity and robustness (Street et al. 2005). Generally, DCM is chosen to interpret utility of key factors on aggregated level (whereas conjoint analysis allows interpretation on individual level). To estimate the main effects a fractional factorial design is used considering level balance, orthogonality and minimal overlapping. Thus, to keep cognitive stress low and still retrieve reliable results (fatigue vs. learning effects) nine choice tasks with two options are defined. The DCM ends with some general questions, e.g. group of decision-makers, quantity of TEU/year. The survey period was from July to September 2017. The decision-makers were contacted via e-mail with an online link to the DCM. 125 received, 65 started and 44 respondents completed the DCM. Here only the answers of shippers (14) and forwarders (18) are considered. The average time spent with the DCM is 4 min. The results were again discussed and validated in face-to-face interviews with managers from the port and the intermodal operator.

3 Results

For shippers (see Table 2) the most important attribute is transport costs followed by transit time and frequency, which have the same relative importance. The utility value of these levels are not surprising (the lower the costs or time the better; the higher the frequency the better). The IT services are least important. However, no IT service has a negative and tracking and tracing the highest positive utility value. The best option consists of 450 €, 15 h, 5 times/week and tracking and tracing; the worst option 550 €, 40 h, 2times/week and no IT service.

For forwarders (see Table 3) the transport costs are even more important, also followed by the transit time and frequency. Hereby transit time is more important than frequency. IT services are also the least important. However, looking at the mean utility value of the levels the results reveal that no IT service has the highest positive utility value. Tracking and tracing has also a positive utility value but eMarketplace has a high negative utility value. The best option therefore contains no IT services and the worst option the eMarketplace.

Table 2. Shippers

Attributes	Relative importance of attributes	Levels	Mean utility value of levels
Transport costs (in €/shipment)	38 %	450 €	0.94
		480 €	0.11
		550 €	-1.06
Transit time (in hours)	27 %	15 hours	0.55
		20 hours	0.29
		40 hours	-0.85
Frequency (no. of weekly de-partures)	27 %	2-times/week	-0.61
		3 times/week	-0.18
		5 times/week	0.79
IT services (additional service provided)	8 %	none	-0.24
		eMarketplace	0.04
		tracking and tracing	0.2

Table 3. Forwarders

Attributes	Relative importance of attributes	Levels	Mean utility value of levels
Transport costs (in €/shipment)	43 %	450 €	1.28
		480 €	0.13
		550 €	-1.41
Transit time (in hours)	26 %	15 hours	0.69
		20 hours	0.24
		40 hours	-0.93
Frequency (no. of weekly de-partures)	18 %	2-times/week	-0.56
		3 times/week	-0.03
		5 times/week	0.59
IT services (additional ser-vices provided)	12 %	none	0.27
		eMarketplace	-0.51
		tracking and tracing	0.24

4 Conclusions

The investigation confirms that transport costs, transit time and frequency have a high influence on the choice behavior of shippers and forwarders for container transport services in the maritime hinterland. The importance of IT services could not be specified in prior research. In this case, the choice behavior of shippers and forwarders is influenced by IT services. However, the impact depends on the decision-maker and the characteristic of the IT service. Shippers prefer tracking and tracing, while forwarders prefer no additional IT service and eMarketplace even has a negative utility value. This might indicate the perceived threat of these platforms to their business models. Ports should therefore evaluate the effects of different IT service in order to strengthen transport chain competitiveness. A limitation of this research is the quantity of respondents. To analyze variations and significance of the results further respondents are required. Moreover, the level selection determines the results and other levels might generate different findings. Therefore, further research is needed to obtain generalization.

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Fleet Expansion Strategy of Indonesian Container Line Integrated with Sea Tollway Logistics System

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Abstract. This paper presents the potential fleet expansion strategy to be deployed by one of Indonesian shipping liners for Indonesia's domestic shipping market. Incorporating the new changes on the sea tollway logistics system, the study performed an analysis to provide a subtle investment strategy for container shipping given market uncertainties that might happen in the future. The study performed economic growth analysis and translated them into freight growth potential. By incorporating diverse company market capitalization scenarios, relevant expansion strategies were discovered. It is found that slot utilization and carrying capacity plays important role in assuring company's profitability. The proposed research also suggested potential new routes to be exploited by the container shipping line.

1 Introduction

Being the worlds largest archipelago, Indonesia depends on sea transport for its domestic transportation as well as international trading links (OECD 2012), therefore Indonesia could potentially have the access to lowering transportation costs if the maritime network can be optimized. From domestic trading point of view, the growth of trading volume will come as an effect of growing local economy, and one of the means to see the growth potential is by inspecting GDP growth.

However, it should be noted that the rapid development in the Indonesia's domestic shipping market will face some challenges that need to be tackled to improve and expand its market. The vast economic disparities found in the eastern and western part of Indonesia is one of the most challenging problem that need to be solved by the Indonesian government, as it affects trade flow imbalance in these two regions. Furthermore, the lack of access to the port infrastructure causes higher shipping cost particularly in the less developed area of Indonesia.

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To address those challenges, the Indonesian government rolled out its plans through Indonesia Sea Tollway initiative which is predicted to be a driving factor for Indonesias port infrastructure development. This initiative is coined by Indonesia's current president to improve connectivity between islands by providing regular services connecting developed and less developed regions. Five main seaports are considered as the main loop in Sea Tollway program which are *Belawan/Kuala Tanjung* (North Sumatera), *Tanjung Priok* (DKI Jakarta), *Tanjung Perak* (East Java), *Makassar* (South Sulawesi), and *Bitung* (North Sulawesi).

The main goal of this research is to provide a contribution in identifying the fleet development strategy to improve Indonesias domestic container shipping performance. Following the given objective, the primary research question of this study is "*To what extent the fleet strategy development could be implemented by an Indonesian container liner to expand their domestic shipping market?*"

This question can be divided in the following sub-questions:

1. What is the future demand of the Indonesias domestic shipping developments?
2. Which strategies could be performed to best utilize the fleet vehicle in the domestic shipping market?

To examine those research questions, freight demand growth analysis and fleet expansion strategy analysis will be used as the main methods for this research.

2 Methodology

Port is traditionally seen as an economic catalysts for the region it serves, where the agglomeration of services and manufacturing activities generate economic benefits and socio-economic wealth (Warf and Cox 1989; Pettit and Beresford 2009; Zhang 2014; Danielis and Gregori 2013). This study aims to quantify the effect of port infrastructure development to the economic growth of the region. To achieve such goal, multiple regression analysis was conducted by using parameters based on the study of Song and Geenhuizen (2014) (Eq. (1) in Appendix A). With this model, growth level of GDP can be used as one of the scenarios (that will be explained more detail later on) to estimate the growth of inter-regional freight flow between provinces in Indonesia until 2025 (*the target year of Indonesia Sea Tollway*). Only five main seaports will be the focus since these ports altogether account for nearly 85% of the container movements in the domestic trade (OECD 2012).

The subsequent process covers the estimation of freight demand growth. Current inter-regional freight flow between five provinces where the five main ports located are formed in origin-destination matrix which was used afterwards to calculate the freight flow at the future scenario until 2025. The calculation utilizes growth factor method (Ortuzar and Willumsen 2002) referring to Eq. (2) in Appendix A with GDP as the rate. The growth factor of a region is determined by the change in its trade supply. Therefore, the growth factor was applied from the origin provinces.

Fleet expansion can be performed in two means; by increasing the ship size and the number of the fleet. Various level of change in ship size, carrying capacity, and slot utilization were defined as the decision variables, while other measures including oil price and freight rate were set as control variables. These variables can be seen in Table 4 in Appendix B. The possible ship size growth is determined based on the future capacity of Indonesian ports, while future carrying capacity is determined based on projected freight growth. The profitability of investment options was evaluated according to financial indicators, covering expected revenue and cost growth. The analysis refers to the fleet expansion model developed by (Tran and Haasis 2015). Utilizing this model, optimization which aims to find a set of decision variables that maximize the company's profit is performed. The model for this relationship takes the form of Eqs. (3), (4), (5), and (6) shown in the Appendix A. Future oil price is based on World Bank forecast, while freight rate is estimated using UNCTAD model (Beverelli et al. 2010).

3 Analysis and Result

Economic and Freight Volume Growth Projection

As mentioned earlier, the estimate of Indonesian regional economic growth does not merely depend on current economic trends; one should also take into account the effect of governments policy measures that are currently focusing on extensive infrastructure developments especially the Sea Tollway *(Tol Laut)* program. Referring to this context, five independent variables are used to measure economic growth based on the study conducted by Song et al. (2014). These variables include port investment plan, manufacturing share, transport infrastructure density, port spillover effect, and international connectivity. Using the multiple regression analysis, the result shows high correlation between the independent and dependent variables. Figure 1 below demonstrates the outcomes of the model, including the significance of the input variables using 95% confidence interval.

From P-value of the result, it can be clearly seen that all variables are statistically significant (P-value < 0.05). Moreover, as shown in the Fig. 1, the adjusted R square is identified as 0.96. Hence, it indicates that all variables have strong correlation in fostering the regional economic growth, which is also aligned with the result of previous study conducted by Song et al. (2014).

Considering the significant correlation (see Fig. 1) between the decision variables and the regional economic development by using the regression formula (Eq. (2) of Appendix A), it is found that port investment variable is likely to have greater impact compared with other variables. This means that the regional GDP will increase approximately by 8% if the port infrastructure investment is increased by 100 percent. In order to examine to what extent the port investment could generate the economic growth, it is therefore essential to identify the

	Coefficients (β)	Standard Error	P-value
Intercept	-349.4446943	273.8834698	0.212478173**
K (Port Investment)	8.582632104	3.268005449	0.013838673**
MAN (Manufacture Share)	2.450973756	0.126167714	8.69105E-18**
TID (Transport Infrastructure Density)	0.889903383	0.083845393	2.54365E-11**
S (Spillover effect)	8.04561188	29.26126658	0.006503145**
IC (Aircraft Movement)	0.002090978	0.00199436	0.030339949**
Adjusted R Square		0.960049796	
Number of Observation		34	
Degree of freedom (df)		4	

Fig. 1. Statistical significance test of regional economic growth

growth share of port investment in each provinces. In relation to the Sea Tollway initiative, this study therefore will mainly focus in assessing the economic growth of five main seaports in Indonesia. Those seaports are located at North Sumatera province *(Sumatera Utara)*, DKI Jakarta province, East Java province *(Jawa Timur)*, South Sulawesi province *(Sulawesi Selatan)*, and North Sulawesi province *(Sulawesi Utara)*.

The overall calculation of the regional economic growth projection (Fig. 2) shows that the regional economic disparities which initially happened in the eastern part of Indonesia slowly decreased. The result is somewhat in line with the visioned future economic development of Indonesia mentioned in the National Medium Term Development Plan Document (RPJMN 2015–2020) established by Indonesia Ministry of National Development Planning (2015) which aims to reduce the regional disparities, particularly in the eastern part of Indonesia as it lags behind others provinces, namely provinces in Java island. Additionally, This condition suitably depicts the implementation of Sea Tollway initiative which expectedly could reduce the shipping cost and promote economic equity through sea connectivity as the effective distribution backbone.

As shown in Fig. 2, the model foresees that the new port investment in the eastern part of Indonesia, especially North Sulawesi/*Sulawesi Utara* and South Sulawesi/*Sulawesi Selatan*, could be a driving factor in developing the regional economic growth in 2025. The real GDP is then implemented as the growth factor to estimate the future inter-regional freight flow between five provinces. Current inter-regional freight flow between every province in Indonesia were obtained from ATTN (National Freight Transport Flow) survey conducted by Indonesia Ministry of Transportation (2016).

Although massive port investment in Indonesia will likely to stimulate trade volume growth, uncertainty in the global economy requires companies to anticipate worse cases. To accommodate this, three background economic scenarios were considered to estimate the freight flow; low, medium, and high economic growth. In the low economic situation, it is assumed that the investment on ports will only bring small impact on local economy. This is possible given the

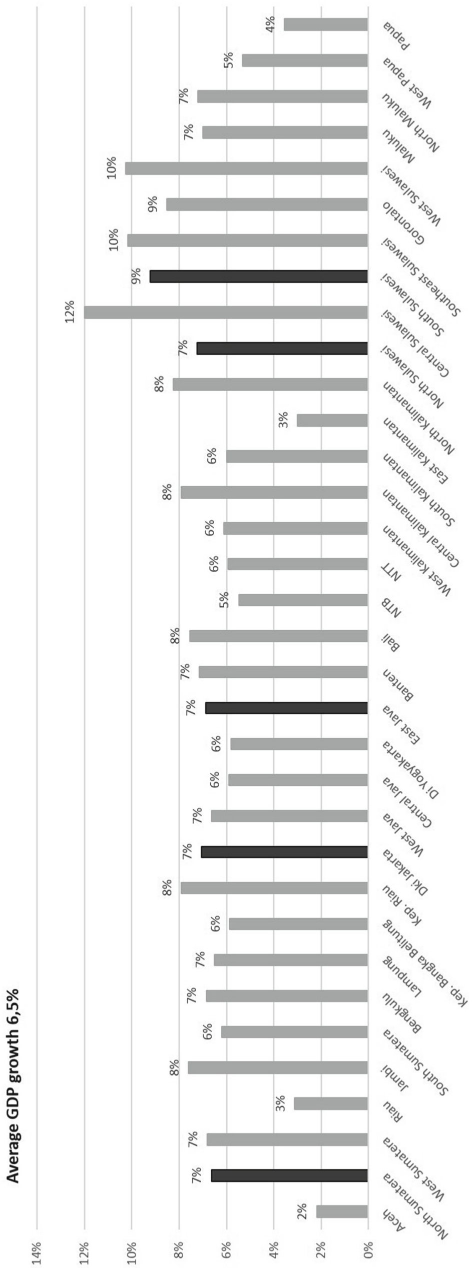

Fig. 2. The estimates of regional economic growth per province in 2025

improvement in the logistics infrastructure, i.e. ports, is not balanced with the growth of domestic industry. The value of 5.5% annual growth is chosen for this scenario, representing average annual GDP growth for the past five years (OECD 2012). Medium economic growth is based on the estimation performed with projected GDP growth rate of 6.5% per year. The high economic growth represents an optimistic situation in which the infrastructure growth will drive domestic logistics cost down and increase trade volume between regions. This scenario is depicted by 7% annual economic growth (Fajar 2014). For this study, as it is related with container fleet development, only flow of commodity in con-

Table 1. Inter-regional container flow 2025 in TEUs (*Optimist Scenario*)

OD	NS	DKI	EJ	SS	NS
NS	-	101,736	255,268	48,441	16,954
DKI	751	-	4,123	399	80
EJ	254,736	389,993	-	306,119	64,647
SS	218,820	210,355	1,316,877	-	139,951
NS	31,453	25,006	123,966	63,033	-

NS = North Sumatera, DKI = DKI Jakarta, EJ = East Java, SS = South Sulawesi, NS = North Sulawesi

Table 2. Inter-regional container flow 2025 in TEUs (*Medium Scenario*)

OD	NS	DKI	EJ	SS	NS
NS	-	97,537	244,731	46,442	16,254
DKI	720	-	3,971	384	77
EJ	244,221	375,650	-	294,861	62,269
SS	185,226	181,389	1,135,542	-	120,680
NS	29,871	23,860	118,286	60,145	-

NS = North Sumatera, DKI = DKI Jakarta, EJ = East Java, SS = South Sulawesi, NS = North Sulawesi

Table 3. Inter-regional container flow 2025 in TEUs (*Pessimist Scenario*)

OD	NS	DKI	EJ	SS	NS
NS	-	89,597	224,810	42,661	14,931
DKI	662	-	3,648	353	71
EJ	224,341	345,072	-	270,859	57,200
SS	177,580	173,902	1,088,669	-	115,698
NS	27,700	22,126	109,687	55,773	-

NS = North Sumatera, DKI = DKI Jakarta, EJ = East Java, SS = South Sulawesi, NS = North Sulawesi tainerized form is considered. The resulting freight growth per each scenario are shown in Tables 1, 2, and 3.

Fleet Expansion Strategy

To account for future uncertainties in the economy, three economic background scenarios as explained in preceding subsection were considered. In shipping market context, each of the economic situation will imply different freight volume projection. From the company perspective, its power lies on the capitalization of the container shipping market, which in a straightforward way can be translated into the offering capacity it provides. As such, the policy scenario of the company is distinguished into three level with regards to market share capitalization; 11% market share which represents the *status quo*, 15% market share which represents medium market share increase, and 20% market share which represents an optimistic situation. In total, nine scenarios were introduced for fleet expansion profitability analysis.

			Market Share		
			Low (11%)	Mid (15%)	High (20%)
Economic Growth	High (7%)	Total Revenue	253.84%	326.77%	413.02%
		Unit Revenue	85.08%	93.99%	88.99%
		Total Cost	216.02%	282.05%	361.23%
		Unit Cost	85.08%	81.46%	78.25%
		Profitability	62.02%	75.86%	91.16%
	Mid (6.5%)	Total Revenue	234.55%	301.93%	381.63%
		Unit Revenue	101.56%	95.74%	90.65%
		Total Cost	198.71%	259.46%	332.29%
		Unit Cost	86.24%	82.58%	79.32%
		Profitability	58.19%	71.25%	85.71%
	Low (5.5%)	Total Revenue	222.89%	286.92%	362.66%
		Unit Revenue	102.77%	96.89%	91.74%
		Total Cost	188.30%	245.86%	314.87%
		Unit Cost	87.00%	83.30%	80.01%
		Profitability	55.84%	68.41%	82.35%

Fig. 3. Profitability simulation result

The output of profitability analysis can be seen in Fig. 3. The values for Total Revenue, Unit Revenue, Total Cost, and Unit Cost represents the ratio between future value and base year value. The values for Profitability marks the relative difference between Total Revenue and Total Cost. It is apparent that the profit gain is more sensitive towards market share capitalization instead of background economic condition, which indicates that in any economic situation expanding market share is a favored decision to improve profitability. Consequently, the company must focus on expanding its business coverage (fleet capacity) as well as optimizing the utilization of its current fleet. The estimated increase of freight rate on 2025 brings positive impact, marked by profitability improvement in all situations.

Economic Growth		Market Share					
		Low (11%)		Mid (15%)		High (20%)	
		Optimum Value	Upperbound	Optimum Value	Upperbound	Optimum Value	Upperbound
High (7%)	Avg Ship Size Expansion	0.00%	30.00%	0.00%	30.00%	0.00%	30.00%
	Total Carrying Capacity Expansion	90.43%	90.43%	159.68%	159.68%	246.24%	246.24%
	Slot Utilisation Improvement	33.33%	33.33%	33.33%	33.33%	33.33%	33.33%
Mid (6.5%)	Avg Ship Size Expansion	0.00%	30.00%	0.00%	30.00%	0.00%	30.00%
	Total Carrying Capacity Expansion	72.81%	72.81%	135.65%	135.65%	214.21%	214.21%
	Slot Utilisation Improvement	33.33%	33.33%	33.33%	33.33%	33.33%	33.33%
Low (5.5%)	Avg Ship Size Expansion	0.00%	30.00%	0.00%	30.00%	0.00%	30.00%
	Total Carrying Capacity Expansion	62.32%	62.32%	121.35%	121.35%	195.13%	195.13%
	Slot Utilisation Improvement	33.33%	33.33%	33.33%	33.33%	33.33%	33.33%

Fig. 4. Investment decision variables

Figure 4 depicts the optimum decision variables for each scenarios. Zero values in ship size expansion variable implies that improving ship size does not seem affecting profitability, which is reasonable given historical evidence (see Tran and Haasis 2015) that some companies investing in a bigger vessel ended up with poorer performance due to increasing fixed cost and less flexibility to cope with demand changes. Otherwise, shipping liner that operates at a smaller scale will have the flexibility to respond demand fluctuation which results in high operation efficiency. This phenomenon was also found in OOCL. In 2013 OOCL was one of the most profitable shipping liner business while it was not even in the top 10 players of the world. The success of OOCL has been partly due to its prudent strategies of fleet investment; investing on smaller vessel scale but focusing on high slot utilization (Jallal 2016).

Other decision variables values i.e. carrying capacity and slot utilization show that both need to be maximized for a better profit gain. It implies that slot utilization needs to be increased together with the capacity expansion; failing to cope demand with increasing capacity will lead to poor operations performance as huge portion of fleet capacity will remain empty. In the case where economy is not very attractive, slot utilization is still an essential part to be improved. It can be concluded that slot utilization plays a more important role than carrying capacity in all situations. Another observation is that in any economic situation, the profit grows at a slower pace than the carrying capacity expansion if the market share is high. The phenomenon might indicates that when the market is getting saturated, much higher effort is needed to acquire more market share.

To translate the fleet expansion scenarios into corporate strategy, the framework developed by Lorange (2001) is used to plot each market share and economic situation into the relevant strategy as can be seen in Fig. 5. In the research context, the x-axis (the resource capability) can be translated into the market share policy, while the y-axis (growth opportunities) can be translated into economic situation. To exemplify, the dominate/defend strategy will be suitable when both the economic growth and the intention to expand market share are low. The relevant action within this strategy could be improving slot utilization, for instance by sharing the operating capacity with other container lines.

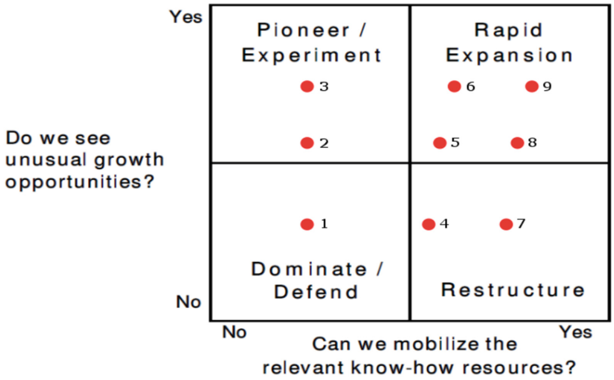

Fig. 5. Strategic planning topologies (bottom to top: low to high economy, left to right: low to high market share). Adapted from Lorange (2001)

As can be observed, four out of nine scenarios fall into rapid expansion strategy. To capture the projected massive growth of trade flows, the shipping liner is indeed should be ready to position themselves in this strategy while also may go to pioneer or restructure strategy depends on the economic situation and the market share policy. Rapid expansion also deemed to be in line with corporate strategic focuses, i.e. improving asset utilization, route rationalization and selection of appropriate target markets. Looking into the most pessimistic scenario (low economy, low market share), additional ship is not necessary to get the best financial performance. Rather, the company should focus solely on slot utilization improvement. On the other hand, in the most optimistic scenario (high economy, high market share), beside slot utilization improvement, carrying capacity expansion is inevitable. With the huge difference between the two aforementioned distinct scenarios, fleet size expansion should be carefully executed. The shipping line can approach the strategy by implementing the fleet expansion into phases. The company should constantly monitor the market developments, assess which scenarios that most likely will be true, and adapt accordingly. Additional measure that can be taken is to cope with the uncertainty is by opting more for medium and long term charter vessels rather than spot charter or self-owned vessels as they will provide flexibility while at the same time incurs lower operational cost.

In the coming years, the shipping line should put more attention to the eastern part of Indonesia as previously estimated that the regions in that area will experience much bigger impact of the Sea Tollway program compared to the more developed western regions. Considering the vast growth in regional economic and volume trade flow particularly happened in Central Sulawesi (Pantoloan Port), Maluku (Ambon Port), Papua (Sorong Port), Jambi (Muara Sabak Port), and North Maluku (Ternate Port), these regions could be determined as a potential route expansion for the shipping lines business development.

4 Conclusions and Future Research

To conclude, the rolled out Sea Tollway program is expected to bring regional economic growth in Indonesia. By estimating the potential inter-regional freight flow derived from real regional economic growth, the container shipping demand is highly likely to increase and should be balanced with the development of shipping liner. In the most pessimistic scenario, slot utilization will only be the focus. While for the most optimist situation, carrying capacity expansion is also inevitable. Given massive difference between strategies, conveying fleet expansion into phases is advised. The shipping line should also consider eastern region as a potential route expansion.

The analysis of fleet expansion strategy proposed in this research might be beneficial to assist the development of Indonesia's shipping market in the future. However, some limitations found in this study may hinder the reliability of the research results. Firstly, it was difficult to find the relevant data needed by the models employed in this study. For instance, the model deployed for the profitability analysis was based on another study that covers different samples (i.e. international shipping market). This situation might lead to misleading results as the domestic shipping market may exhibits different characteristics. More extensive and accurate data is thus needed to get better model estimates, where subsequently, may lead to more accurate predictions. Secondly, as explained in the estimation of freight growth part, GDP alone is not sufficient to be used as the sole indicator of freight growth. According to Meersman and Van De Voorde (2013), relying only to GDP may not be desirable since its composition is changing over time. Thus, to get better freight growth estimation, better model that not only considering GDP can be used for the future research.

Appendix A

Detail Formula

Regional Economic Growth (Song and Geenhuizen 2014)

$$Y = f(K, MAN, TID, S, IC) \tag{1}$$

Where Y denotes the real gross domestic products as an outcome; i and t are the indices for the main port of each province and year respectively; K describe about the ferry and inland waterways investment plan; MAN represents about the share of manufacturing sector in the annual GDP; TID is the traffic infrastructure density; S is the potential spillover effects in the adjacent port of each provinces; and IC which represents the total aircraft movements (used to assess connectivity of the port provinces to the international connectivity).

Freight Demand Growth (Ortuzar and Willumsen 2002)

$$T_{ij} = \tau_{ij}.t_{ij} \tag{2}$$

Where T_{ij} is the flow from i to j at the design year, τ_{ij} is the growth factor and t_{ij} flow at the base year. The growth factor of a region determines the change in its supply, therefore, the growth factor is applied from the origin provinces.

Fleet Development Analysis (Tran and Hassis 2015)

$$rev_{it} = \beta_0.cap_{it}^{\beta_1} size_{it}^{\beta_2} slot_{it}^{\beta_3} oil_{it}^{\beta_4} fr_{it}^{\beta_5} \epsilon_{it} \tag{3}$$

$$u - rev_{it} = \beta_0.cap_{it}^{\beta_1} size_{it}^{\beta_2} slot_{it}^{\beta_3} oil_{it}^{\beta_4} fr_{it}^{\beta_5} \epsilon_{it} \tag{4}$$

$$cost_{it} = \beta_0.cap_{it}^{\beta_1} size_{it}^{\beta_2} slot_{it}^{\beta_3} oil_{it}^{\beta_4} fr_{it}^{\beta_5} \epsilon_{it} \tag{5}$$

$$u - cost_{it} = \beta_0.cap_{it}^{\beta_1} size_{it}^{\beta_2} slot_{it}^{\beta_3} oil_{it}^{\beta_4} fr_{it}^{\beta_5} \epsilon_{it} \tag{6}$$

Where

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$: slope parameter;
rev_{it} : variation of total revenue;
$u - rev_{it}$: variation of unit revenue;
$cost_{it}$: variation of total cost;
$u - cost_{it}$: variation of unit cost;
cap_{it} : variation of fleet capacity;
$size_{it}$: variation of average ship size;
$slot_{it}$: variation of slot utilization;
oil_{it} : variation of oil prize;
indexes : i for carrier, t for year;

Appendix B

Parameters for fleet expansion profitability analysis

Table 4. Decision and control variables

Variable	Variable type	Definition	Data source	Upper-bound value (% of increment)
Shipping size	Decision	Ratio between future average ship size and current average ship size	Shipping line	30%
Carrying capacity	Decision	Ratio between future total fleet capacity and current total fleet capacity	Shipping line	Based on freight volume projection
Slot utilisation	Decision	Ratio between future slot utilisation and current slot utilisation	Shipping line	33%
Freight rate	Control	Ratio between future freight rate and current freight rate	UNCTAD	35.5%
Oil Price (Brent)	Control	Ratio between future oil price and current oil price	World bank	39.8%

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Decommissioning of Offshore Wind Farms

A Simulation-Based Study of Economic Aspects

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Abstract. After a useful life of 20 to 25 years of existing offshore wind farms, the decommissioning will be a challenging task. In this context, an optimized planning of decommissioning enables savings of energy costs. Due to the lack of sufficient empirical data about decommissioning of offshore wind farms, simulation techniques represent a suitable analysis tool to investigate such planning problems. The present contribution examines the effects of tactical decisions in the decommission phase of offshore wind farms by the use of a discrete-event, agent-based simulation study. The variation in the number of used vessels as tactical decision in connection with weather conditions is investigated. The results show that adapting the number of vessels can reduce about 6% of the decommissioning duration.

Keywords: Offshore wind farms · Decommissioning · Simulation study

1 Introduction

Due to the planned exit from nuclear energy in Germany, offshore wind energy (OWE), as a form of energy generation, which is able to provide base load, has evolved into a crucial component of the future energy mix. Both, the specific challenges of OWE and the competition with conventional and other renewable energy sources, lead to the need of optimization and cost reduction in all areas of the value chain of this young industry (German Federal Ministry Economic Affairs and Energy 2015). After the current construction and operating phase, the offshore wind turbines (OWTs) has to be decommissioned after a use period of 20 to 25 years (Kerkvliet and Polatidis 2016). Up to now, only a few mature concepts for the decommissioning process are introduced. This mainly roots is the fact that the decommissioning of many OWTs will start in 2030 until 2035. However, the special resources, which are needed for decommissioning, are available in limited number. Furthermore, the planning of decommissioning of offshore wind farms (OWF) is a challenging task, because of harsh weather conditions and this limited resource availability. Restrictions on decommissioning processes based on hardly predictable weather conditions are considered the main source of uncertainty for the performance of the supply chain. The decommissioning

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cost of OWFs is estimated to be around 3% of the total capital cost. Consequently, it is required to investigate potential logistics concepts at an early stage to reduce costs.

Based on this motivation, this paper examines the impact of tactical decisions of resource use on the decommissioning period. Accordingly, the challenges of decommissioning of OWTs are described in the subsequent section. This is followed by the state of the Art in decommissioning strategies. After the description and discussion of the results of the simulation study, the paper concludes with a summary and an outlook.

2 Challenges of the Decommissioning of OWTs

Different decommissioning strategies have been introduced in the literature. In this context, instead of dismantling (total or partial removal) a complete wind turbine, the repowering or refurbishment may be considered as a suitable solution extending the lifetime of a wind farm (Hou et al. 2017; Kerkvliet and Polatidis 2016).

The challenges in the decommissioning process are similar to those in the installation phase. Within the different planning levels individual challenges are faced. For instance, designing the right network is a main challenge at the strategic level. This includes special vessels, port facilities and disposal in the hinterland. At the tactical level, decommissioning the right number of resources as well as the starting time are the predominant challenges. For the tactical planning, the weather conditions represent the largest uncertainty factor. As consequence, it results in a large number of economic

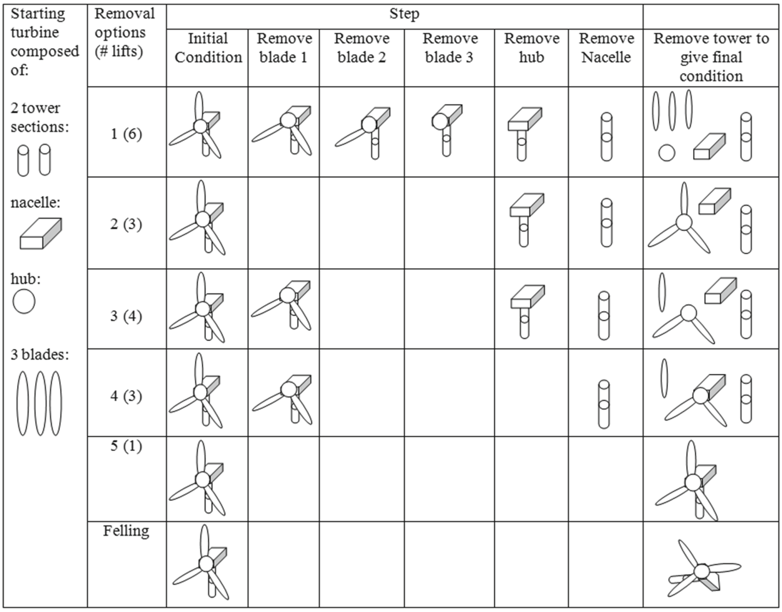

Fig. 1. Traditional OWT decommissioning without foundation (Kaiser and Snyder 2010, p. 181)

effects such as losses in the energy production, additional costs due to longer chattering times of the special vessels and port capacities as well as impacts on subsequent projects. At the operational level, the management of resources is the main challenge. This is particularly evident in the parallel decommissioning of several offshore wind farms (OWFs) and their different weather conditions.

Figure 1 illustrates the decommissioning of an offshore turbine without considering the foundation. It can be stated that an OWE can be decommissioned in different ways depending on the adopted strategy. Similar to the installation process, for which different installation concepts exist, and only two concepts are considered as appropriate to be established, it will be expected that during acquiring experiences about future decommissioning projects, only some decommissioning strategies will be established.

3 State of the Art – Analyses of Decommissioning Strategies

The decommissioning has been given little attention, and only few works can be found, which investigate this problem. The main reason for this lack of investigation is that no major project has been carried out. In this context, and therefore no practical experience is available besides the decommissioning of small wind farms (Topham and McMillan 2017). The first work, which deals with decommissioning is given in (Kaiser and Snyder 2010). In this report, the purpose was developing a methodological framework to assess installation and decommissioning costs and to parameterize these models in order to generate a substantial understanding of installation and removal processes and the corresponding costs. Topham and McMillan (2017) analyses the main operation parameters, which affect the decommissioning process, identifying the benefits and drawbacks of the influencing variables. The authors designed a model for comparing different transportation strategies in order to reduce the decommissioning costs. Kerkvliet and Polatidis (2016) developed and applied a framework for identifying an appropriate decommissioning method for offshore. The whole approach is based on Multi-Criteria Decision Aid techniques, which perform an integrated evaluation of three available wind farms' decommissioning methods namely the partial removal internal cut, the partial removal external cut and the total removal of the foundation methods. The evaluation showed that the partial removal of the foundation method is by far the most appropriate method for the decommissioning. The authors in (Hou et al. 2017) focused on optimization of offshore wind farm repowering. In an optimized repowering strategy, different types of wind turbines are selected to replace the original wind turbines to reconstruct the wind farm, which is demonstrated to be better than the refurbishment approach, which replaces the old wind turbines with the same type. The simulations performed in this research reveal that the reconstructed wind farm, which consists of multiple types of wind turbines, has a smaller levelized cost of energy (10.43%) than the refurbishment approach, which shows the superiority of the proposed method.

Most of those described research consider the decommissioning process as a reverse process of the installation process. Moreover, the decommissioning can leverage from the long experience gathered from the offshore oil and gas industry as well as from the onshore wind sector (Topham and McMillan 2017).

The dynamic influences of weather and sea conditions in connection with the number of used vessels have not yet been considered. Therefore, these potential impacts are investigated and considered in this paper by means of a simulation study.

4 Simulation Study

In this paper, an agent-based discrete event simulation model is proposed. This research considers the decommissioning process as a reverse process of the installation process. That means that first all top structures of a wind farms have to be decommissioned, and thereafter the decommissioning of foundations will be carried out. As yet empirical values for the decommissioning process are not available, the decommissioning processing times and operation restrictions are derived from the installation process (see Beinke et al. 2017, p. 48).

The purpose of this study is to analyse the impact of tactical decisions on the number of used vessels depending of the weather conditions during the decommissioning phase in order to reduce the costs of decommissioning. These are foundation removal cost, top-structure removal cost, port cost, vessel mob- and demobilisation (*MobCost*), and transport costs of disassembled components to corresponding manufacturer.

$$\sum_i DF_{\mathrm{i}} * Cost_{\mathrm{vi}} + \sum_j DTop_{\mathrm{j}} * Cost_{\mathrm{vj}} + Dp * Cost_{\mathrm{p}} + MobCost + TransportCost$$

Where

i is the index of vessel used for the decommissioning of foundation,

j is the index of the vessel used in the decommissioning of top structures,

DF_{i} is total duration of vessel i operation during decommissioning of foundation,

$DTop_j$ is total duration of vessel j operation during decommissioning of top structures,

$Cost_{\mathrm{p}}$ is the port infrastructure, port charges inclusive port personnel costs per day, and

Dp is the total duration time of port operations during decommissioning phase.

In order to evaluate the effect of the weather on the number of used vessels, two different scenarios are selected, scenario 1: one vessel is used for decommissioning, scenario 2: two vessels are used. The decommissioning of a wind farm located in the German North Sea consisting of 180 OWTs have be simulated. The simulation has been run for each year in a period of 5 years.

5 Simulation Results and Discussion

The description and discussion of the simulation results is mainly based on the trend of decommissioning of both scenarios as well as completion time of the decommissioning. Figure 2 demonstrates the results and the weather availability of the foundation process as well as top-structure process execution in a 50-year average.

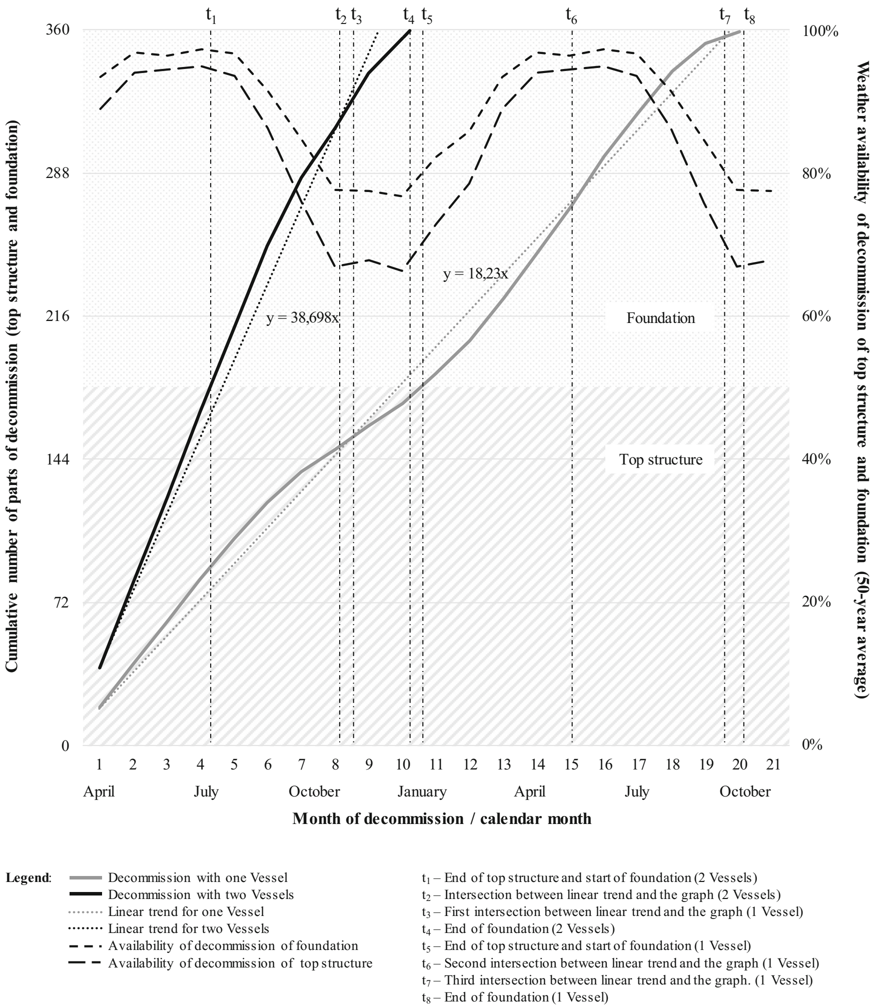

Fig. 2. Simulation results and the weather availability decommissioning process

For this study, the decommissioning starts on 01.04. The use of several vessels brings advantages and disadvantages. The advantage is the adequate utilization of good weather periods for example in the summer months. The disadvantage is that in the bad weather periods; the vessels would not be exploited perfectly, which force the vessel to wait for good weather phases. This leads to high costs since the daily price of one vessel is about 170,000 Euro (Topham and McMillan 2017). According to the simulation results, 6% of the total duration can be reduced by using two vessels (19.75 months for one vessel in comparison to 18,60 months two vessels). This results in the reduction of about 5,87 Millions Euro.

For the selected start month and the size of the OWF considered, two vessels are able to dismantle the whole wind farm before the bad weather months. Since the top structures of OWE are more weather-restricted than the foundations, it is recommended to start the decommissioning of top structures in the good season.

The result of the simulation confirms this assumption and shows, that the trend of the decommissioning of top structure with two vessels is larger than the double of trend with one vessel. Regarding the foundation, the trend of decommissioning foundation with two vessels is almost equal to the double with one vessel. This is due to the fact, that foundations are less weather-prone. From these results, it can concluded, that the variation of the number of used vessel during the decommissioning as tactical decision is key factor in the reduction of decommissioning cost.

6 Conclusion and Outlook

An agent-based and discrete event simulation model is applied for analysing the impact of tactical decisions on the number of used vessels depending on weather conditions during the decommissioning phase. The results show that a suitable usage of vessels can indeed reduce the costs. In this context, increasing the number of vessels in good season between April and September, and the use of a single vessel during bad season between October and March can reduce the cost of decommissioning. For future work, other research activities are planned. We will extend the current simulation to consider different decommissioning starts to cover the whole year in order to understand better the influence of weather. Additionally, the transfer of other concepts from the offshore installation process such as the feeder concept into the decommissioning processes, will be examined. Furthermore, different vessel types will be used. For example, the heavy lift vessel as a less expensive vessel alternative will be used in combination with installation vessels in the decommissioning. Based on the background of this paper - adopted the total dismantling of wind turbine as decommissioning strategy - in the future work we will consider the combination of total dismantling and repowering of OWF.

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Towards a Flexible Banana Supply Chain: Dynamic Reefer Temperature Management for Reduced Energy Consumption and Assured Product Quality

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Abstract. We propose a strategy for dynamic temperature management inside reefer containers in banana supply chains, with the objective of reducing energy consumption and deliver bananas with good quality. In this paper a model is developed to determine optimal temperature profiles for the future days during shipment. To assure the right quality in a dynamic environment, continuous monitoring inside reefers can be used to check the status of bananas. The optimization takes into consideration of disturbances of banana quality and estimated arrival time. Therefore, decisions are updated each day to cope with the possible disturbances. Simulation experiments compare the proposed approach and currently used approach. Results show that with the proposed approach, bananas can be delivered with right quality and reduced energy consumption.

Keywords: Banana supply chain · Green-life · Energy reduction
Temperature management · Reefer container

1 Introduction

Bananas are one of the most traded and consumed fruit in the world. Approximately 4 million tonnes bananas were imported into Europe alone in 2014 from tropical countries [4]. To maintain quality of bananas along shipments is essential for a banana supply chain. In today's supply chain, reefer containers are used to keep bananas in a cool environment so that they do not get ripen too early and spoil.

In general, the cooling strategy in perishable goods supply chains is often to keep the temperature close to an "optimal target temperature", which maintains quality and prolongs shelf life of perishable goods [3]. For banana transported in reefers, the target temperature is set to around 13 °C [6]. With this temperature, the decreasing rate of so called "green-life" is kept minimal, delaying the ripening process until they reach their customers. However, this strategy requires

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a large amount of energy for cooling, leaving potential for reduction of energy consumption [5,14].

Although most research agrees that certain products should be chilled or frozen during transport, very few articles considers sustainability in temperature controlled supply chains [2]. However, some of the studies do consider energy use for cooling as a factor of cost. Rong et al. [13] integrate quality degradation of perishable goods with temperature control. In their model, transport costs are related to a chosen temperature. Zanoni and Zavanella [15] investigate the relationship between product quality, temperature, and energy. They develop a model to jointly optimize temperature management at different supply chain players, showing that temperature is an important factor in efficiently managing supply chains for perishable goods. However, these papers do not investigate dynamic temperature management according to the freshness of products.

In the previous research, we have applied a quality-aware modeling approach in order to reduce banana wastage due to early ripening in a typical banana supply chain. The paper mainly focuses on scheduling logistics activities [11] by making decisions of moving reefer containers and processing bananas in ripening facilities. Following that, this research explores the possibility to reduce energy consumption during shipments by means of dynamic temperature management in reefer containers, with the consideration of bananas' arrival time and real-time green-life information.

The remainder of this research is organized as follows: Sect. 2 explains the modeling and optimizing strategies for dynamic temperature management. Section 3 carries out simulation experiments followed by discussions to illustrate the potential of the dynamic temperature management strategy. Section 4 concludes the paper and provide future research opportunities.

2 Modeling Quality and Temperature Management in a Banana Supply Chain

In this section, we firstly explain the objective of the paper and some assumptions. Then, a model for banana quality is presented. Subsequently, we use an optimization method to determine the temperature configuration of reefer containers in real-time.

2.1 Objective and Assumptions

The objective of this research is to develop a temperature management strategy to reduce energy consumption from cooling, with the consideration of bananas estimated arriving time and remaining green-life.

Technical foundations could be made possible for the dynamic temperature management: bananas' state can be monitored using computer vision systems [12]; this information can then be communicated using communication technologies developed in the Intelligent Container project [10]. Thus even reefers are closed during shipping, bananas inside can be monitored in real-time.

In this paper we take one step further in assuming that reefers can adjust their temperature configurations according to decisions given by logistics supervision units. Although not explicitly considered, this paper could lay the theoretical foundation for container ripening [7], since it considers decisions at such detailed level of dynamic temperature management.

Other assumptions are also considered in this paper. Although it is known that even in the same container, environment differs from spot to spot [8], as a starting exploration, we assume that bananas in the same container share the same quality, i.e., remaining green-life. Besides, we consider the relationship of cooling costs and temperature approximated using a linear function, in the temperature range suitable for banana sea transport.

2.2 Modeling Banana Quality and Estimated Time of Arrival

Bananas are transported when they are green. As a result of experiments done by Jedermann et al. [9], a model is developed that can predict the remaining green-life period according to the temperature inside reefer containers (with a 98% relative humidity). The green-life period G in days is a function of temperature T in °C is given in Eq. (1) and can be used within the temperature range of 13 °C to 18 °C:

$$G(T) = 159.86 \cdot e^{-0.124T}. \tag{1}$$

Bananas inside the container are cooled for preservation so that their green-life reduces at a slow rate. We use a discrete time step k to represent days in our model. The green-life is represented by a quality index q. Bananas begin with an initial quality as $q(1) = 100$, where the index for the initial quality is 100 at time step $k = 1$. Estimated time of arrival (ETA) at step k is represented as $l(k)$. We model the quality evolution of bananas in a reefer container as follows:

$$\alpha^T = \frac{80}{(159.86 \cdot e^{-0.124T})}, T \in \mathbb{R}, 13 \leq T \leq 18; \tag{2}$$

$$\alpha(k) = 0.4416(T(k)) - 3.3709, T \in \mathbb{R}, 13 \leq T \leq 18. \tag{3}$$

$$q_k(k+\tau) = q_k(k+\tau-1) - \alpha_k(\tau),$$
$$k \in \{1, 2, \dots\}, \tau \in \{1, \dots, l(k)\}; \tag{4}$$

$$q_{k+1}(k+\tau-1) = q_k(k+\tau-1) + \Delta q_k(\tau),$$
$$k \in \{1, 2, \dots\}, \tau \in \{1, \dots, l(k)\}; \tag{5}$$

$$l(k+1) = l(k) + \Delta l(k) - 1, k \in \{1, 2, \dots\}; \tag{6}$$

The decreasing rate of green-life period α depends on the temperature inside the container, described by Eq. (2). After linearizion using a least square linear fitting method, we have Eq. (3). In Eq. (4), $q_k(k+\tau)$ represents the estimated quality on time step $k+\tau$, and the estimation is done on time step k. The predicted quality of the next time step $q(k+\tau+1)$ is calculated using Eq. (4). Quality estimation made on time step k is adjusted on the next time step $k+1$ by a value of $\Delta q_k(1+\tau)$ using Eq. (5). ETA given by the next time step $l(k+1)$ is derived in (6), where $\Delta l(k)$ represents the change of ETA in days that is known on day k.

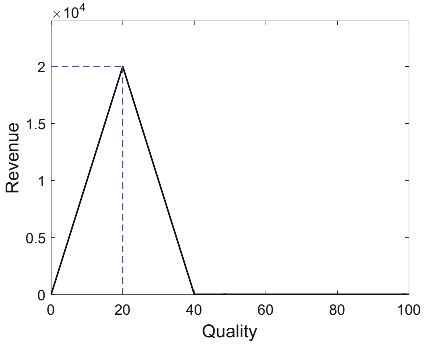

Fig. 1. Revenue as a function of quality.

2.3 Dynamic Temperature Management

In this paper, we assume that customers prefer bananas with shorter green-life, so that they are ready to ripen and sold to consumers. Meanwhile, bananas should not be too ripe. We assume that the desirable bananas are at a state when $q(k) = 20$. As is shown in Fig. 1, bananas with quality at 20 generate the highest profit. If bananas are too raw or too ripe, they bring less profit. Variable revenue $y(k)$ is the amount of money paid for a container of bananas, estimated at time step k. We use a piecewise function in the representation of the relation between revenue and quality:

$$y^1(q) = 0, \qquad \text{for } q < 0; \tag{7}$$

$$y^2(q) = 1000q, \qquad \text{for } 0 \leq q < 20; \tag{8}$$

$$y^3(q) = 40000 - 1000q, \qquad \text{for } 20 \leq q < 40; \tag{9}$$

$$y^4(q) = 0, \qquad \text{for } 40 \leq q \leq 100, \tag{10}$$

$$q - RS_1 \quad < 0; \tag{11}$$

$$-q - R(1 - S_1) \quad \leq 0; \tag{12}$$

$$q - 20 - RS_2 < 0; \tag{13}$$

$$-q + 20 - R(1 - S_2) \leq 0; \tag{14}$$

$$q - 40 - RS_3 < 0; \tag{15}$$

$$-q + 40 - R(1 - S_3) \leq 0. \tag{16}$$

$$\begin{aligned} y_(q) = y^1(q) &+ \Big[- y^1(q) + y^2(q) \Big] \cdot S_1 \\ &+ \Big[- y^2(q) + y^3(q) \Big] \cdot S_2 \\ &+ \Big[- y^3(q) + y^4(q) \Big] \cdot S_3. \end{aligned} \tag{17}$$

The piecewise function is defined in four parts using Eqs. (7) to (10). Constraints (11) to (16) determine which parts of the function are used for calculating the total revenue. S_1, S_2, and S_3 are axillary binary decision variables that select parts of the revenue function. Variable R is a large, positive number. When quality starts decreasing from 100 before becoming less than 40, $S_1 = 1, S_2 = 1, S_3 = 1$, therefore $y(q) = y^4(q)$; when quality drops below 40 but no less than 20, $S_1 = 1, S_2 = 1, S_3 = 0$, and $y(q) = y^3(q)$; when quality goes below 20 but is still non-negative, $S_1 = 1, S_2 = 0, S_3 = 0$, and $y(q) = y^2(q)$; when quality becomes negative, $S_1 = S_2 = S_3 = 0$ and $y(q) = y^1(q)$.

The cost for cooling a container for one day is depending on the temperature inside a container and thus depends on α. Variables b and c are arbitrarily chosen parameters and can be adjusted to approximate the reality. Cost $C(k)$ is a summation of cooling costs over all the following days $\tau \in \{1, \ldots, l(k)\}$ from day k:

$$C(k) = c \sum_{\tau=1}^{l(k)} (b - \alpha(\tau)) \,. \tag{18}$$

The objective function calculates the total profit by subtracting the cooling costs from the revenue. Therefore, the optimization for time step k is shown in the following form:

$$\max J(k) = y\left(q(k + l(k))\right) - C(k), \tag{19}$$

subject to constraints (3)–(4), and (7)–(18). The revenue term is the total revenue based on quality estimation on the day of arrival. This optimization problem is a mixed integer non-linear programming (MINLP) problem. At each day k, the optimization considers the updated information of the current quality $q_k(k)$ and ETA $l(k)$, and determines a temperature plan $T_k(\tau), \tau \in \{1, \ldots, l(k)\}$ for the future days until the container arrives at the destination. The decision $T_k(1)$ is then implemented for day $k+1$, resulting in a new quality $q_k(k+1)$. On the next day $k+1$, Eqs. (5) and (6) are used to generate the new conditions considering disturbances in quality (Δq_{k+1}) and ETA ($\Delta l(k+1)$) acquired in the next day, from which the optimization goes on.

2.4 Comparison of Temperature Management Strategies

In order to illustrate the effectiveness of the proposed dynamic temperature management strategy, we consider in total three strategies as follows for comparisons in the simulation experiments:

- In Strategy A, the goal is to prolong the green-life of bananas as much as possible as described in [3]. Therefore, the temperature inside reefers are set to the lowest value without damaging the bananas. This strategy is currently used by industry in banana transport.
- Strategy B makes a plan for temperature management ahead of the trip based on bananas' estimated remaining green-life and ETA with the objective of preserving bananas with lowest possible energy consumption. But it does not keep track on the disturbances that may occur.

– The proposed Strategy C in this paper has a similar objective with Strategy B, but keeps taking in new information regarding remaining green-life and travel time. When these disturbances occur, it can react to them by adjusting its future plans on temperature settings.

3 Simulation Experiments

We use simulation experiments to assess the potential of the proposed temperature management strategy. The MINLP is solved using SCIP [1]. Experiment parameters are listed in Table 1. The following scenarios are considered:

– In Scenario 1, no disturbances occur. It provides a benchmark for strategies to be compared.
– We consider disturbances in Scenario 2, where both quality disturbances and delays occur. We specify in this scenario that $\Delta q_1(3) = 5$, $\Delta q_1(5) = 5$, $\Delta l(3) = 2$, $\Delta l(4) = 2$, as the rest of Δq and Δl are 0.

As 3 strategies are applied to 2 scenarios, 6 experiments are done. Numerical results are shown in Table 2. We compare the outcomes of the 3 strategies in terms of banana quality upon delivery, cost for cooling, the revenue that the shipper gets for the container of bananas with that quality, and the profit the shipper makes. In Scenario 1, no disturbances occur. Strategy A delivers bananas with very raw quality, while B and C produces the same results, delivering bananas at the exact needed quality with a lower cost for energy consumption. This results in a much higher profit for the shipper. In Scenario 2 where disturbances take place, Strategy A delivers quite raw bananas and only gain a revenue of 2500 EUR. Being not flexible to cope with disturbances, Strategy B delivers bananas that are too ripe and spoiled, results in 0 revenue. Strategy C has the better result than other strategies in Scenario 2, delivering bananas with the ideal quality and a slightly lower cooling cost than strategy A.

These results indicate that the currently used cooling strategy leads to a quality of which bananas can still be very raw, with energy consumption unnecessarily high. With the initial temperature planning the energy utilization drops, resulting in lower energy consumption. However, this only holds when there are no disturbances along the shipping. Our proposed strategy can cope with disturbances, and allocate resources when necessary by updating temperature settings

Table 1. Experiment parameters

Variable	Value
Initial quality	$q(1)$=100
Initial estimated ETA	$l(1) = 21$
Range of temperature	13–18 °C
Cost for cooling	$b = 19, c = 20$

Table 2. Results of control strategies applied in different scenarios

	Scenario 1				Scenario 2			
	Quality	Cost	Revenue	Profit	Quality	Cost	Revenue	Profit
Strategy A	55.9	7098	0	−7098	37.5	8246	2500	−5746
Strategy B	20.0	6380	20000	13620	−6.4	7572	0	−7572
Strategy C	20.0	6380	20000	13620	20.0	7917	20000	12083

according to estimated time of arrival and bananas' green-life. Bananas delivered in this way can be at the desired quality with more efficient cooling strategy.

4 Conclusions and Future Research

During sea transport of bananas in reefer containers, quality preservation largely depends on cooling. The current cooling strategy often results in high energy consumption, because it sets temperatures as low as possible without damaging the bananas. This research proposes a dynamic temperature management strategy, which keeps track on bananas' remaining green-life and estimated time of arrival. The strategy aims at reducing energy consumption while delivering bananas with desired quality. To make sure that bananas arrive with the right quality, continuous monitoring inside a reefer is necessary to estimate the remaining green-life. The proposed strategy determines temperature settings of reefer containers for all the future days, and can adjust the plan in response to disturbances of quality and arriving time. In simulation experiments we illustrate the effectiveness of the proposed strategy by comparing other strategies in different scenarios. Results show that the proposed strategy has the capability to manage temperature settings in a dynamic environment, while still preserving quality of bananas.

This research is an extension of Lin et al. [11], and can be further extended on the implementation of container ripening with the objective of designing a flexible banana supply chain. To be able to implement this concept in practice, some of the details need to be further investigated. For instance, since bananas in the same containers may not have the same green-life [8], more than multiple sensors should be deployed at different locations in one container to get thorough awareness of the quality within a container. Future research also includes decisions of on-board ethylene treatment and routing in scenarios with multiple destinations. Field tests can also be considered to bring the research closer to practice.

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Assessment of Cooperation and Competition Among Container Ports in the Northern Adriatic

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Abstract. In this article, we analysed container throughput in Northern Adriatic ports (NAPs) in period 1990–2015. Along with well-known market indices method, we also discussed a simple two-state Markov chain model for qualitative forecasting of containers throughput evaluation, and the Lotka-Volterra dynamical model to identify possible competition/cooperation relationships between NAPs. In the end is given a comparison of throughput dynamics of NAPs and ports in Le Havre – Hamburg region.

Keywords: Northern Adriatic ports · Container throughput
Port competition/cooperation

1 Introduction

Container ports today are not only a place where containers are transhipped from land to sea and vice versa, but they represent one of the most complex environments in the whole transport industry. Since the container transport has grown in the last decade with an average of 7%, ports were obligated to follow this demand. To obtain their competitive advantage against other container ports and to serve their main customers, shipping lines, they had to invest in new technologies. Investment in container ports means investment in modern equipment, sophisticated information technology, maritime and hinterland infrastructure and in operational management. On the other hand, the risk is high, as they depend on the decisions of shipping lines about choosing a port from the competition in the same or close-by area, of hinterland connections and from the overlapping of the catchment area. Container ports operate as highly complex and heterogeneous system, and they present a very important part of the logistic chain, that is also complex and depends on different factors. Importance of a port also depends on the importance of the logistic chain, and usually, a successful port presents a part of a successful logistic chain.

We will pay attention only to the throughput of containers (in TEU), and we will try to find out if our thesis about forecasting is correct. The paper presents the author's continuation in research on North Adriatic Ports (NAP) and the test of the methodology presented (Twrdy and Batista 2016) by analysing ports of North Adriatic in the period

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1990–2015. With the new data of the throughput in the NAP in years 2015 and 2016, we find that the model was correct and that it has some possibility.

First, we will analyse the containers throughput data and compare it with the data of the throughput of Le Havre – Hamburg (LHH) region. Technical details of the methodology used in this section are present in the Appendix. Then we will present a simple Markov chain forecasting model which can give us first qualitative insight about the evaluation of various throughput characteristic in future. For more sophisticated Markov chain modeling see (Hamilton 1989). In last forth section we will shortly discuss Lotka-Volterra dynamical model (LVM) which can help us to identify competition/cooperation relationships between NAPs. The article ends with the conclusion. For more details on quantitative forecasting and competition dynamics between containers ports see (Twrdy and Batista 2016) and the references given therein.

2 North Adriatic Multi-port Gateway Region

2.1 General Presentation

NAPs are one of twelve European multi-port gateway regions (Notteboom 2010). They are located on the coast of north Adriatic, within the range of about 300 km (see Fig. 1). Table 1 presents the main infrastructure characteristics of the container terminals of NAPs.

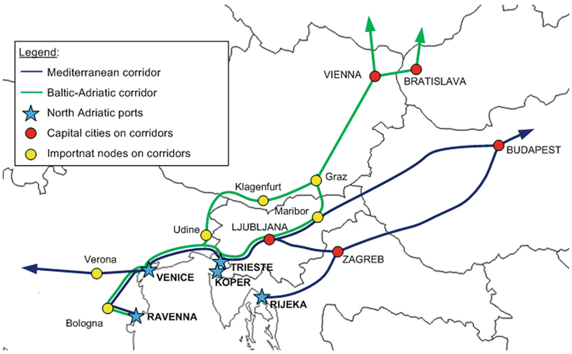

Fig. 1. Location of NAPs

NAPs are main containers ports for Croatia, Slovenia and East Italy, however, NAPs also share the same hinterland (with the most important countries being) Austria, Hungry and Slovakia (MDS 2012). Overlapping of the hinterland implies possible competition or cooperation relationship between NAPs. Currently, all NAPs have ambitious plans for new containers terminals that will provide them with further growth of throughput and some new business opportunities.

Table 1. Main characteristics of container terminals in NAPs

Characteristic	Unit	Koper	Rijeka	Venice[a]	Trieste	Ravenna[a]
Terminal capacity	1000 TEU	750	450	500 + 300	600	300 + 200
Terminal area	1000 m^2	300	150	300 + 135	400	300 + 10
Length of quay	m	600	628	850 + 1,060	770	640 + 608
No. of cranes	–	8	4	9	7	8
Max sea depth	m	13.5	14	11.4	18	10.5
Approx. capacity utilization of the terminal in 2014	%	90	43	57	84	45

[a]The data for the port of Venice and Ravenna include the characteristics of two containers terminals (Venice: Vecon and Intermodale Venezia; Ravenna: Ravenna and Stermar).
Source: data from the respective porta authorities.

By being located in Adriatic Baltic Corridor and Mediterranean Corridor, NAPs have a very good geographical position. These two corridors are the most important European Corridors that connect Europe from Baltic Sea to the Adriatic Sea and from Iberian Peninsula to Ukrainian border (see Fig. 1). However, nowadays, a good geographical location of a port is not enough for it to be an important player on the market. According to Meersmann et al. (2013), the competitiveness of ports depends on their infrastructure, organization and market forces, as the ports are an integral link in a logistic chain, with highly heterogeneous environments. However, when ports are located in the same region, throughput could be lower since competing ports handle parts of the cargo for the same hinterland.

Koper, Trieste, and Venice ports are currently connected via direct calls from deep-sea container services, with short sea intra-Mediterranean services and deep sea feeder services, while the port of Rijeka has only deep sea services and deep feeder services. The port of Ravenna has no calls from deep-sea container services and is connected to other ports only by intra-Mediterranean and feeder services. Due to its facilities, the terminal is inadequate for accommodating large post-Panamax ships (MDS 2012). The main goal of the NAPs for the future is to obtain more direct calls from deep-sea services with larger ships in their ports, which would allow them to receive even more cargo that is at this point destined for the northern European ports. Investments in their terminal capacity are therefore of vital importance. For the near future, Venice has planned a new offshore terminal outside lagoon, Molo VII in Trieste has plans for the extension of the existing terminal and the purchase of new quay cranes, while the port of Ravenna has decided not to invest in further terminal extension and instead focus their business on intra-Mediterranean and feeder lines. The port of Koper has planned to extend pier 1 by 100 m and to purchase two Super Post Panamax quay cranes, while its long-term plan is the construction of a third container pier. This should increase the port capacity to 1 million TEUs (port of Koper, 2015). The Rijeka port authority plans the construction of the new ‘Zagreb’ Pier, which will include 680 m of quayside with a maximum draft of 18 m and 25 ha of terminal area (port of Rijeka, 2015).

2.2 Container Throughput in NAPs

We can see from Fig. 2 that in the observed period 1990–2016 containers throughput increased in all NAPs. The largest increase was reached in 2015, in the port of Koper with 790736 TEUs (+17.3% compared to 2014), followed by the ports of Venice, Trieste, Ravenna and Rijeka, which has the lowest container throughput in the observed period. Uneven growth in containers throughput during this period resulted in a struggle for market share. From Fig. 3 we can observe three periods. In the beginning of 1990s. The leading container port in the beginning of 1990s was port Ravenna, but its market share continually drops over time. At the end of previous millennium and beginning of this millennium, the leading role was taken by the port of Venice which in 2003 reached a record market share of 39%. In this decade the leading container port among NAPs became the port of Koper which market share now reaches 35%.

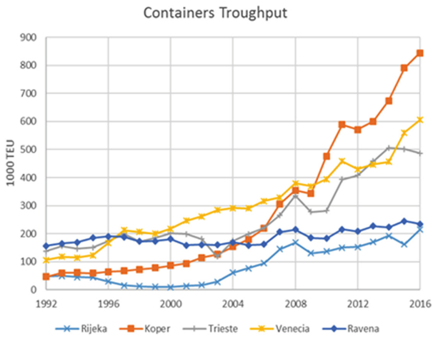

Fig. 2. Containers throughput for NAPs (1992–2016) Source: data from the respective port authorities

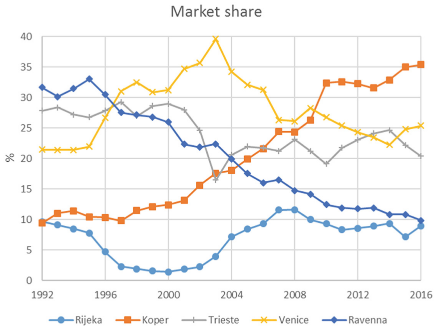

Fig. 3. The evaluation of containers market shares for NAPs (1992–2016)

While we can observe substantial changes in market shares of NAPs in Fig. 3, the situation of market concentration (shown on Fig. 4) present by the Hirschman–Herfindahl index (see Appendix) is more stable since it stays within 0.21 and 0.27. This, roughly speaking, means that there were always four main players among NAPs.

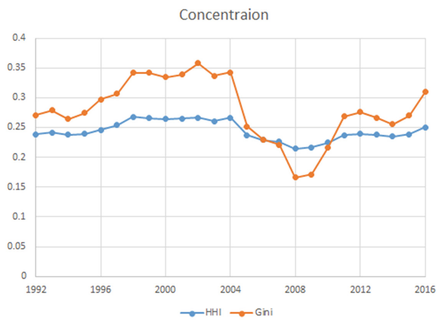

Fig. 4. The evaluation of Hirschman–Herfindahl index and Gini index for NAPs (1992–2016)

Or said in another way: the containers market in NA region is competitive; none of the NAPs overtook the market and became a monopolist. The same can be concluded (from Fig. 4) with the evaluation of Gini index (see Appendix), though it has slightly larger variation, from 0.2 to 0.4.

2.3 Comparison of NAPs and Ports in Le Havre - Hamburg Region

To get a better inside to main characteristics of NAPs multiport gateway region we compare it to Le Havre - Hamburg ports (LHHPs), a union of two of the biggest European multiport gateway regions, which include the ports of Le Havre, Dunkirk, Zeebrugge, Antwerp, Zeeland Seaport, Rotterdam, Amsterdam, Bremen and Hamburg (Notteboom 2010). From Table 2 it can be seen that NAPs throughput in average reach about 4% of containers throughput of LHHPs. While this figure was largest at the beginning of the observed period and reached 5.33%, it then decreased at the beginning of global recession in 2008 and fell to about 2.5%. In this decade the figure slightly increases and in 2014 reaches 4.1%. From the Table 2 and also from Fig. 5 we can see that in the observed period the containers throughput in LHHPs increased by factor five while in NAPs by factor four. Also, we can see from Fig. 5 that throughput dropped in 2009 in both regions; for 10% in NAPs and for 16% in LHHPs region (see Fig. 6).

Table 2. Total containers throughput in 1000 TEU

	1992	1996	2000	2004	2008	2012	2016
LHHPs	11037	14137	20143	28630	40245	40299	41572
NAPs	496	626	698	849	1452	1769	2386
NAP/LHHP (%)	4.50	4.43	3.47	2.97	3.61	4.39	5.74

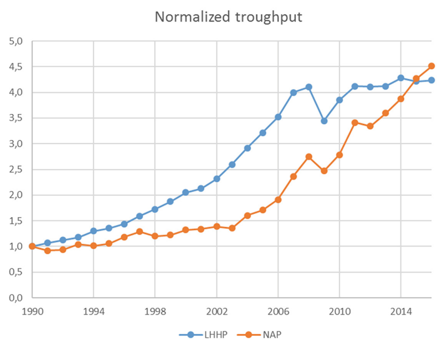

Fig. 5. Evaluation of container throughput in LHHPs and NAPs (1990–2016). Throughputs are normalized to year 1990

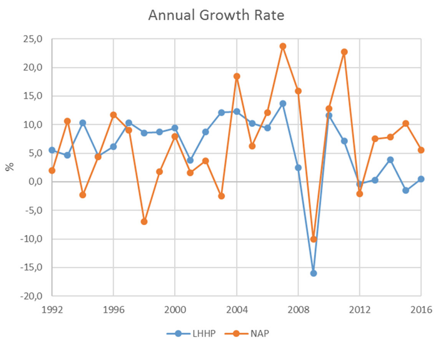

Fig. 6. The evaluation of annual growth rate range for LHHPs and NAPs (1992–2016)

In Fig. 6 the annual containers throughput growth rates (AGR) (see Appendix) for both regions are displayed. For LHHPs the AGR oscillates but is always positive, except in the crisis year 2009 and stagnation year 2012, and reaches its maximum at 13.7% in 2007. For NAPs, the AGR oscillation is more distinct and was negative in years 1991, 1994, 1998, 2003, 2009 and 2012. In 2007, i.e. a year before global recession, NAPs AGR gains its maximal value of 23.7%. It is also noticeable that AGR is higher for NAP then for LHHP. In 2016 AGR for NAP was 5.6% while for LHHP was only 0.5%.

From the comparison of AGRs, we can conclude that containers traffic in LHHPs is more stable than NAPs. This can also be confirmed with evaluation of instability index (see Appendix). For LHHPs the instability index is within 3% most of the time, meaning that market shares of LHHPs do not change much; or in other words, only 3% of containers are shifted between LHHPs. Like with AGR, the instability index for NAPs is more distinctive; it oscillated between 2% to 6% even up to 8% in 2003.

3 Forecasting by Markov Chain Model

In this section we will try to build a simple Markov chain model, about the future evaluation of containers traffic in NAPs such as: will throughput grow, will AGR grow or drop etc. Such model can be constructed in the following way.

Consider a sequence $y_0, y_1, \ldots.., y_N$. To this sequence we assign a binary sequence $b_1, b_2, \ldots.., b_N$ in the following way:

$$b_i = \begin{cases} 0 & y_{i-1} \geq y_i \\ 1 & y_{i-1} < y_i \end{cases} \quad (i = 1, .., N) \tag{1}$$

Now we assume that this sequence is realization of Markov process (Kemeny and Snell 1976), with two possible states of the transition probability matrix P:

$$\begin{array}{ccc} & & \text{next state} \\ & & \begin{array}{cc} 0 & 1 \end{array} \\ \text{current state} & \begin{array}{c} 0 \\ 1 \end{array} & \begin{bmatrix} p_{00} & p_{01} \\ p_{10} & p_{11} \end{bmatrix} \end{array} \tag{2}$$

The Markov process is described by

$$\pi_n = \pi_{n-1} P \tag{3}$$

where $\pi_n = \begin{bmatrix} p_0^{(n)} & p_1^{(n)} \end{bmatrix}$ is state vector and $p_i^{(n)}$ is probability that the process will, after n steps, be in state i. The steady state vector is given by:

$$\lim_{n \to \infty} \pi_n = \begin{bmatrix} \frac{p_{10}}{p_{01} + p_{10}} & \frac{p_{01}}{p_{01} + p_{10}} \end{bmatrix} \tag{4}$$

Transition probabilities p_{ij}, $(i, j = 0, 1)$ are estimated from the realized bit-sequence using maximum like hood estimates, which leads to formula (Guttrop 1995)

$$\hat{p}_{ij} = \frac{n_{ij}}{\sum_k n_{ik}} \quad (i,j = 0,1) \tag{5}$$

where n_{ij} is number of transitions from state i to state j in the given sequence.

Before we proceed with examples we (should?) note that Markov process is assumed to be random. Therefore, we have to establish if patterns of bits in the bit-sequence are random. This is done with the Run test (NIST 2013) where the null-hypothesis is that the sequence is random. Practically the assumption requires that the business conditions do not change over the years. But this cannot be not true due to various influences such as global regression in 2008, civil war in Croatia in the 1990s, strikes in port Trieste at the beginning of this millennium…

We now consider three examples. As the first example, we have a question if throughput will increase in the future. The calculation results of transition matrix and steady state vectors are given in Table 3. Steady-state probabilities indicate that in the long run, throughput will increase most of the time in all NAPs, the highest probability of 84% is for port Koper and lowest 63% for port Ravenna. We note that binary sequence for port Rijeka does not pass the Run test, therefore calculated probabilities are a bit questionable.

Table 3. Markov chain transition matrix for throughput (1990–2015)

		Rijeka	Koper	Trieste	Venice	Ravenna	Total
Transition	p_{00}	0.67	0.20	0.38	0.17	0.20	0.00
	p_{01}	0.33	0.80	0.63	0.83	0.80	1.00
	p_{10}	0.20	0.16	0.31	0.28	0.50	0.28
	p_{11}	0.80	0.84	0.69	0.72	0.50	0.72
Steady state	p_0	0.38	0.16	0.33	0.25	0.38	0.22
	p_1	0.63	0.84	0.67	0.75	0.62	0.78
Run test	Reject H_0	Yes	No	No	No	No	No

We can discuss the evaluation of AGR, given in Table 4, in a similar way. We can expect that in a long run AGR will increase by 62%. It will grow for Rijeka, Koper and Ravenna, while it will decrease for Trieste and Venice. All AGR associated binary sequences pass the Run test.

As the last example, we consider market share. From Table 5 we can see that, in the long run, market shares for ports Rijeka, Trieste and Venice will oscillate i.e. it will increase for 50% of the time and decrease for 50% of the time. However, for port Koper, it is expected that in a long run, its market share will increase for 73% of the time, while for port Ravenna it will decrease for 75% of the time. This indicates possible competition relationship between ports Koper and Ravenna. However, these conclusions could be questionable since binary sequence for ports Rijeka, Koper and Venice do not pass the Run test.

Table 4. Markov chain transition matrix for AGR (1990–2015)

		Rijeka	Koper	Trieste	Venice	Ravenna	Total
Transition	p_{00}	0.36	0.25	0.46	0.31	0.25	0.20
	p_{01}	0.64	0.75	0.54	0.69	0.75	0.80
	p_{10}	0.54	0.67	0.64	0.73	0.67	0.50
	p_{11}	0.46	0.33	0.36	0.27	0.33	0.50
Steady state	p_0	0.46	0.47	0.54	0.51	0.47	0.38
	p_1	0.54	0.53	0.46	0.49	0.53	0.62
Run test	Reject H_0	No	No	No	No	No	No

Table 5. Markov chain transition matrix for market share

		Rijeka	Koper	Trieste	Venice	Ravenna
Transition	p_{00}	0.75	0.50	0.45	0.67	0.76
	p_{01}	0.25	0.50	0.55	0.33	0.24
	p_{10}	0.25	0.19	0.54	0.33	0.71
	p_{11}	0.75	0.81	0.46	0.67	0.29
Steady state	p_0	0.50	0.27	0.50	0.50	0.75
	p_1	0.50	0.73	0.50	0.50	0.25
Run test	Reject H_0	Yes	Yes	No	Yes	No

At the end of this section, we note that the established transition probabilities, and consequently steady-state probabilities, clearly depend on the length of the observation period. In our case, the variation in probabilities is estimated to be within 10%.

4 Lotka-Volterra Dynamical Model

In this section, we will use Lotka-Volterra predator-prey dynamical model (LVM), to identify possible competition/cooperation relationships between NAPs. The system has the following form (Takeuchi 1996):

$$\frac{dx_i}{dt} = a_i x_i + \sum_{j=1}^{n} b_{ij} x_i x_j \quad (i = 1, \ldots, n) \tag{6}$$

where x_i is the total throughput of port i, t is time and n is the number of ports in the system. In our case $n = 5$. The coefficients a_i is natural decay/growth rate(s); off-diagonal coefficients b_{ij} $(i \neq j)$ are called interacting coefficients while diagonal terms b_{ii} are self-interacting coefficients. If we rewrite the system (6) in to the following form:

$$\frac{1}{x_i}\frac{dx_i}{dt} = a_i + \sum_{j=1}^{n} b_{ij}x_j \quad (i = 1, \ldots, n) \tag{7}$$

then we see that it(s) models the instant throughput growth rate. Obviously, throughput will increase if these rates are positive and this will happen if the coefficients of the system are positive. For $i \neq j$ we, therefore, adopt the following terminology (Lee et al. 2005; Twrdy and Batista 2016):

- if $b_{ij} > 0$ and $b_{ji} > 0$ then we have pure cooperation between ports i and j (win-win situation)
- if $b_{ij} < 0$ and $b_{ji} < 0$ then we have pure competition between ports i and j (no-win or lose-lose)
- if $b_{ij} > 0$ and $b_{ji} < 0$ then we have a predator-prey situation where port i is the predator and port j is the prey.

To estimate the coefficients of the system (6) from empirical data, we minimize the sum of squares of residuals:

$$\sum\nolimits_{i=1}^{n}\sum\nolimits_{t=1}^{N}\left(x_{i,t} - \hat{x}_{i,t}\right)^2 = \min, \tag{8}$$

where $x_{i,t}$ are throughputs at time t and $\hat{x}_{i,t}$ are solutions of (6) at time t. For more details see (Twrdy and Batista 2016).

The results of calculation are present in Table 6. For all NAPs, except for the port of Ravenna, the coefficient of determination R^2 is above 0.9 so we can conclude that LVM fits data well. This can also be observed in Fig. 7, where actual and fitted data for total throughput is shown.

Table 6. Result of calculation of parameters of LVM model for NAPs (1990–2016)

	Rijeka	Koper	Trieste	Venice	Ravenna	Growth	R^2	Adj_R2
Rijeka	-1.26E-03	-6.47E-05	-1.32E-03	1.81E-03	-1.48E-04	2.24E-02	0.878	0.849
Koper	1.27E-03	1.14E-04	-1.44E-04	6.70E-04	-4.23E-03	5.61E-01	0.990	0.987
Trieste	2.06E-03	6.40E-04	-1.18E-03	-7.88E-04	2.67E-04	1.69E-01	0.936	0.921
Venice	-2.99E-04	1.22E-04	-4.53E-04	-2.01E-04	1.93E-03	-1.16E-01	0.981	0.977
Ravenna	5.81E-04	5.56E-04	-8.65E-04	-3.90E-04	1.85E-04	1.17E-01	0.658	0.577

Based on the results in Table 6, we set up competition matrix shown in Table 7. Comparing with competition matrix from (Twrdy and Batista 2016), we see that the relationships remain the same for all ports except port Rijeka. For example, the relationship between ports Rijeka and Koper now turns out to be no-win, while in the period up to 2013 it was identified as win-win, while for Rijeka and Trieste goes from no-win to win-win. We note that the matrix shows that port Ravenna competes with other ports. However, as it was noted in (Twrdy and Batista 2016) we must use the

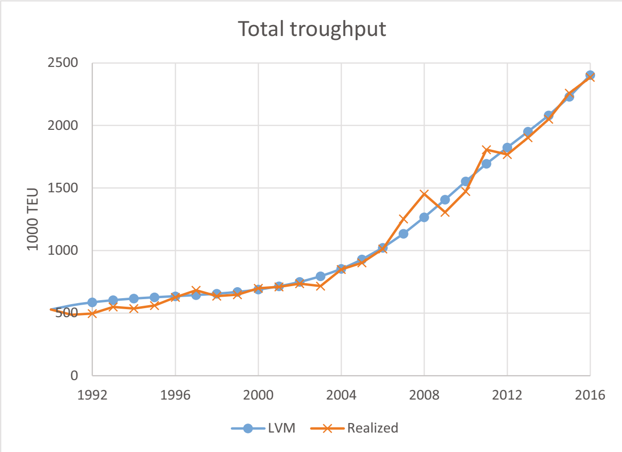

Fig. 7. LVM regression of total throughput in 1000 TEU in NAPs in period 1992–2016

Table 7. Competition matrix for NAPs (1990–2016). Shaded relations are the same as for 1990–2013 (Twrdy and Batista 2016). The relations are read in rows. An example: Rijeka is predator to Venice

	Rijeka	Koper	Trieste	Venice	Ravenna
Rijeka		prey	prey	predator	prey
Koper	predator		prey	win	prey
Trieste	Predator	predator		lose	predator
Venice	prey	win	lose		predator
Ravenna	predator	predator	prey	prey	

interpretation of identified relationships with caution, because these are not necessarily institutionalized relationships but relations identified only in this model.

5 Conclusions

In the paper, we have explored several methods of extracting useful information from containers throughput data for NAPs. We have shown that the NAPs containers market is competitive, it is more unstable than LHHPs and containers throughput will probably increase in the long run for all NAPs.

LVM shows that NAPs have developed more competitive than cooperative environments in the last 25 years. This is especially true for the three Italian ports.

Appendix: Methodology

In this appendix, we explain the methodology and the indices used in Sect. 3 in some details.

We consider n ports with containers throughputs $x_{i,t} \geq 0$, $i = 1, \ldots, n$, at time t. We define total throughput x_t at time t

$$x_t \equiv \sum_{i=1}^{n} x_{i,t} \tag{9}$$

There are three characteristics of a market of interest: its growth, its concentration and its instability.

The most common measure for growth of a market in time t is market annual growth rate r_t which is defined as (Farris 2009)

$$r_t \equiv \frac{x_t - x_{t-1}}{x_{t-1}} \tag{10}$$

This tells us how the market changed in the preceding time period.

For measure of concentration, the commonly used indices are the Hirschman–Herfindahl index (HHI) at time t and Gini index (Notteboom 1997; Notteboom 2010). The HHI H_t at time t is defined as follows

$$H_t \equiv \sum_{i=1}^{n} s_{i,t}^2 \tag{11}$$

where

$$s_{i,t} \equiv \frac{x_{i,t}}{x_t} \qquad (i = 1, \ldots, n) \tag{12}$$

is the market share of $s_{i,t}$ of port i at time t. It can be shown that $1/n \leq H_t \leq 1$ where $H_t = 1/n$ if all ports have the same market share and $H_t = 1$ if one port took all the market. The Gini index G_t at time t is defined as "relative mean difference" of market shares (Santos and Guerrero 2010)

$$G_t \equiv \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \left| s_{i,t} - s_{j,t} \right|}{2(n-1)} \tag{13}$$

We note that we normalize the index by $n - 1$ rather than by n. In this way index becomes normalised, that is $0 \leq G_t \leq 1$. When all ports have equal market share, then $G_t = 0$ and if one port takes all throughput then $G_t = 1$.

A third characteristic of a market is its instability. A measure for instability of market at time t is instability index I_t (Hymer and Pashigian 1962; Mazzucato 1998)

$$I_t \equiv \frac{1}{2} \sum_{i=1}^{n} \left| s_{i,t} - s_{i,t-1} \right| \tag{14}$$

In this article we multiply the index by factor ½ so it becomes normalised $0 \leq I_t \leq 1$. Obviously, the instability index vanishes if all ports retain their marked share. The index has yet another interpretation, it can show that it equals to relative net volume shift of containers (Notteboom 2010).

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A Concept for Predictability and Adaptability in Maritime Container Supply Chains

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Abstract. Logistics is an essential industrial sector for the digital transformation. Particularly maritime container logistic processes, which include many regional and global distributed stakeholders and numerous interfaces for data exchange between these parties, will benefit from digitalization. Using real time data about container vessels, truck fleets and containers for process predictions and adaptions will enable more efficient maritime container supply chains. In this paper, a concept for prediction and adaption of suitable cut-off times in maritime container supply chain will be introduced. Dynamic cut-off times at ports instead of static promise several process improvements, e.g. shorter throughput and storage times at container terminals and an increased utilized capacity of completely booked container vessels. Furthermore, the impact of adaptive times on selected process times will be estimated using a sample calculation in this paper.

Keywords: Maritime container logistics · Dynamic cut-off times
Future seaports · Predictability · Adaptability · Digitalization

1 Introduction

Logistics is an essential industrial sector for the digital transformation. Particularly maritime logistic processes, which include many regional and global distributed stakeholders and numerous interfaces for data exchange between these parties, will benefit from digitalization. Cloud Computing and Internet of Things enable an ubiquitous data and information visibility as well as process transparency and space- and time-independent platforms, which integrate hitherto separate service systems and data sources, provide the right information at the right time and at the right place. This technological evolution enables process innovations in maritime container logistics.

In maritime container logistics, seaports build the connection between the mass transport with container carriers (maritime main run) and plenty preparatory and subsequent hinterland transportations. Due to this important role, seaports have to adapt the changing circumstances in maritime transportation with priority and implement disruptive business models and services (Schönknecht 2009). According to the Industry 4.0 Maturity Model, process innovations occur on various stages. Visibility, Transparency, Predictability and Adaptability describe sequent maturity stages for information systems, which will improve process efficiency and enable further process innovations

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systematically (Schuh et al. 2017). Intelligent containers and complete information about arrival times, hinterland destination and required process steps will enable predictability and adaptability in container logistics (Jahn and Saxe 2017). Therefore, this paper presents a concept for adaptive deadlines in maritime container logistics based on predicted reliable arrival times.

2 Maritime Container Logistics

Maritime container logistics is highly relevant for German and European ports and economy. The evolution of received and shipped respective handled twenty foot equivalent units (TEU) in Bremen ports illustrate the increasing importance of maritime container logistics, which doubles itself within the last 15 years. While the Bremen ports (Bremen and Bremerhaven) handled 2,752 thousand TEU in 2000, total container handlings increase up to 5,479 thousand TEU in 2015 and 5,535 thousand TEU in 2016 (Bremenports 2017). Other German and European container terminals and the global container traffic show similar trends (ISL 2017a, b). Thereof 52.16% are exported containers, while 47.84% TEU were imported in Bremen ports. The most relevant trading partner are the USA (722 thousand TEU or 13.04%) followed by China (10.24%) and Russia (4.82%) (Bremenports 2017). Thus, this paper is focusing on container exports to the USA, but other container supply chains are similar. While the most containers (57.54%) will be transshipped, hinterland transportation is required for 2,345 thousand TEU (42.36%). Thereof the transport via trucks (1,189 thousand TEU or 50.70%) is more important than the transport via trains and barges (Bremenports 2017). Therefore, maritime container supply chains with preparatory and subsequent transportation via trucks are considered in the following.

3 Processes

In General, maritime container logistics considers the intermodal supply chain for ISO containers in marine transportation including the preparatory and subsequent hinterland transportation (Schönknecht 2009). For sending a container from Germany (Bremen) to America (New York City) a complex process is required. First, the shipper has to order an empty container from the carrier, which will be stowed afterwards. Then, the stowed container has to be loaded onto a truck and transported to the selected container terminal (Bremerhaven, DEBRV).

According to US customs regulations carriers have to submit required information, e.g. container gross weight, for all cargo through the Automated Manifest System (AMS) 24 h before loading at a foreign port. “Do not load” orders are issued to the carriers at the foreign port for cargo that does not meet the 24-h Rule. In order to ensure the compliance with this rule and other global and European restrictions, carriers are requiring shippers to deliver containers to the port several days before loading (Alderton 2008). The latest time a container may be delivered to a terminal for loading to the scheduled container vessel is called cut-off time or (gate) closing time. The required advance delivery time varies among the shipping companies but four days is typical (Alderton 2008).

These cut-off times are essential milestones in container logistics because all earlier process steps are aligned with this dates. Nowadays, Shipping companies are publishing their ship schedules and respective cut-off times in a decentralized manner at different platforms and in different formats, e.g. HTML table, PDF or mailing, and cut-off times are submitted together with booking confirmations to the shippers and will never updated. This results in supply chain inefficiencies, particularly when container vessels are delayed. Container vessel delays have still a significant influence on maritime container supply chains. According to previous research and statistics, in average 25.30% of all container liners were delayed in the third quarter 2017 and a survey of the Deutschen Seeverladerkomitees (DSVK) in 2016 shows that about 40% of the participants recognize delays up to few weeks in maritime transportation (DVZ 2016, 2017). Furthermore, for about 75% of the shippers is the information policy of the carriers in case of delays not sufficient. They got no or partial information about delays and in most cases over detours (DVZ 2016).

If a container met the cut-off time and arrived at the container terminal in time, it will be proceeded, handled and later loaded to the scheduled container vessel. If there are delays in the preparatory hinterland transport, the container will not be loaded to the scheduled container vessel, neither in the case the container vessel is delayed as well. Nowadays, this leads to increased throughput times, more stored containers at the terminals and increased no-show rates. The no show rate varies between 10% and 25%, which means that between 75% and 90% of vessel capacity is used on a completely booked vessel.

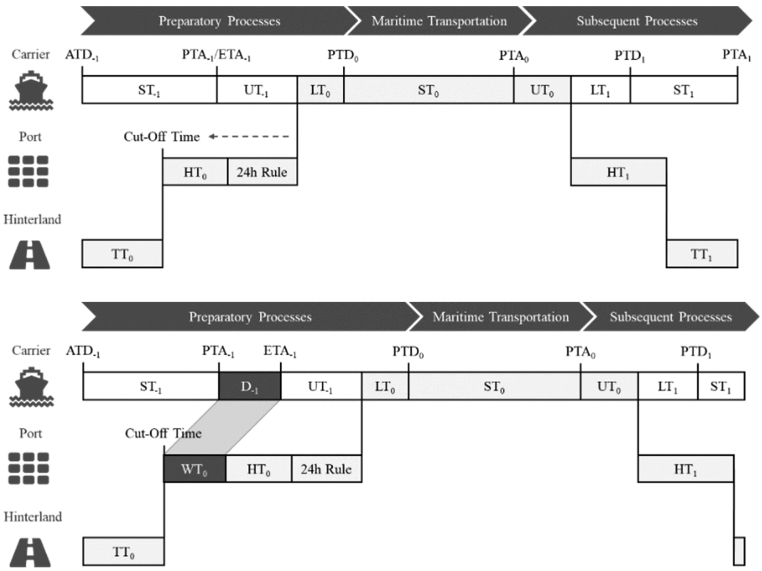

Fig. 1. Process times and dates in maritime container logistics as scheduled (upper part) and with delays (lower part)

The described maritime container supply chain including the respective process times and their dependencies are shown in Fig. 1. As long as container vessels are in time, the planned time of arrival (PTA) and the estimated time of arrival (ETA) are equal. When a delay occurs during the trip, e.g. due to bad weather conditions, PTA and ETA differ. In this case, there will be wasted time (WT) for the waiting containers at the ports in the same duration like the delay as long as the cut-off time remains at the original date. As there are vessel delays between few days and weeks, the impact for throughput or storage times of the containers is significant.

4 Concept and Process Innovation

The described process model and relations between various process steps build the basis for the calculation of process deadlines, e.g. cut-off times, which adapt process changes, e.g. container vessel delays. Respecting the relations and process step order, it would be possible to recalculate cut-off-times in real time but reliable information about (predicted) arrival times are required.

Using real time data about container vessels, truck fleets and containers for process predictions and adaptions will enable more efficient maritime container supply chains. Nowadays, all container vessels have a unique identifier (IMO) and provide various information about position, speed, heading, destination etc. to the Automatic Identification System (AIS) frequently (Harati-Mokhtari 2007). Linking the AIS data with port call information and ship schedules allow an informational mapping or digital shadow of the seaside processes. As previous research shows, the provided estimated times of arrival (ETA) is not reliable because 49% considered AIS datasets show obvious errors in this in destination related information (Harati-Mokhtari 2007; De Jong 2017; Parolas et al. 2016). Due to less reliable information about the ETA, some projects using artificial intelligence algorithms, e.g. neuronal networks, to predict the time of arrival based on historical data and the actual container vessel positions. The shorter the distance between the vessel and its destination, the more accurate is the prediction. However, within a time window about 14 h before arrival, predicting the time of arrival is possible with a probability above 95% and a tolerance about 20 min (De Jong 2017). Thus, artificial intelligence algorithms are able to generate reliable information about arrival times. The comparison between schedules and these predictions allows the identification of delays. A platform, which will provide reliable information about arrival times and delays to all parties in the preparatory processes, build the basis for adaptable and more efficient maritime container supply chains.

$$DCO_0 = CTA_{-1} + CUT_{-1} - 24\,\text{h} - HT_0 \tag{1}$$

Enabled by reliable information, suitable cut-off times for the next tour can be dynamically calculated in real time. The dynamic cut-off time (DCO) will be calculated with formula (1), where CTA_{-1} is the predicted or calculated arrival time for the previous vessel trip, CUT_{-1} is the calculated unloading time and HT_0 is the required handling time for containers, which depends on the carrier.

Using such dynamic cut-off times, delayed containers can be accepted at terminals when the corresponding container vessel is delayed as well. This will increase the utilized capacity in container vessels and reduces costs. Compared with the current situation, adapting cut-off times in dependence on container vessel delays will avoid wasted times and reduce overall storage times of containers at the terminals. Many seaports have a limited capacity and longer storage times for containers come along with an increased demand of storage places. Therefore, reducing the storage time has the same impact like increasing the storage capacity. As shown in Fig. 2, the saved wasted time (WT) is as large as the container vessel delay. According to the Drewry Carrier Performance Insights, 23% of transatlantic vessels are delayed for more than 24 h. The average deviation between the planned time of arrival (PTA) and the actual time of arrival (ATA) is 1.1 days (Marine Insight 2017). An evaluation average deviation between the cut-off times and planned times of departures (PTD) for 410 container vessels scheduled between Bremerhaven and US ports between August and November 2017 is 3.79 days and thus similar to the four days, which are typical (Alderton 2008). In case of static cut-off times and vessel delays about 1.1 day, the terminal throughput time of affected containers will be extended about 29,02%. With a delay rate about 23%, the average deviation between the cut-off times and planned times of departures (PTD) will be extended from 3.79 days to 4.043 says. In reverse, using dynamic cut-off times in Bremerhaven for US container export processes will reduce the average throughput time for containers about 6.68%. This is a conservative calculation and probably improvements about 10% are feasible. In 2016, 722 thousand TEU were transported between Bremen ports and US ports (Bremenports 2017). Thereof, about 376.595 thousand TEU were exported. In total, dynamic cut-off times will save about 95.279 additional container throughput days at Bremen ports in US export business per year.

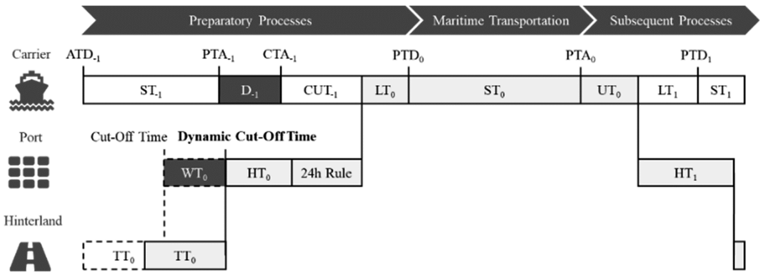

Fig. 2. Process times and dates in maritime container logistics as scheduled (upper part) and with delays (lower part)

5 Conclusion and Outlook

As described above, reliable information about the arrival times enable the dynamic calculation of suitable cut-off times for the next tour. Using such dynamic cut-off times, which will be adapted to the actual state and position of container vessels, promise significant improvements in maritime container supply chains. Container throughput or storage times at ports can be shortened about 10% in case of vessel delays, which will increase the calculative terminal capacity. Furthermore, dynamic cut-off times allow the acceptance of delayed containers when the scheduled vessel is delayed as well. This will increase the utilized capacity in container vessels and reduces costs. Qualitative interviews with some stakeholders confirmed the plausibility and general benefit of dynamic deadlines. Predictability and adaptability for cut-off times and other process times in maritime transportation are required to enable intelligent, autonomous and synchromodal container supply chains. In this paper, the concept of prediction and adaption for cut-off times in maritime container logistics was presented and the impact on relevant process times was calculated. Nevertheless, further research is required to evaluate the described concept and provide a suitable guideline to the maritime container industry. In particular, simulations (using system dynamic models) will allow more concrete statements about the impact of dynamic deadlines on relevant key performance indicators and the overall container supply chain efficiency.

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Impacts of the BRI on International Logistics Network

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Abstract. Chinese President Xi Jinping unveiled the Belt and Road Initiative (BRI) in 2013, intends to promote traffic connectivity and regional economic cooperation by reviving the ancient Silk Road. Under this background, this paper aims to give an overview about the impacts of the BRI on international logistics network, through identifying crucial influencing factors and analyzing the relationships between the BRI and these factors. The analytical study shows the BRI influences international logistics network by both qualitative and quantitative factors in a comprehensive way. The BRI-induced challenges and opportunities also indicate the future research possibilities about international logistics network design/redesign.

Keywords: The Belt and Road Initiative (BRI) International logistics network

1 Introduction

To update the domestic industry structure, and promote regional economic co-operation, the Chinese government proposed the Belt and Road Initiative (BRI) in 2013. It is a long-term development strategy intends to connect Asia, Europe, and Africa by establishing "the Silk Road Economic Belt (SREB)" and "the 21st Century Maritime Silk Road (MSR)". The SREB focus on roads, railways, and gas pipelines; while the MSR targets on shipping corridors through the South China Sea, the South Pacific Ocean, and the Indian Ocean area (Lo 2015). Along the Belt and Road 65 countries are involved, "jointly account for 62.3%, 30.0% and 24.0% of the world's population, GDP and household consumption, respectively" (Chin and He 2016).

China's ambitious vision is gradually changing the landscape of world economy from many aspects, leads to several consequences to the business environment and logistics activities. The World Bank research group has labeled the BRI as one of the "major new international initiatives address logistics issues" (Arvis et al. 2016). Thus, it is essential to investigate how the BRI affects international logistics logistic network to further explore the implication for decision-makers. This article discusses the effects of the BRI on international logistics network by giving an overview of the influencing factors referring network design. The overall research goal of the paper is to give first ideas on how the BRI influences the design of international logistics network on a

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strategical and tactical level. The rest of this paper is structured as follows. The second section presents a general structure of international logistics network and the classification of decisions. The third section comprehensively analyzes the impacts in the view of business environment and transportation. The last section gives the conclusion and implications.

2 International Logistics Network

In this article, international logistics network is investigated from a perspective of international manufacturers, it is a system including a set of facilities (suppliers, manufacturing plants, distribution centers, and consumers), the physical flows (flow of raw materials, products, and commodities) between these facilities, and the relationship between these elements. Figure 1 presents a general structure of international logistics network.

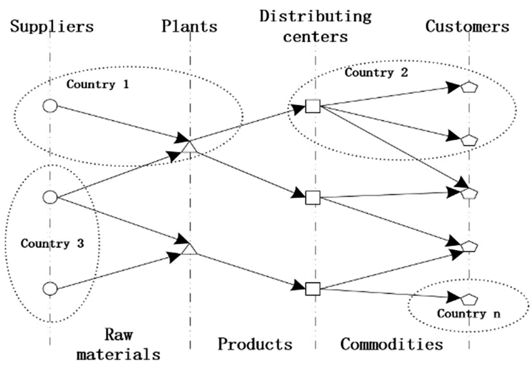

Fig. 1. General model of international logistics network

According to some early research (Vidal and Goetschalckx 1997; Schmidt and Wilhelm 2000), decisions in international logistics network can be categorized into three levels according to the time horizon of planning: strategic, tactical, and operational. Strategic level designs a set of facilities including the echelon, number, location, capacity, function. The tactical level concerns about the material flow management, while the operational level focuses on schedules (for example in-time delivery) to satisfy customers demand. Therefore, considerations regarding different levels are varied, and the lower level decision is limited by the higher levels. A lot of researchers consider strategic and tactical decisions together as the design of international logistics network, because of the tradeoffs (for example, inventory cost and transportation cost) existing between these two levels.

3 Impacts on International Logistics Network

The effects of the BRI only concerns about strategic level and tactical level decisions. There are three reasons: (1) different from domestic logistics, various functional facilities in international logistics network are allocated in several countries to pursue competitiveness advantage, which makes long-term strategic decisions more sensitive to the changing socio-economic environment; (2) the BRI increases the access to global markets, which means logistics performance can be improved by choosing alternative transport routes or modes. The tactical decisions which regarding the physical flow management are as well affected; (3) the operational levels only consider short-term planning (normally within 24 h) (Vidal and Goetschalckx 1997), thus not obviously affected by the long-term initiative.

According to the international logistics performance index (LPI) provided by the World Bank and the connectivity index provided by the UNCTAD, economic factors are not the only decisive criteria, political factors and other social factors should be considered as well. Thus, referenced from related literature from platforms like Web of Science and Emerald Insight, the factors which should be concerned referring strategic decisions in international logistics network, are categorized into three groups, listed in Table 1. These factors prominently lead to changes in network strategic planning.

Table 1. Influencing factors relevant to strategic decisions

Economic factors	Market demand and prices, production costs, transportation costs, import tariffs/export taxes, monetary exchange rates, inflation and interest rates, duty drawbacks, transfer prices, etc.	(Vidal and Goetschalckx 1997; Vos 1997; Alles and Datar 1998; Schmidt and Wilhelm 2000)
Political factors	Political stability, trade regulations, local content rules, financial incentives, etc.	(Schmidt and Wilhelm 2000; MacCarthy and Atthirawong 2003; Chen and Paulraj 2004)
Others	Labor characteristic, infrastructure, telecommunication technologies, culture differences, etc.	(Canen and Canen 2001; MacCarthy and Atthirawong 2003)

As for the physical flow management in international logistics network, except for the socio-economic factors, influencing factors also related to transportation, such as transportation cost, transportation modes and delivery time (Hammami et al. 2009; Badri et al. 2013).

Meanwhile, the implementation of the BRI leads to worldwide consequence in economics and politics, enhancing the complexity. Depend on the official documents released by the National Development and Reform Commission, Chinese authorities have identified five priority areas to push forward the BRI: policy coordination, facilities connectivity, unimpeded trade, financial integration and people-to-people bonds (NDRC et al. 2015), which has considerable effects on the above-mentioned aspects.

Policy coordination: the BRI puts efforts into making bilateral and regional agreements with countries and international organizations. Until the end of 2016, there are

129 countries signed 131 bilateral investment agreements. These are of significant impacts on the socio-economic factors such as exchange rate (Lai and Guo 2017), import/export markets (Cheng 2016), taxation and customs (Yang et al. 2016; Fallon et al. 2016). Since the goal is to provide an inductive trade and invest environment by government regulations, political factors are most highly affected.

Facilities connectivity: infrastructure projects include the construction of ports, roads, railways, airports, power plants, oil and gas pipelines, as well as telecommunications and financial infrastructure. Transportation factors are mainly influenced (Ylander 2017).

Unimpeded trade and financial integration: trade and investment are growing robust along the Belt and Road, 56 economic and trade zones in more than 20 countries have been built. China's imports from the BRI-involved countries reached more than US$100 billion in the first quarter of 2017, increasing considerable international markets demand. These two priorities affect the economic factors especially the markets (Mengzhao and Shumin 2015).

People-to-people bonds: cultural and academic exchanges, personnel exchanges and media cooperation are the main content. Related influencing factors are labor characteristic and cultural differences.

4 Conclusion

This paper discusses the four aspects effects that the BRI has on international logistics network: the economic factors, the political factors, the transportation factors, and other social factors. This means, with respect to the BRI, both qualitative and quantitative factors should be considered when making strategic and tactical decisions. This can be used by decision-makers in international companies as well as ministries to rethink the present international networks to find corresponding adequate decisions. In this BRI context, challenges and opportunities for international logistics in the medium and long-term are existing. Future research is necessary related to international logistics network design/redesign.

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Cyber-physical Production and Logistic Systems

Towards an Adaptive Simulation-Based Optimization Framework for the Production Scheduling of Digital Industries

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Abstract. The effective and efficient assignment of orders to productive resources on manufacturing systems is relevant for industrial competitiveness. Since this allocation is influenced by internal and external dynamic factors, in order to be responsive, production systems must possess real-time data-drive integration. The attainment of this kind of integration entails relevant praxis and scientific challenges. In this context, this paper proposes an adaptive simulation-based optimization framework for productive resources scheduling which takes advantage of forthcoming data transparency derived from the application of digital factory concept. The proposed framework was applied in a test case based on a production line of a Brazilian automotive parts supplier. The outcomes substantiate the applicability of adaptive simulation-based optimization approaches for dealing with real-world scheduling problems. Furthermore, potential improvements on the management of dynamic production systems derived from the application of digital factory concept are also identified.

Keywords: Manufacturing systems · Simulation-based optimization
Adaptive scheduling · Industrie 4.0 · Digital factory

1 Introduction

The rationalization of the manufacturing processes stands out as one of the crucial factors that influence production cost, productivity and quality. However, improving the management of manufacturing systems has challenged researchers and industry professionals. In this way, new concepts such as the smart digital factory has been explored (Pimentel 2014). The increasing customisation of products requires these manufacturing systems to handle higher numbers of product variants along with decreasing lot sizes, leading manufacturing systems to become more and more complex (Lin and Chen 2015). Hence, the scheduling and control of production processes control have great influence on the performance of the industry. For instance, in a digital factory

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environment, the computers, sensors and software, when integrated, are able to collect data from the materials needed for the manufacturing processes. Moreover, the connected systems for intelligent production provide support for several different areas inside companies, such as the product design, the production flow and materials planning, the staff planning, finance and even the project management. This new industrial phase is characterized by the use of sensors and networked machines and has led to a growth in the quantity of data being collected along the production processes through the communication of the many different parts of a manufacturing system. In this environment with a high volume of data, more accessible technologies digital factories could be further developed order to achieve the goal of intelligent and self-learning manufacturing (Lee et al. 2014).

In this context, the "Digital Factory" illustrated in Fig. 1 represents some manufacturing technologies that are addressed on the test case. This work also shows a set of relevant attributes that can provide an intelligent production environment for complex and flexible systems, which is the reality of several production systems. Consequently, it is possible to respond more effectively to the dynamic behaviour. Also, this digital factory concept enables the application of the adaptive simulation-based optimization framework, aiming an optimized adaptation for scheduling problems.

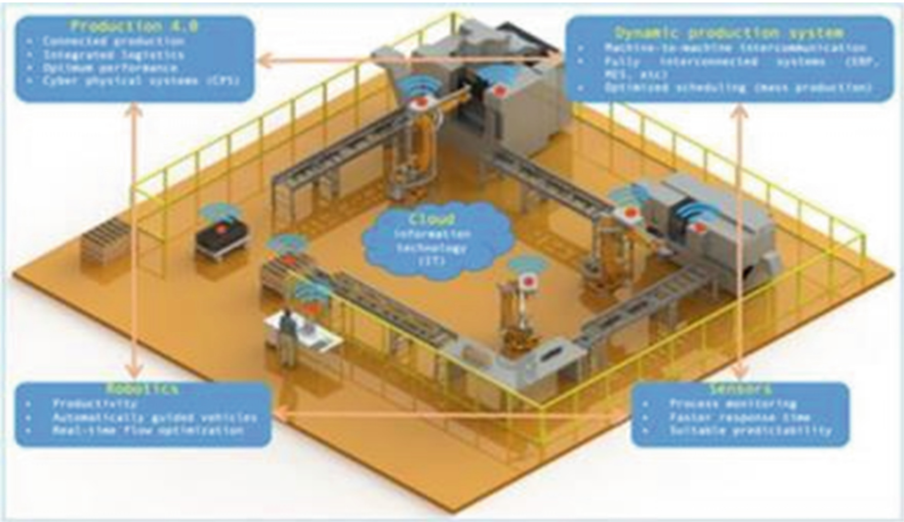

Fig. 1. Example of a digital factory.

A promising approach with the aim of combining the strengths of both is the so-called simulation-based optimisation (SBO). In this setting, the simulation model is used as the objective function of the optimisation and the optimisation method determines the optimal configuration of parameters for the simulation. Since the simulation model represents the real system in detail, it is not always necessary to express all relations of parameters analytically in the optimisation model, which reduces the computational effort (Krug et al. 2002).

Ivanov et al. (2016) added the current status and an algorithm for short-term supply chain scheduling in the smart factory industry 4.0, the authors outlined that the digital industry concepts are promised in factories of the future. In this context, this research proposes an adaptive simulation-based optimization (SBO) framework for the scheduling and control of manufacturing systems in digital factories. The structure of the paper is organized as follows. In Sect. 2, a detailed explanation of the adaptive simulation-based optimization framework for the production scheduling and control problem is presented. Then, an application with real data from an industrial test case, along with obtained results and discussions, is detailed. Lastly, conclusions are stated in Sect. 3.

2 Adaptive Simulation-Based Optimization Framework

Due to the nature of real-world manufacturing systems, the generation of optimal schedules is often a complex stochastic optimization problem. To schedule complex stochastic and dynamic manufacturing systems, a data-driven simulation-based optimization (SBO) approach was proposed by Kück et al. (2016). In this research, the proposed approach is materialized into a detailed framework, which is applied to a test case based on a production line of a Brazilian automotive parts supplier. The adaptive simulation-based optimization framework is embodied on the interaction between two main parts. Based on the characteristics of a real flow shop factory and its demand, an adaptation of a genetic algorithm developed in MatLab language is used to generate a schedule for the entering times (referred here as dispatch times) of every job in every machine. Thus, makespan (processing total time) is used as a main parameter of the fitness function, as follows:

$$C_{max} = Min\{Max. \sum_{i=1}^{n} \sum_{j=1}^{m} \left(T_{i,j,k} + P_{i,j,k}\right)\} \tag{1}$$

Where C_{max} represents the minimal total order makespan, $T_{i,j,k}$ represents the start time of operation j for job i in machine k and $P_{i,j,k}$ represents the processing time of operation j for job i in machine k. The flexible job shop scheduling problem (FJSP) entails organizing the execution of N jobs on M machines. A set of machines is represented by U. Each job J_i contains a number of ordered operations $O_{i,j} \subseteq O_i$, where $O_{i,j}$ represents the j_{th} operation of the i_{th} job. Each $O_{i,j}$ requires at least one machine for processing from a set of available machines $U_{i,j} \subseteq U$. The processing time of operation $O_{i,j}$ assigned to machine M_k ($M_k \in U_{i,j}$) is represented as $P_{i,j,k}$, where job $J_i = \{1 \leq i \leq N\}$, operations $O_{i,j} = \{1 \leq i \leq N; 1 \leq j \leq O_i\}$, and machines $M_k = \{1 \leq k \leq M\}$ (Chang et al. 2015).

Along with the genetic algorithm, to consider the probabilistic processing times of each machine, a simulation model is used to virtually apply the selected schedule and estimate a makespan for the jobs left in the production line. After the interaction, the resulting schedule is then sent back to the digital factory to be applied. The real factory administration (represented by the "real factory" entity in Fig. 2) maintains a spreadsheet regularly updated with the factory characteristics (numbers of available machines in each operation, number of operations, the list of products processed in the real factory and the sequence of operations for each product), and the current demand of the real factory (list of jobs, with respective identification numbers, product types and lot sizes).

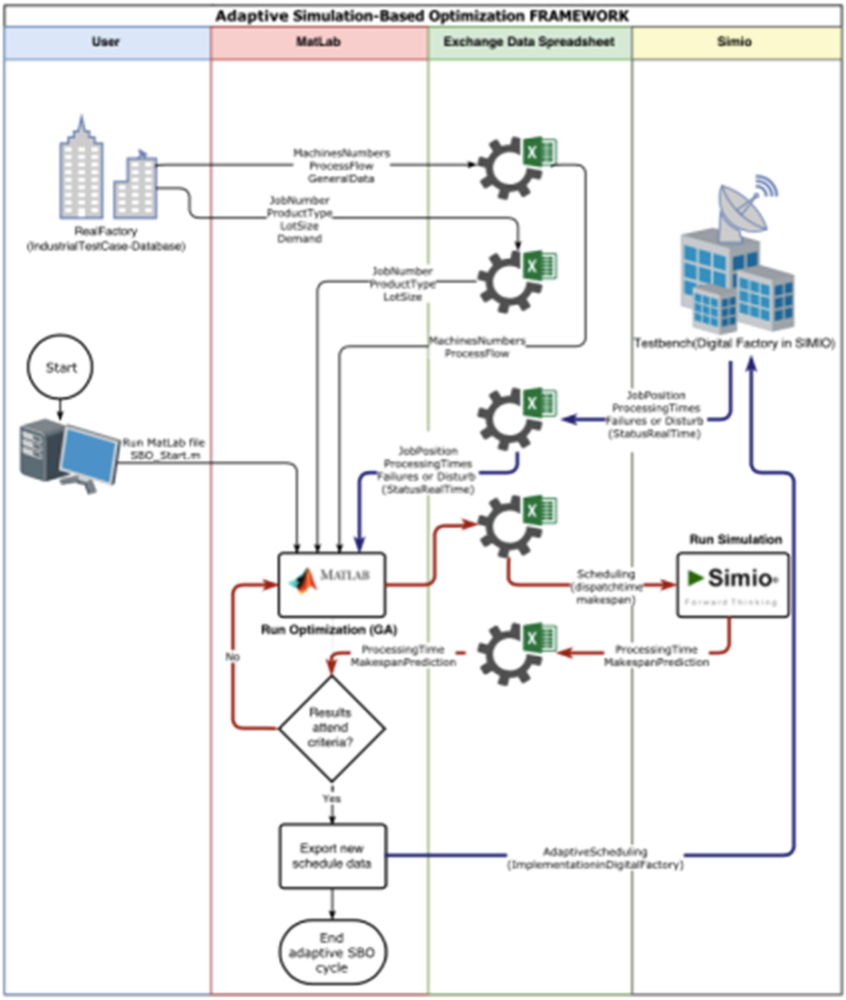

Fig. 2. Adaptive simulation-based optimization framework.

With an up-to-date system, the adaptive SBO framework is started either by a triggering event (such as a machine breakdown or a demand update) or in regular time intervals, so that the production line is kept always working according to a proper schedule. In the model, the system is started by the user, by running the SBO_Start.m MatLab algorithm which manages all the data operations.

When triggered, the program gets real time information from the simulated online factory: the position of each job in the production line (the machine in which the job is), the recent average processing times for each kind of product in each machine and the status of every machine (available or in maintenance). Thereof, to imitate the real-world factory behaviour, a test bench model (also in SIMIO) was built including machine breakdowns and processing time disturbances. The Simio software is called by MatLab using an application programming interface (API) developed by Dehghanimohammadabadia and Keyserb (2016), which runs an experiment previously set in the Simio model. The outputs of the experiment are exported by Simio to a spreadsheet, and then accessed by the MatLab manager algorithm. After getting the digital factory status information and the complete list of jobs, the system runs a genetic algorithm to generate a proper schedule considering the current status of the production line (jobs demanded and available machines). It then writes the dispatch times of each job for each machine in a spreadsheet, making it available for the Simio software.

The next step is to run a simulation model in Simio. This model reads the dispatch times made by the genetic algorithm and gives back an estimated makespan. If there's any operation in which all the machines are stopped (meaning at least a part of the production line is stuck) the framework recognizes it and doesn't generate any new schedule, exiting the loop with no changes in dispatching times' spreadsheets. As shown in Fig. 2, this adaptive framework is divided in 4 interactive essential segments running as follows.

Furthermore, the genetic algorithm GA-Simulation keeps running (generating new schedules and the respective makespan) until one estimated makespan is kept as the best result for three consecutive iterations. When the system gets out of the loop, it shows for the user the new estimated makespan with other information about the process (time elapsed in the framework, number of iterations) and exports the new instant schedule and the respective best makespan found in the spreadsheet, making it available for the testbench digital factory.

The described framework was applied in a test case based on the production line of a Brazilian automotive parts supplier. The process flow for the referred production line can be seen in Fig. 3.

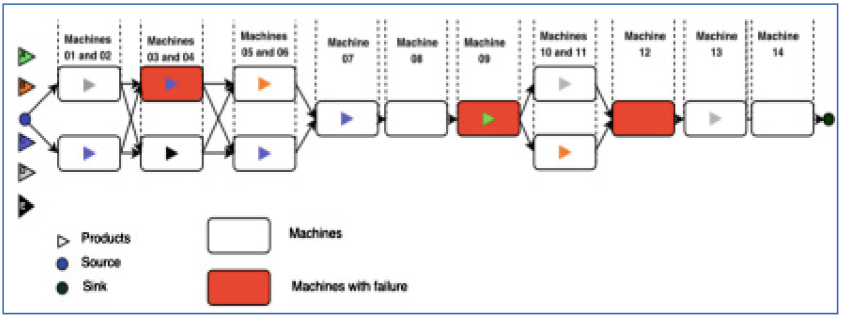

Fig. 3. Process flow of the test case.

The production line used as study case has ten operations that require fourteen machines and six workers. Moreover, this production line produces five kinds of products with different technical characteristics, process flows, delivery dates and demands. The information flow and interactivity occur dynamically, even as the planning changes. For this reason, the more adaptable and interconnected is the production system, the faster will be the response to the disturbances, such as: broken machines, demand oscillation, delivery dates' changes, broken tools, unexpected setup, among others disturbances. In this first test case, machine breakdowns were introduced in the test bench model. These disturbances are also represented in Fig. 3 (machines with failure in red).

The Fig. 4 shows the schedule generated by the proposed framework after the disturbances. The makespan after the occurrence of disturbances in the production line represented by the test bench digital factory was 192 h, which allowed for the delivery of all monthly orders *on time in full*. Note that, when the adaptive re-scheduling was triggered, machines 1, 2, 3 and 4 had already finished their operations to attend current month orders.

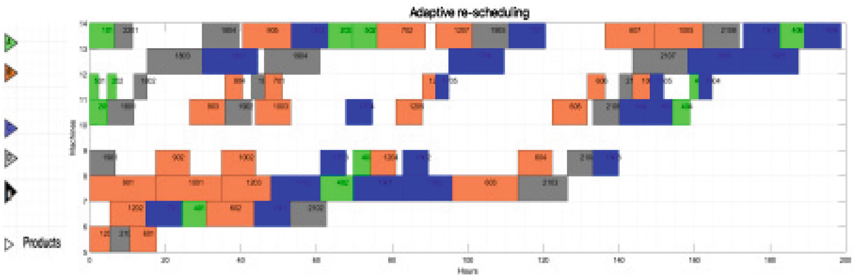

Fig. 4. Gantt chart after the re-scheduling.

3 Conclusion

The proposed framework embodies the implementation of an adaptive simulation-based optimization approach. In a model of a real-world production line of automotive parts, the proposed framework was able of adapting the production scheduling to dynamic disturbances (i.e. machines breakdown). This outcome supports the applicability of the proposed adaptive simulation-based optimization for dealing with real-world production job shop scheduling problems. Moreover, the implementation of digital factory concept and related technologies into real-world manufacturing, logistics and services systems will allow for the application of proposed framework and approach to deal with diverse scheduling problems, supporting the digital transformation of today´s industry into future´s industry 4.0, with positive operational performance benefits.

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Operator-Based Capacity Control of Job Shop Manufacturing Systems with RMTs

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Abstract. Capacity adjustment by using reconfiguration machine tools (RMTs) is one approach to deal with customers rapidly changing demands. However, disturbances (e.g. rushed orders and machine broke down) and delays (e.g. transportation delay and reconfiguration delay) are great challenge for the manufacturers. In order to deal with these problems, we propose an operator-based robust right coprime factorization (RRCF) method to improve the capacity control process of job shop systems. We illustrate the applicability of this approach by simulation results of a four-workstation job shop system are given to support the efficiency of the proposed method.

1 Introduction

Capacity adjustment of job shop manufacturing systems has attracted much attention. In contrast to traditional labor based approaches, Reconfiguration Machine Tools (RMT) as one advanced technology of Industrie 4.0 provides an opportunity for machinery-based capacity adjustment, which cannot be achieved by using Dedicated Machine Tools (DMT) only. In [1], RMTs harmonizing throughput-time capacity control approach was utilized to plan the delivery dates and analyze the inventory range of each workstation considering reconfiguration delay. Proportional-Integral-Differential (PID) [2,3] control method was applied to capacity adjustment, and an mathematical model of job shop systems was developed including new degree of freedom of RMTs. Furthermore, the respective model was continuously extended including the WIP and planned WIP level of each workstation and a model predictive control (MPC) approach was applied considering time-varying input orders [4].

However, job shop systems are not simple single-input-single-output (SISO) systems, but instead show nonlinear dynamics as wells as a multi-input-multi-output (MIMO) structure with strong coupling between the workstations (subsystems). Additionally, this system also suffers from many disturbances and delays, which are unaccounted for in the literature. Operator-based robust right

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coprime factorization (RRCF)[5] is one opportunity to deal with these issues and has been studied for the above application in [6]. Robust stability of a respective closed loop with unknown bounded disturbance was studied in [7,8], whereas tracking control for delays or time-varying delays was considered in [9,10]. Additionally, decoupling techniques were studied in [11,12].

In this paper, we will include transportation delays between workstations, reconfiguration delays of RMTs, and rushed orders into the capacity control process of job shop systems. To this end, we first state mathematical preliminaries in Sect. 2 before shortly describing the job shop model in Sect. 3. Thereafter, in Sect. 4 we propose the capacity control design and show simulation results in Sect. 5 before drawing conclusions in Sect. 6.

2 Mathematical Preliminaries

In this paper, we consider general nonlinear input–output systems of the form

$$P : U \to Y \tag{1}$$

where the input and output spaces U and Y are two normed linear spaces over the field of complex number, endowed, respectively with norms $\|\cdot\|_U$ and $\|\cdot\|_Y$. We denote the set of all (nonlinear) operators by $\mathcal{N}(U, Y)$ and call $\mathcal{D}(P)$ and $\mathcal{R}(P)$ the domain and range of P. A (semi)-norm on (a subset of) $\mathcal{N}(D_s, Y)$ is defined via

$$\|P\| := \sup_{x,\tilde{x}\in D_s \& x\neq\tilde{x}} \frac{\|P(x) - P(\tilde{x})\|_Y}{\|x - \tilde{x}\|_U}$$

Let U_s be the stable input subspace and Y_s the stable output subspace of the operator P, then the operator $P \in \mathcal{N}(U_s, Y_s)$ with $U_s \subseteq U$ and $Y_s \subseteq Y$ is called causal, stabilizable or unimodular if

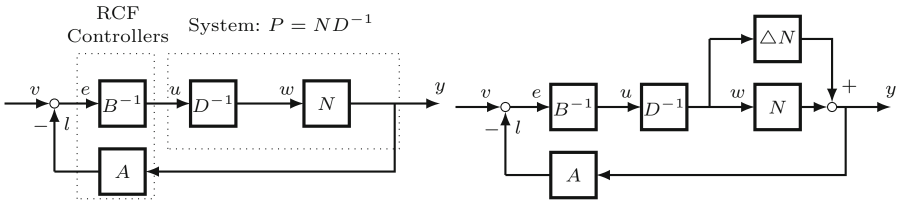
1. for the projection (causal)

$$Q_T(x(t)) = \begin{cases} x(t), & 0 \le t \le T \\ 0, & T \le t \le \infty \end{cases}$$

   we have $Q_T \circ P \circ Q_T = Q_T \circ P$ for all $x(t) \in U$ and all $T \in [0, \infty)$,
2. there exists an operator $Q : \mathcal{D}(Q) \to \mathcal{D}(Q)$ such that $P \circ Q$ is input-output stable, (stabilizable)
3. P is stable and $P^{-1} \in \mathcal{N}(U_s, Y_s)$. (unimodular)

These three properties allow us to introduce our main tool to design the controllers:

Definition 1 (Right Coprime Factorization (RCF) [5]). *Let $P : \mathcal{D}(P) \to \mathcal{R}(P)$ be a causal and stabilizable operator. We say that P has a right coprime factorization as illustrated in Fig. 1a, if there exist stable and causal operators $D : \mathcal{D}(P) \to \mathcal{D}(P)$, $N : \mathcal{D}(P) \to \mathcal{R}(P)$ as well as $A : \mathcal{R}(N) \to \mathcal{D}(P)$ and $B : \mathcal{R}(D) \to \mathcal{D}(P)$ such that*



(a) RCF control system (b) RRCF control system

Fig. 1. Operator-based feedback control of nonlinear systems

1. *D is causal, invertible and $P = N \circ D^{-1}$ holds on $\mathcal{D}(P)$, and*
2. *for the unimodular operator $M : \mathcal{D}(P) \to \mathcal{D}(P)$, we have the Bezout identity*

$$A \circ N + B \circ D = M. \tag{2}$$

Considering bounded disturbances, we are interested in robust controllers.

Definition 2 (Robust Right Coprime Factorization (RRCF)). *If a plant operator P satisfying Definition 1 subject to a bounded disturbance $\triangle N$ as illustrated in Fig. 1b has right factorization such that two operators A and B exist satisfying the Bezout identity $A \circ (N + \triangle N) + B \circ D = \tilde{M}$, where $\tilde{M}$ is an unimodular operator, then we say that the system has robust right coprime factorization.*

Using these definitions reveals an effective approach to control and analyze stability and performance of a class of nonlinear control systems, which include job shop systems. Before designing a respective controller, we now shortly recap the model of such a system.

3 Mathematical Model

Following [3], each workstation can be represented as a control system of the form

$$\begin{aligned}\dot{y}_j(t) = X_{0j}(t - \tau_2) + \sum_{k=1}^{n} p_{kj} \cdot (n_k^{DMT} \cdot v_k^{DMT} + u_k(t - \tau_2 - \tau_1) \cdot v_k^{RMT}) \\ + d_j(t) - (n_j^{DMT} \cdot v_j^{DMT} + u_j(t - \tau_1) \cdot v_j^{RMT})\end{aligned} \tag{3}$$

where we utilize the variables defined in Table 1. Each workstation may receive orders from the initial stage ($k = 0$) and workstation $k \in \{1, 2 \ldots, n\}$, and delivers its products to a final stage ($i = 0$) and workstation $i \in \{1, 2, \ldots, n\}$ according to the flow probabilities p_{ji} satisfying $\sum_{i=0}^{n} p_{ji} = 1$ for all $j \in \{1, \ldots, n\}$. Each workstation is equipped with a fixed number of DMTs and may be assigned a variable number of RMTs. We suppose that all RMTs can be used within all workstations, but only perform one operation at the specific period, which reveals the constraints

Table 1. Variables within a job shop system with RMTs

Variable	Description
$X_{kj}(t)$	Orders input rate from workstation k to j for $k, j \in \{0, \ldots, n\}$
$u_j(t)$	Number of RMTs in workstation $j \in \{1, \ldots, n\}$
$y_j(t)$	WIP level of workstation $j \in \{1, \ldots, n\}$
p_{jk}	Flow probability from workstation j to k for $j, k \in \{0, \ldots, n\}$
p_{j0}	Flow probability from workstation $j \in \{1, \ldots, n\}$ to final stage
p_{0j}	Flow probability from initial stage to workstation $j \in \{1, \ldots, n\}$
n^{RMT}	Number of RMTs in the system
n_j^{DMT}	Number of DMTs in workstation $j \in \{1, \ldots, n\}$
n^{DMT}	Number of DMTs in the system, which is equal to $\sum_{j=1}^{n} n_j^{DMT}$
v_j^{DMT}	Production rate of DMTs in workstation $j \in \{1, \ldots, n\}$
v_j^{RMT}	Production rate of RMTs in workstation $j \in \{1, \ldots, n\}$
$d_j(t)$	Disturbances in workstation $j \in \{1, \ldots, n\}$
τ_1	Reconfiguration delay
τ_2	Transportation delay

$$u_j(t) \in \mathbb{N}_0 \quad \text{and} \quad \sum_{j=1}^{N} u_j(t) \leq n^{RMT}. \tag{4}$$

Note that there are two difficulties arising from constraints (4): For one, the upper bound is formulated for the entire job shop system and not a single workstation, and secondly, the requirement $u_j(t) \in \mathbb{N}_0$ represents an discrete constraint in a continuous setting.

We like to note that the model (3) only applies if the system is working on high WIP level. In this case, the orders output rate equals the maximum capacity, i.e. the WIP level can be controlled via the assignment of RMTs $u_j(\cdot)$ for all workstations.

4 Capacity Control

Based on the mathematical model from the previous section, we follow [9] and obtain the right factorization

$$\begin{aligned} w_j(t) &= D_j^{-1}(u_k(t-\tau_2-\tau_1))(u_j(t-\tau_1)) \\ &= X_{0j}(t-\tau_2) + \sum_{k=1}^{n} p_{kj} \cdot (n_k^{DMT} \cdot v_k^{DMT} + u_k(t-\tau_2-\tau_1) \cdot v_j^{RMT}) \\ &\quad - (n_j^{DMT} \cdot v_j^{DMT} + u_j(t-\tau_1) \cdot v_j^{RMT}) \end{aligned} \tag{5}$$

$$y_j(t) = N_j(w_j(\cdot)) + \triangle N_j(d_j(t)) = y_j(0) + \int w_j(t) + d_j(t) dt \tag{6}$$

In (5), the coupling between the workstation is given by

$$\begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} = X_0 \cdot \begin{pmatrix} p_{01} \\ p_{02} \\ \vdots \\ p_{0_n} \end{pmatrix} + \begin{bmatrix} p_{11}-1 & p_{21} & \cdots & p_{n1} \\ p_{12} & p_{22}-1 & \cdots & p_{n21} \\ \vdots & \vdots & \vdots & \vdots \\ p_{1n} & p_{2n} & \cdots & p_{nn}-1 \end{bmatrix} \cdot \begin{pmatrix} n_1^{DMT} \cdot v_1^{DMT} + u_1 \cdot v_1^{RMT} \\ n_2^{DMT} \cdot v_2^{DMT} + u_2 \cdot v_2^{RMT} \\ \vdots \\ n_n^{DMT} \cdot v_n^{DMT} + u_n \cdot v_n^{RMT} \end{pmatrix}$$

Solving the latter n linear systems, we obtain

$$u_j(\cdot) = \sum_{k=1}^{N} D_{jk}(w_k)(\cdot), \qquad j = 1, 2, \ldots, n.$$

To avoid the difficult computation of an RRCF control for the MIMO system, we utilize decoupling as proposed in [12] to transfer it into simple SISO systems. To obtain n independent SISO systems, the decoupling controller H and G need to satisfy

$$\sum_{k=1, k\neq j}^{N} [H_{jk}(w_j)](w_k) + G_j D_{jk}(w_k) = 0 \tag{7}$$

$$H_{jj}(w_j) + G_j D_{jj}(w_j) = F_j(w_j) \tag{8}$$

where G_j is linear and F_j is stable and invertible.

Here, we assume the decoupling operator $\mathbf{G} = (G_1, G_1, \ldots, G_n)$ to be identity operators, H_{jj} to be unimodular for $j = 1, 2, \cdots, n$, and $(H_{jk}(w_j))(w_k) = -G_j D_{jk}(w_k)$. Combining the latter with (7), (8), we obtain

$$F_j(w_j) = H_{jj}(w_j) + D_{jj}(w_j), j = 1, 2, \ldots, n$$

where F_j is stable and invertible, i.e. the MIMO system to be decoupled. Now, based on the Definition 2, the RRCF operators A_j and B_j can be designed following the Bezout identity

$$A_j \circ (N_j + \triangle N_j) + B_j \circ F_j = M_j.$$

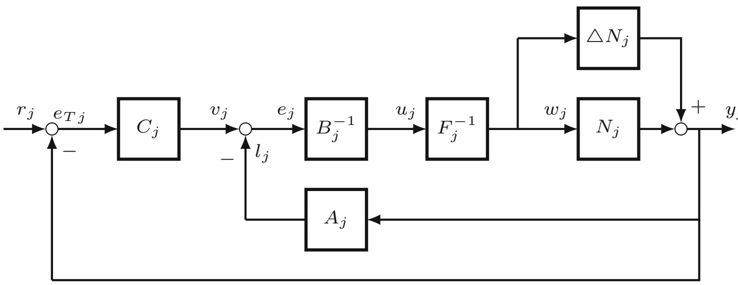


Fig. 2. Nonlinear feedback tracking control of MIMO system

In order to track a given WIP level, we integrate a tracking controller C_j as proposed in [7], cf. Figure 2 for a sketch. Note that as the number of RMTs is integer, the controller can only practically asymptotically stabilize the system, cf. [13, Chapt. 2], where the maximal difference between the planned WIP and current WIP is less than the production rate of one RMT in that workstation.

5 Case Study

To evaluate our proposed controller, we consider a four-workstation job shop system with bounded disturbances and delays is considered. The flow probabilities for the three different products A_1, A_2, A_3 given by p_{jk} of the orders output from workstation j to workstation k and the final stage, cf. Figure 3. The parameters setting are shown in Table 2 and the scenario additionally features 10 RMTs and 40 and 20 rush orders to workstation 1 and 2 at time instant 80.

For this setting, the resulting performances of all workstations with delays and disturbances are shown in Fig. 4. As expected, we observe that the WIP level of each workstation is practically asymptotically stabilized with upper and lower

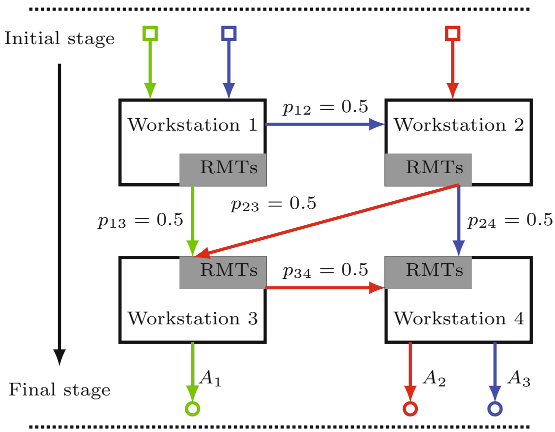


Fig. 3. Four-workstation job shop manufacturing system with RMTs

Table 2. Parameters setting of the four-workstation system

Number of workstation	1	2	3	4
Initial WIP level	400	400	300	200
Planned WIP level	240	400	400	240
Orders input rate from initial stage	102	51	0	0
Number of DMTs	4	2	2	4
Production rate of DMTs	20	40	40	20
Production rate of RMTs	10	20	20	10

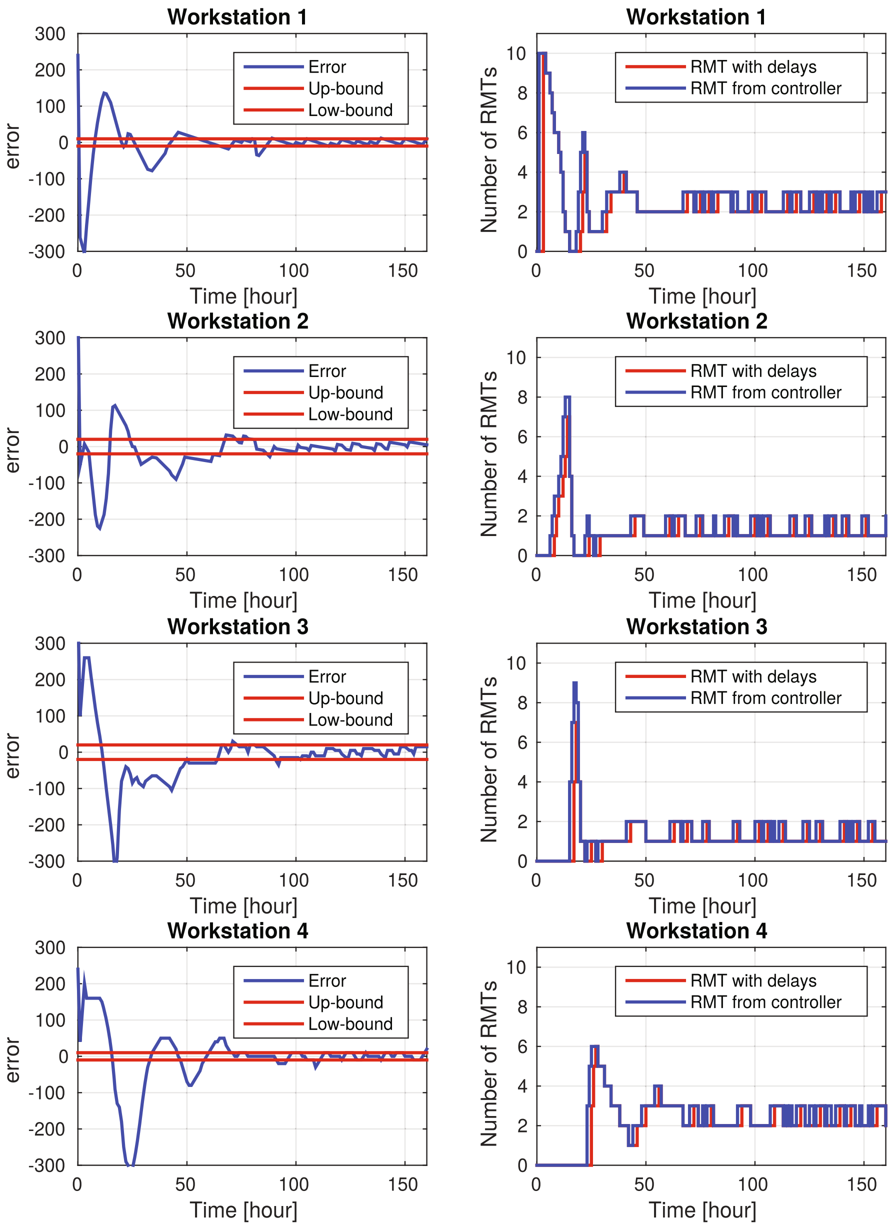


Fig. 4. Dynamic performances of the four-workstation job shop system

deviation $\pm v_j^{RMT}$ from the planned WIP level. In the right figure, we observe the reconfiguration delay of 2 h if the number of RMTs is increased. At time instant 80, due to the rush orders the WIP levels of workstations 1 and 2 are suddenly increasing and the errors are out of the bound. Yet, the controller is compensating by allocating RMTs to workstation 1 and 2. After about 10 h, the rushed orders flow to workstation 3 and 4 and the controllers reconfigures the RMTs to these workstations ahead of time rendering the system to be practically stable again.

6 Conclusions

In this paper, an mathematical model is extended to include transportation and reconfiguration delays as well as disturbances. Furthermore, RRCF method is proposed to deal with couplings, delays and disturbances in the capacity adjustment of job shop manufacturing systems with RMTs. The simulation results are additionally depicted the efficiency of the method. In the future work, we will focus on the following points. First one is to optimize the integer problem in the number of RMTs, which as the input of the system has a great influence on the dynamic performance. Another will be the modeling development. We will including more factors in the job shop systems considering new freedom of RMTs.

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Wireless Pick-by-Light: Usability of LPWAN to Achieve a Flexible Warehouse Logistics Infrastructure

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Abstract. Pick-by-light is used for fast localization of items at the picking process in ware-house logistics. In general, pick-by-light systems are installed on racks or shelves which have to be powered by wires. This is very expensive and often involves complex installation procedures, wherefore wireless pick-by-light systems have gained a lot of research interest due to their flexibility, portability and low deployment costs. However, the existing wireless pick-by-light systems have limited range and introduce additional maintenance efforts, which make them inapplicable for bigger warehouses. This paper presents a wireless pick-by-light system based on LoRaWAN, a leading LPWAN standard, which is fully scalable. The proposed system offers long range due to unique LoRa RF modulation technique. In order to extend the battery life and thereby to minimize maintenance costs, the pick-by-light modules are built on power optimized LoRaWAN end devices. The system also suggests RSSI based asset tracking inside warehouses within the same framework for smarter routing of the human picker. In order to verify the proposed system, a prototype is developed and evaluated. The evaluation shows the technical implementation and its results.

1 Introduction

Order picking technologies provide methods to maximize picking productivity, enhance order accuracy and to reduce operating costs. Today, many picking technologies such as pick-by-voice, pick-by-vision and pick-by-scan exist, but pick-by-light is widely used due to its fast speed, accuracy and reliability [16]. Such a system uses simple, yet effective light directed approach to guide hand picker to the right storage location. Pick-by-light systems can be categorized in to two distinct groups: wired and wireless. Wired systems have been frequently deployed as they provide a dependable and low maintenance solution. However, wired infrastructure has limitations in two key aspects of a modern day warehouse framework namely, flexibility and scalability. It is a time consuming process to

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replace or add new storage shelf light module. While wireless systems offer more flexibility, they require additional efforts that result from the frequent replacement of batteries and other maintenance activities [8]. Furthermore, short range wireless communication technologies as used in current systems, are unable to satisfy coverage requirements of large picking zones.

At this point, Low Power Wide Area Networks (LPWAN) technologies in wire-less communication play an important role due to their long range connectivity at low power. There are several competing standards that are based on LPWAN [10]. Amongst these standards, LoRa (Long Range) is one of the most adopted technologies [2] as it is well suited to be used in low-power, low-throughput and long-range networks [6]. LoRa technology commonly refers to two distinct layers: (i) a physical layer called LoRa that uses the Chirp Spread Spectrum radio modulation technique and (ii) LoRaWAN, an energy efficient media access control (MAC) layer protocol [4]. In this paper, we propose a long range wireless pick-by-light system based on LoRaWAN. It overcomes the problem of wide area coverage while maintaining long battery life. Moreover; the system offers asset localization without the need of additional hardware.

The rest of this paper is organized as follows: Following this brief introduction, Sect. 2 presents state of the art. An overview of LoRa technology along with its network layer protocol LoRaWAN is discussed in Sect. 3. It also describes the proposed long range wireless pick-by-light system along with the concepts of asset tracking and smart human routing. In Sect. 4, system prototype design, its evaluation results and discussions are delineated. At the end, Sect. 5 concludes the research work and discusses the possible future work.

2 State of the Art

During recent years, wireless pick-by-light systems have gained much attention due to their enhanced flexibility and mobility. In this section, we will present existing solutions with focus on specific parameters such as wireless technology, range and battery life.

In [1] a proprietary wireless technology is used to establish a wireless sensor network (WSN) that gives a 30 m range with low latency. The light modules can have 1 month battery life. The wireless system developed by lightning pick on Ai-net wireless technology also achieves a range 30 m. However, modules have a short life cycle of approximately 160 h [15].

Pick-by-local-light (PbLL) employs s-net technology to design self-organizing, multi hop network. The multi hop communication allows easy extension and wider area coverage. The system is highly energy efficient as LEDs are activated once picker is in immediate vicinity of storage locations [8]. Picduino utilizes wireless technology and can cover an area up to 10 m. Under normal operation, 1000 picks per day, picking modules can have an extra-long battery life of up to 12 months [7].

It is evident that most of the current systems have a fairly short range (less than or equal to 30 m), while the battery life of most light modules varies from 1 to 12 months. The communication range is too short as compared to the size of a typical picking zone which covers an area of hundreds of square meters. This limits their usage to confined areas as their ranges could be extended at the cost of additional hardware.

3 Applicability of Long Range Wide Area Network in a Pick-by-Light System

As outlined in Sect. 2, it is apparent that existing wireless technologies fail to meet the requirements of a large-scale picking zone due to their limitations in range and battery life of light modules. This chapter will describe LoRa technology and its applicability in a wireless pick-by-light system.

3.1 Key Features of LoRa Technology

LoRa technology has two major components. The first one, LoRa, is a physical layer or wireless modulation scheme proprietary to Semtech. It is based on a variation of chirp spread spectrum (CSS), allowing multiple data rates as both bandwidth and spreading factors are configurable [12]. It has a maximum link budget of about 157 dB, which enables long range communication i.e. 15 km outdoor and 1–2 km inside buildings. LoRa products have extremely low power profile, Microchip's LoRa RN 2483 provides 10 years of battery life (TX 14.1 dBm 38.9 mA, RX 14 mA, Idle 3.4 mA deepsleep 1.8 uA duty cycled) [11].

The second component is LoRaWAN, a network layer MAC protocol, which has been added to standardize and extend the physical communication layer onto internet networks. It defines a star network topology, where gateways relay messages between end-devices and the application server as shown in Fig. 1. The important aspects of LoRaWAN protocol include: secure fully bi-directional symmetrical communication link between end devices and network server, long battery life (5–10 years), GPS free geo-location and capability to support thousands of devices per gateway. LoRaWAN also define three classes of end devices

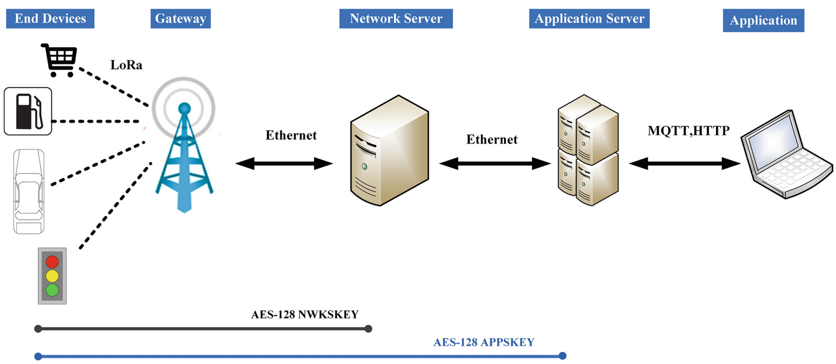

Fig. 1. LoRaWAN network architecture [4]

namely: Class A (the default), Class B and Class C (both optional) to support multitude of applications [5,13].

3.2 Commissioning System for Logistics on LoRa

The unique features of LoRaWAN network architecture (long battery life and long range communication) enable to bear a smart solution for wide area connectivity in larger picking zones at low power. Therefore, we propose our long range wireless pick-by-light system supported by LoRaWAN protocol. The overview of the system is shown in Fig. 2. The major components are as follow: LoRa pick-by-light (LR-PbL) modules, a LoRa handheld (LR-Hh) module, gateway, the cloud (network server and application server) and an information application running on a PC or tablet.

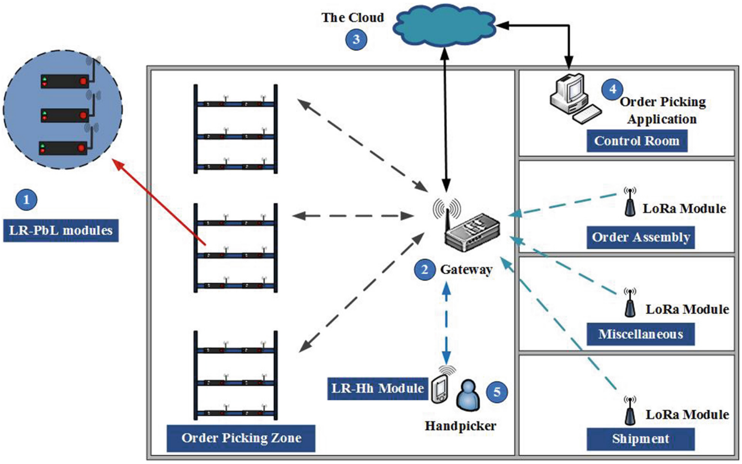

Fig. 2. System overview: long range wireless pick by light system

The LR-PbL modules are installed on racks or shelves inside a picking zone, while a hand picker is provided with a LR-Hh module (e.g. a tablet) which contains task-related information. The LR- modules i.e., LR-PbL and LR-Hh module are built on LoRaWAN end devices and use wireless LoRa modulation to communicate with the cloud through a gateway. The cloud contains network and application server. The application server, connected to warehouse management server (WMS) is responsible for processing orders and maintaining data base of LR-PbL modules along with their signal parameters such as received signal strength indicator (RSSI) and time of arrival (ToA). These signal parameters are relevant if localization service has to be included. A picking application installed on a PC monitors and steers the picking process. In case of a new picking activity, the application server has two main tasks. The first job is to alert all the relevant LR-PbL modules about the picking activity. This is achieved by preparing a queue which is used by network server to send down-link messages. These down-link transmissions which holds the information about picking activity can be done in two ways: one way is to group the required modules and then send a single down-link message, while the other method is to send individual messages to each required module. Once the down-link transmission is completed, the application server sends picking task-related message to the LR-Hh module. This contains information about picking zone and relevant modules along with required number of pickings. The hand picker goes to each location, fetches the required quantity and puts them in a collecting box. After having collected all items of a picking order, the collecting box is forwarded to the following warehouse processes. We recommend that a LoRa module is attached to each collecting box so that completed orders could be tracked inside the warehouse using signal parameters such as RSSI.

The proposed system is a very low cost solution to the problem of wide area connectivity in bigger warehouses. Unlike existing systems, where a TCP/IP controller covers an area of 30 m, here, a single gateway can cover a range of about 1–2 km inside buildings. The LR-PbL modules and LR-Hh modules have low cost and extremely low power consumption, thanks to unique LoRa RF modulation characteristics. The use of the wearable device (LR-Hh module) effectively eliminates the use of alphanumeric displays on the picking modules (LR-PbL modules), which normally consume considerable amounts of current from the batteries. Furthermore, the installation and configuration of these modules is a very simple process. For a new picking site, the operator just needs to fix modules on a shelf or rack and turn it on. The rest of the procedure can be managed via picking application.

3.3 Geo-Location - Asset Tracking

Wireless fingerprinting has been validated as an effective localization technique due to its simplicity and ease of deployment [3,14,17]. It works in two phases: an offline learning phase which involves gathering of RSSI at known locations and an online identification phase. In the proposed system as shown in Fig. 2, RSSI from fixed known locations i.e. LR-PbL modules are readily available which can be used to generate a radio map and train machine learning algorithms such as K-nearest neighbor (KNN). During online phase, the position of any unknown device e.g., a collecting box can be approximated by applying position estimation techniques. The radio map can be updated each time a new LoRa module is added to the network e.g. installing LoRa modules in different sections of a warehouse as depicted in Fig. 2.

4 Verification of the Applicability of LoRa in Logistical Picking Processes

In order to verify the potential of a real world application of the system proposed in Sect. 3.2, a system prototype was developed and tested. The quantitative objective of prototyping was to evaluate different system parameters such as battery life of LR-PbL modules, range and localization capability.

4.1 Prototype Design

We have used Microchip's LoRa network evaluation toolkit to design a prototype for our system. It operates at 868 MHz and consists of RN2483 LoRa motes, a six channel gateway and a local LoRaWAN network/ application server. The prototype system includes four main blocks: Two LR-PbL modules, one LR-Hh module, one gateway and The Things Network as shown in the Fig. 3. The LR-PbL modules, running class A stack, sent the query packets over the air using LoRaWAN protocol and the gateway forwarded these packets via UDP/IP to the TTN along with signal parameters such as RSSI, time of arrival, channel frequency and payload. In TTN console, a new application was created to view the up-links and to schedule down-link messages.

The two types of modules i.e. LR-PbL and LR-Hh were developed using LoRa RN2483 mote which consists of a low power microcontroller PIC18LF45K50, a LoRa transceiver module RN 2483, on board LEDs, push buttons and an LCD display.

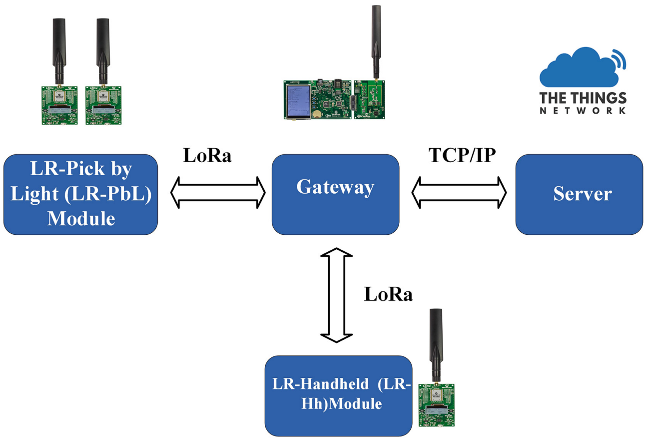

Fig. 3. Elements of prototype design

4.2 Scenario

The prototype developed in Sect. 4.1, was deployed inside the main building of Bremer Institut für Produktion und Logistik GmbH (BIBA). Two picking zones were established at the ground floor where LR-PbL modules were installed. Additional test points (TP1, TP2, and TP3) were marked inside the gallery to test the range of LoRa modules (Fig. 4). One hand picker, equipped with the LR-Hh module was free to move inside the building. Since, it was just a demonstration, the TTN console was used to generate random picking jobs for the modules. First of all, down-link messages were scheduled for LR-PbL modules. After sending messages to the LR-PbL modules, the server sent the complete picking task related information to the LR-Hh module. This alerted the picker about a new picking task and provided the picking related information on the LCD dis-play of LR-Hh module. The picker went to the required locations, in our case picking zone I and II, fetched the required quantity and at the end sent an order confirmation to the application server.

Fig. 4. Test Scenario at BIBA - Bremer Institut für Produktion und Logistik GmbH

4.3 Results and Discussion

In order to test the range, the picker with LR-Hh module moved to different spots inside the building. The transmissions were done using spreading factor SF-7 and Power Index 14 dBm. Table 1 summarizes the results. The results shown below indicate the long range capability of a LoRa network. In all cases the packets have been successfully received by the gateway and delivered to the TTN server. At 14 dBm, LoRa has communication link budget of 151 dB while, even at a distance of 50 m we achieved a budget of about 124 dB. This means we can get to longer distances even using the same data rate settings.

RSSI readings from LR-PbL modules were used as fingerprints that were used to estimate the location of asset inside a warehouse. RSSI fingerprinting is highly efficient localization technique in case of Non-line-of-sight (NLoS) conditions. It is due to the fact that RSSI fingerprints provide one to one relation between the characteristics of multipath signal received at gateway and transmitter's location. In our scenario, with RSSI readings it is possible to estimate the location in which of the two picking zones the picker or collecting box can be found. It is based on the fact that the RSSI from PbL modules are different i.e. −74 dBm in Picking zone-I and −60 dBm in picking zone-II. Each picking zone has around 30 m^2, so that a LoRa module attached to picker helps in estimation it locations inside a warehouse.

Table 1. RSSI Readings

Location	Range (m)	No. of samples	Mean RSSI(dBm)	Received (%)
Test point 1 (TP1)	10	20	−70	100
Test point 2 (TP2)	35	20	−91	100
Test point 3 (TP3)	50	20	−110	95
Picking Zone-I	40	20	−74	100
Picking Zone-II	25	20	−60	100

In order to make precise power measurements, voltage is measured on an oscilloscope by attaching probes across a 10 ohm resistor, connected in series with the LR-PbL module. By using ohms law, current can be calculated for the LR-PbL module [9]. The total estimated power consumption of a module for one day (CTotal) is the sum of the power consumptions for the different status of the system: Single Up-link (CSU), Deep sleep state (CDS) and Single Picking Order (CSPO) multiplied with their overall daily duration (tdi, i = SU, DS, SPO).

$$C_{total} = C_{SU} \cdot td_{SU} + C_{DS} \cdot td_{DS} + C_{SPO} \cdot td_{SPO} \tag{1}$$

The testing processes intended the investigation the power consumption of different states of the module during single up-link. The results of the measurement and the derived power consumption for each state are shown in Table 2.

Table 2. Single up-link power consumption

Serial No	Description	U (mV)	I (mA)	Duration (ms)	C (mAms)
1	Idle state	46,9	4,7	227	1066,9
2	Transmission Tx	418,88	41,8	46	1922,8
3	Idle state	46,9	4,7	1000	4700
4	First Rx window	165	16,5	12,65	208,7
5	Idle state	46,9	4,7	1000	4700
6	Second Rx window	166,68	16,6	24	398,4
7	Idle state	46,9	4,7	149	700,3
8	LoRa module sleep	17,04	1,7	57	96,9

$$\textit{Total duration tSU} = \textit{2515,65}\,\mathrm{ms}$$
$$\textit{Total Power per cycle} = \textit{13794}\,\mathrm{mAms}$$

The calculation of the current whilst deep sleep state is shown in Table 3

Table 3. Deep sleep state power consumption

Serial No	Description	U (mV)	I (mA)	Duration (ms)	C (mAms)
9	Deep sleep state	2,4	,24	tDS	

In case of orders that have been received, one new state is added i.e., order processing. Here the LR-PbL goes to sleep mode after turning on the LED. This state is maintained until the user acknowledges by pressing the push button. However, in our use case we assume that it will take 60 seconds until a picker retrieved the items from one LR- PbL module (Operating time per request: tSPO = 60 s). Once the button is pressed, the modules fall asleep until the next scheduled up-link time slot arrives. The current for this additional state is 1.4mA. In order to estimate the battery life of the LR-PbL module, we made the following assumptions. Each LR-PbL module transmits query packets at an interval of 2 min (therefore No. of transmissions per day: xSU = 30 * 24 = 720 1/d) with SF-7 and output power 14 dBm. 100 order requests are received each day (therefore No. of order requests per day: xSPO = 100 1/d) with each order containing 10 picks from the PbL module. For the calculation of the duration of the total sleeping time per day (tdsl) of a module, the total order processing time for one day (tdopt) as calculated in Eq. 2 and the total time for up-links per day (tdSU) as calculated in Eq. 3 has to be subtracted from 24 h as shown in Eq. 4.

$$td_{SPO} = x_{SPO}[1/d] \cdot t_{SPO}[s] = 6000\,\text{s/d} = 1,6\,\text{h/d} \tag{2}$$

$$td_{SU} = x_S U[1/d] \cdot t_{SU}[s] 720.2515,65\,\text{ms} = 1811\,\text{s/d} = 0,5\,\text{h/d} \tag{3}$$

$$td_{DS} = 24\,\text{h} - td_{SPO} - td_{SU} = 1,6\,\text{h} - 0,5\,\text{h} = 21,9\,\text{h} \tag{4}$$

By applying Eqs. (1), (2, 3, 4) the power consumption for one day is estimated to be 10,23 mAh.

$$\begin{aligned} C_{Total} &= 2,7\,\text{mAh/d} + 5,256\,\text{mAh/d} + 2,24\,\text{mAh/d} \\ &= 10,23\,\text{mAh/d} \end{aligned}$$

Two AAA batteries are connected in series to supply power with current capacity of 3000 mAh. Thus, the Battery life di can be calculated as follows:

$$di = 3000/10,23\,\text{mAh/d} = 293 days = 9,7 months$$

5 Conclusion and Outlook

In this paper, a long range wireless pick-by-light system is proposed. As LPWAN solution, LoRa is used to develop the pick-by-light system. LoRa possesses an innovative modulation technique to achieve long range with extremely low power consumption. In addition to wide area connectivity and extended battery life, the LoRaWAN protocol provides geo-location capability, which is used to locate assets inside a warehouse. For a proof of concept, a prototype system was designed using a LoRa network evaluation kit. The results prove that it is possible to develop a wireless pick-by-light system with LoRaWAN and a battery life of 9 months. With the least spreading factor SF-7, the system achieved better coverage i.e., 50 m than the existing wireless pick by light systems. The LoRaWAN class A end device has been used to develop pick by light modules. It is also shown that RSSI from PbL modules could be used to estimate the location of an unknown target within a warehouse. The achieved accuracy is at least within 100 m^2, which could be improved by acquiring more fingerprints. In future, we will use class B LoRaWAN devices in order to reduce the waiting time for up-link transmission. This will result in lower system latency and a better system dynamic. Additionally, a low power IR proximity sensor could be integrated to automatically detect good pickings. For better geo-location services, TDoA could be integrated with RSSI using machine learning algorithms.

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Internet of Things and the Risk Management Approach in the Pharmaceutical Supply Chain

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Abstract. Technology is advancing rapidly, accelerating and creating strategic innovations and new challenges in traditional business models. The Internet of Things (IoT) brings an opportunity to increase productivity and efficiency on the supply chain processes of the pharmaceutical industry. In this context, a new business vision, based on innovation and supported by new technologies, requires a risk and resources management approaches, encompassing the strategic-tactical-operational planning processes within the companies. This work aims to highlight the potential use of IoT features, considering a risk management approach to the pharmaceutical supply chain (PSC), based on an exploratory research methodology.

Keywords: Internet of Things · Pharmaceutical supply chain
Risk management

1 Introduction

The supply chain (SC) generally requires systematic and strategic coordination of all activities associated with the flow and transformation of inputs, finished goods, information and financial resources (Chopra and Meindl 2007). IoT, refers to end-to-end world connectivity, where objects and beings interact with virtual environment data in the same time and space, looking to a range of possibilities and within different environments (Evans 2011). Tang (2006) defines Supply Chain Risk Management (SCRM) as the coordination and collaboration between various partners in the supply chain to ensure continuity of operations and profitability. Christopher and Peck (2004) classify the risks in SC into three categories: internal risks to the company, external risks to the firm but internal to SC and external risks to the chain (environment). Identification and control of risks (internal/external) can positively affect the functioning of the chain, which can be approached in a coordinated way with mitigation and contingency plans to avoid supply chain disruptions and processes vulnerability (Olson and Wu 2010).

In the manufacturing of pharmaceutical products, it is essential to know the stability, control of the desired quality of the products and other problems subject to transport operations, predominantly composed of random variables, with limits of delivery time

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(Novaes et al. 2017). The production environment cleanliness is a critical requisite to ensure the quality of the product. It involves complex processes management and the use of various equipment types (Pawar et al. 2011). Events like increase of operational and R&D costs, demand volatility, royalties management, etc., are leading them to unprecedented challenges to assure an competitive advantage (Khanna 2012). The main focus of this paper, the pharmaceutical SC, is to guarantee the pharma goods delivered on the right place, at the right time with the required quality (Enyinda et al. 2010) and to analyze the use of IoT associated with a risk management approach in the PSC.

2 PSC Planning: IoT and the Risk Management Context

This research is exploratory and the literature review is an essential step to cover the new theories and cases for a better understanding of this field of study (Easterby et al. 2012; Tranfield et al. 2003). The management of pharmaceutical products (medicines and vaccines) requires the control of parameters like temperature, humidity, impacts and vibration, that adds up a greater complexity to logistics operations along the PSC. The idea of adding intelligence to the SC is described in the literature as the development of a large-scale intelligent infrastructure that combines data, information, physical objects, products and business processes (Chui et al. 2010). This concept presents a vision of anything, anytime and anywhere connectivity, leading huge changes in the day-to-day life (Pang 2015). It is also extended to planning and execution of the supply chain processes.

Adding advanced technology to everyday devices, such as audio or video receivers, detectors, etc., and make them online connected, the data can be extracted through lots of sensors allocated on different parts of the supply chain flow (Gubbi et al. 2013; Whitmore et al. 2015). The challenge is how to process the data collected and use this information as a competitive advantage to improve the performance and react properly when unplanned tactical-operational issues occur over the supply chain.

2.1 Operational Risks in the PSC Distribution Sector

On a pharmaceutical environment, a risk can be explained as any event that affects the supply flow of the goods. This industry faces huge risks like regulatory changes, suddenly sales increase, demand anticipation, scarcity of raw material and quality issues (Jaberidoost et al. 2013; Narayana et al. 2014). The risk management approach is a systematic process for evaluating, monitoring, communicating and examining all the risks related to the quality of medicines through their life cycle. Based on the data collection and analysis, it is possible to take effective decisions based on risk evaluation, including mandatory regulation rules required on pharmaceutical industry, to support the development of procedures and methods for prevention and/or problem solving approaches into the PSC management.

The potential use of IoT solutions integrated with supply chain planning processes could be applied in different areas within the PSC as: tele-medicine and emergency services, health social network, home care, intelligent pharmaceutical packaging, and so on (Fig. 1).

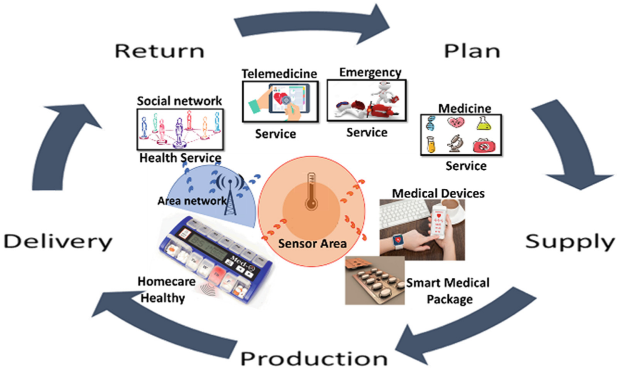

Fig. 1. IoT usage examples on supply chain planning processes (source: the authors)

One of the main challenges in the pharmaceutical industry is to assure an efficient quality control process across the supply chain. For instance, the control of the quality parameters (temperature, humidity, etc.) during the storage and transportation operations of vaccines, bio-pharmaceuticals, blood and transplantation products, requires a properly pro-active monitoring process control. Any deviation on the quality parameters during these SC processes needs an immediate management action to avoid losses and damages of the goods. A continuous risk assessment procedure is necessary to trigger alerts and drive the mitigation and contingency action plans to avoid goods flow disruptions in the PSC. Different risk situations and the real potential of IoT, are shown in Table 1.

Table 1. Risk assessment and IoT processes requirement (source: the authors)

IoT Process Requirement (CISCO 2017; Gubbi et al. 2013; Coetzee and Eksteen 2013)	Risk Assessment (SCOR 11.0)				
	Plan	Supply	Production	Delivery	Return
Networking and Communication	▲	■	▲	▲	■
IoT Infrastructure Management	■	▲	▲	▲	▲
Real Time Transportation Routing	■	■	▼	▲	▲
Emergency Response Planning	▲	■	■	■	▲
Security: Data and Physical	■	▼	▼	▲	▼

High Impact ▲ Medium Impact ■ Low Impact ▼

Networking and communication allow for the identification of data within a dynamic PSC, where devices and sensors are connected to diverse items, which are also interconnected. They are able to communicate data and this data can be analyzed for minimizing risk. The series and volume of data that is transmitted require additional power to transmit them under different conditions along the networked environment. In a former research of our group (Novaes et al. 2015), temperature of perishable food transported in refrigerated vehicles was analysed with univariate capability indices. In the present research, with the support of a specialized logistic operator in Brazil, an initial analytic effort contemplates two basic parameters - temperature and humidity - using a multivariate statistical process (Wang et al. 2000) to control the quality assurance of pharmaceutical products in its distribution. A MKT (Mean Kinetic Temperature) analysis, based on the Arrhenius equation, will also be performed on temperature data (Taylor 2001).

IoT infrastructure management is needed to support storage capacity for temperature control, as well as enough space for the storage of all products, as to guarantee a successful management effort to reach homogeneous refrigeration conditions, therefore avoiding risks along the chain.

Dynamic and integrated transportation routing systems, with real-time information technology developed within an IoT environment, have a high impact on decision-making procedures to determine optimal driver assistance conditions, optimal delivery times, and optimum routing. With regard to emergency response planning, the devices connected to the system can significantly increase their efficiency and effectiveness. Data collected by IoT devices, which are processed and analyzed in data centers, are used to influence changes in real time actions to respond to emergency conditions. On the other hand, security (data and physical) offers a way to improve access control systems and solutions. While much progress has been made in standard solutions, more success is needed, especially in security, privacy, architecture, and communications.

3 Conclusion

The logistics operators and manufacturing industries must integrate data from multiple sources, automate data collection, analyze data to effectively detect practical information for minimizing risks. We adopted a risk management from a qualitative impact table, approach to the PSC based on critical investigation, where the potential elements to IoT were analyzed into the context processes, improving information to make better decisions, reducing costs, reducing risks and shortening project deadlines. IoT highlights an opportunity into the PSC context, and relates it to existing risks. This evaluation can guide future and scientific work as to where more substantial efforts, considering other parameters in the analysis in the table, should be invested with regard to this important logistics chain.

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Effects of Sensor-Based Quality Data in Automotive Supply Chains – A Simulation Study

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Abstract. Supply chain risk management (SCRM) is becoming increasingly attractive as it opens up various control opportunities in case of rising volatility in value-added networks. Sensor-based, real-time quality data will be the founding an event-driven organization of supply chains with regard to more transparency. The following article presents the opportunities of using real-time, sensor-based quality data in automotive supply chain (SC) analyzed within a simulation study. Therefore, a discrete-event simulation of an automotive SC evaluates the usage of quality data. Different scenarios of control mechanisms are developed in three test cases characterized by different quality failure probabilities. For each of the test cases, the effect on stocks is described. The investigations show the positive effect of using real-time quality data to reduce stocks. The most positive effect is related to methods like special transports, but their cost-intensive structure has to be optimized. In conclusion, sensor-based quality data can face the rising volatility. Further research should focus on innovative controlling methods.

Keywords: Supply chain management · Supply chain risk management
Quality data · Early warning system · Simulation study

1 Introduction

Global sourcing and reduction of vertical integration are the main reasons for the ongoing competition between whole value chains. In these supply chains, companies have to cope with several information deficits and time constraints (Braithwaite 2014). Those developments lead to an increased SC complexity with significant challenges for the supply chain management (SCM). Although the amount of international material flows is going to decrease, the flows between different companies are steadily growing (Manyika et al. 2016). Thus, interconnected SC networks and related SCM need to be optimized in several directions. Accomplishing the challenges of the right product, in the right time, at the right time at the right place for the right price in the right condition (6R of logistics) is the main task for companies in SC networks (Schuh et al. 2013).

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For the fulfillment of customer needs in time, concepts like Just-in-Time (JIT) and Just-in-Sequence (JIS) are used to reduce the safety buffers. Emerging low stocks increase company's vulnerability in a highly dynamic environment and they allow just small response time to cope with delays and quality issues. Possible results are reworks, special transports, downtimes or recalls of products in the SC (Braithwaite 2014). The automotive industry, in particular, faces serious challenges for SCM in case of regionally or globally distributed products with suppliers of the different tiers and several logistic service providers (LSP) (Belis-Bergouignan et al. 2000). To secure the quality of the different bought-in parts, components and products at their point of usage quality assurance is necessary in production and logistic. Logistic processes, in particular, are characterized by long transport distances and sometimes extreme environmental conditions (Ambe and Badenhorst-Weiss 2010) which leads to the necessity of improved quality management in transportation and storage part of SCs. Now, automotive companies are facing the responsibility of high quality requirements with securing the processes especially in production, e.g. samples in incoming or outgoing goods inspections.

Increasing digitization offers diverse opportunities to face these uncertainties by raising the level of transparency (Musa et al. 2014). Real-time or near real-time data from sensors proposing high improvements in interconnected information transparency (Werthmann et al. 2017). Ensuring this improved transparency regarding to the quality condition of transported goods leads to several main challenges: Monitoring and documentation of quality and location (i), identifying quality and regarding location as foundation for process control (ii) and real-time information about the actual condition of the products (iii). (Schulz 2014) Consequently, sensor networks are considered a suitable solution to face the challenge to provide necessary information of goods and shipments in real-time (Skorna et al. 2011; Döring 2012). Different researchers describe the effects and possible applications as main opportunities of real-time data in logistic processes of SC environment. Therefore, this paper offers a foundation for further research and the development and evaluation of control mechanisms with sensor-based real-time data. The possible impact of this quality-related data is evaluated in different scenarios.

This paper is structured as follows: The introduction has underlined the necessary opportunities for optimization of SCs in combination with supply chain risk management (SCRM) in the automotive industry as reference industry. A short description of SCRM and the current situation in automotive industry completes the picture. Actual requirements and challenges are highlighted and investigated. A simulation study of a generalized automotive SC emphasizes the importance of transportation processes. The simulation study is fundamental for the following evaluation of effects of sensor-based quality data. A conclusion and an outlook point out necessary adjustments and research potentials.

2 Supply Chain Risk Management in Automotive Industry

The automotive industry faces steadily increasing pressure concerning time, cost and quality related issues (Manyika et al. 2016; Schulz 2014). Resulting from ongoing reduction of vertical integration, this industry is characterized by many interlinked processes in global value networks (Schulz 2014). In particular, outsourcing and concepts like JIT/JIS try to establish dynamic networks with low stocks. Low stocks allow just small response time in case of delays or quality issues, and the growing interconnection increases the risk of these disturbances (Thun and Hoenig 2011). This indicates the need of high transparency and company-wide controlling of transported goods as an important part in optimization of complex production networks.

In the automotive industry, product quality is very important. Within the highly complex network structures and high level of outsourcing, the suppliers are often responsible for the quality of the product parts. In this context, quality defects of supplier parts and components pose a supply risk, effectively reducing the supply volume, as defective parts and components cannot be used. Repair of the quality defective parts is impossible at the OEM for technical, time and cost related reasons. Therefore, they have to be replaced quickly by non-defective parts, either from existing stocks or from post-production. Stock keeping is expensive, in particular with today's large product variation. Post-production upsets existing product plans and thus disrupts the normal flow of production. In addition, both existing stocks and post-production are frequently geographically separated from the customer, necessitating expensive emergency transports. Thus, real-time data propose opportunities in advanced planning systems for dynamic production planning and control.

Consideration of supply risks grows in importance in the controlling and monitoring of SCs. As part of the concept SCM, SCRM is based on identification, assessment, controlling, analyzing, and monitoring of SC processes in combination with possible risks (Thun and Hoenig 2011). SCRM includes management of suppliers and sourcing strategies and reactive mechanisms like safety buffers or preventive mechanisms like robust packaging (Thun and Hoenig 2011). There is a wide range of potential to optimize SCs by using real-time data in controlling mechanisms for complex and dynamic SC as e.g. in using RFID (Genc et al. 2014) (Werthmann et al. 2017). The aim of this paper is to analyze the possible effects of sensor-based quality data in described environment based on a discrete event simulation of an automotive SC. Based on that, possible applications and controlling methods regarding to quality defects out of logistic operations would be developed.

For monitoring quality, early warning systems are developed based on production key figures and general information in the SC (Genc et al. 2014). As shown above, the consideration of logistic parts in automotive value chains is an essential part of optimization regarding transparency and lower vulnerability.

3 Simulation Study

The potential of sensor-based quality data has been evaluated using a discrete-event simulation. An automotive logistic scenario (SZ) has been designed, based on the typical SC for batteries of battery production. Batteries are a probable example of high-sensitive products in automotive production networks. The battery production is globally distributed, and there is an essential need to focus on logistic processes as part of cross-linking production plants. (Bauer 2013) At the moment, only indicators and safety packing are used at occurrence of quality failures (Skorna et al. 2011). Thus, the consideration of environmental influences is unexplored in logistics of automotive industry. Meaningful key indicators are used to evaluate (i) the effects of different mechanisms for reducing safety buffers, (ii) the influence of different risk levels and (iii) the potential of using real-time sensor-based quality data (Fig. 1).

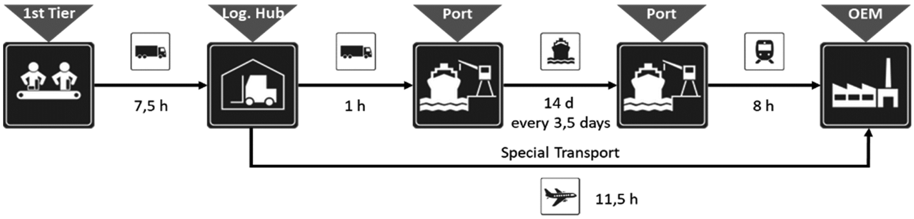

Fig. 1. Transport chain between system supplier and automotive OEM

A battery supplier and an automotive OEM as customer are the main parties of the related use case. The batteries are sent to the logistic hub via truck. A logistic services provider (LSP) assumes the packing and storage of the container and is responsible for adhering to the deadline of ship loading by truck. The shipping company is responsible for the ship transport between the ports. Trains connect the unloading port and the OEM plant. The use case represents the transportation chain of automotive SCs, as the logistic parts need further research in quality monitoring. Production parts (1st Tier and OEM plant) are necessary parts of the observed SC to examine the effects of sensor-related quality data in interconnected SCs. Table 1 shows the transport times and volumes. The emerging special transports in case of post-production through quality defects are also listed.

Table 1. Transport times and volumes of modalities

Scenario	Time	Frequency	Volume of transport
Truck 1	7,5 h	Every 8 h	24 carrier with 24 batteries each
Truck 2	1 h	Once a day	1 container with 48 carriers each
Ship	14 days	Two times a week	3 or 4 container
Train	8 h	Every two weeks	3 or 4 container
Airplane	11,5 h	If needed	Number of post-production

To face the appearance of quality defects, the three main mechanisms in this simulation are safety buffers, the use of sensors and emergency transports. Table 2 represents the different SZ settings. The first SZ is a reference SZ to evaluate different mechanisms without any quality defects. SZ 2a to 3b show the appearance of quality defects in case of damage on the transport routes and the effects of usual (stocks and emergency transports) and innovative (sensor data) mechanisms.

Table 2. Scenarios and probabilities for quality defects

Scenario	Safety buffer	Sensor	Air transport
1			
2a	x		
2b	x	x	
3a	x		x
3b	x	x	x

Three test cases (Table 3) represent different probabilities (p_x) for quality defects through shock, temperature and humidity. Every transport route has different cumulative probabilities out of characteristic weighting factors (g_x) (see following equation example for truck defect probability (DP)).

$$DP_{truck} = p_{shock} * g_{shock,truck} + p_{temp.} * g_{temp..truck} + p_{hum.} * g_{hum.,truck}$$

Table 3. Probabilities for quality defects

Type of level excessing	Test case 1	Test case 2	Test case 3
Shock	0.0025	0.005	0.01
Temperature	0.015	0.03	0.06
Humidity	0.0075	0.015	0.03

The simulation consists of five SZs with three test cases each concluding in 15 experimental scenarios. Ten experiments per test case with 500 days of simulation time are averaged. The settling time is nearly 40 days. For analyzing the effect of quality data, the main indicator is the difference between the minimum and the maximum of the stock at the OEM (variation). The values are based on necessary data collected every hour at receiving at OEM plant. For further comparison, the numbers of transports (truck and airplane) are also used, as those indicate additional transport volumes.

3.1 Results and Discussion

Figure 2 presents the key indicator (variation) normalized to the reference SZ. The highest safety buffers are needed in SZ2a without any reducing mechanisms. A higher defect probability leads to higher safety buffers. In contrast to that, the lowest buffer size has to be implemented in SZ3a based on special transports. Consequently, SZ3a means the lowest uncertainty for planning. SZ2b and SZ3b represents SZs with applied sensor-based quality data. Referring to SZ2a, there is a high reduction potential through the usage of sensors (up to 40 percent). Besides the exception of high defect probability, the combination of quality data and special transports seems to have similar effects to the effects of just using quality data (SZ3b to SZ2b). Therefore, this combination seems to have only low positive effects and it would be not recommendable out of these results. This recommendation is based on the necessary investments for sensors and emergency transports without any big differences between SZ2b and SZ3b. Further research is necessary to provide the foundation for a suitable solution related to possible controlling methods.

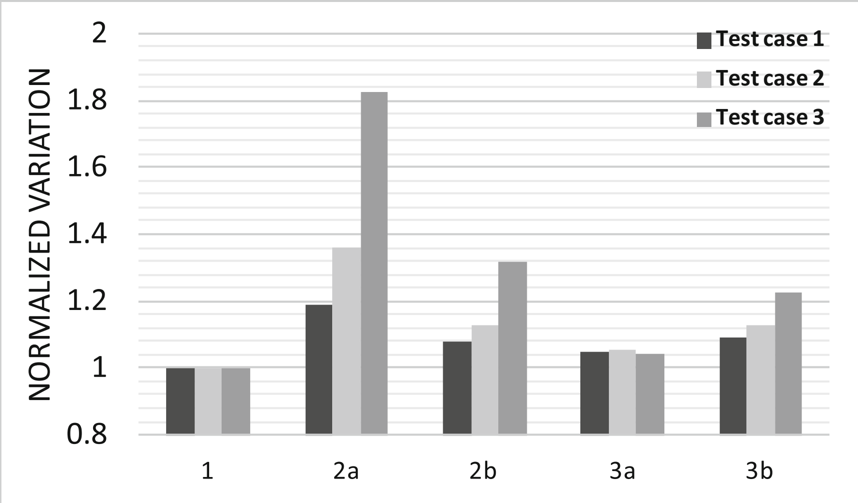

Fig. 2. Comparison between the different scenarios (1-3b) with regard to the relative key figure (variation) of the stocks at the OEM in the three test cases (see Table 1)

In comparison to other SZ, reaching the good results of SZ3a means a high usage of air transport. This kind of transportation is cost-intensive regarding to available airfreight rates. Additionally, this is an effect of this simulation study as the LSP directly use air transport for post-production amounts. In reality, there are many additional mechanisms for reducing the number of air transports, like additional safety stocks at the logistic hub or additional quality checks.

The mechanism of using air transport (SZ3a) causes up to a six time higher efforts (see Fig. 3) in case of amount than the combination of sensor and air transport (SZ3b). This indicates higher transport costs instead of the one-time investment for sensor technology. This would be a foundation for developing new controlling methods. In contrast to that, the usage of sensor-based quality data (SZ2b) leads to nearly the same results underlining the positive effect of using this kind of controlling. Real-time quality data helps to mitigate of the possible quality defects on transportation routes regarding lower safety stocks without any additional long-term transport. Besides the safety of the production, OEMs strive for lowering the transport costs and therefore they try to do it without emergency transports. For reaching this aim, usage of sensor-based quality data seems to be a suitable solution.

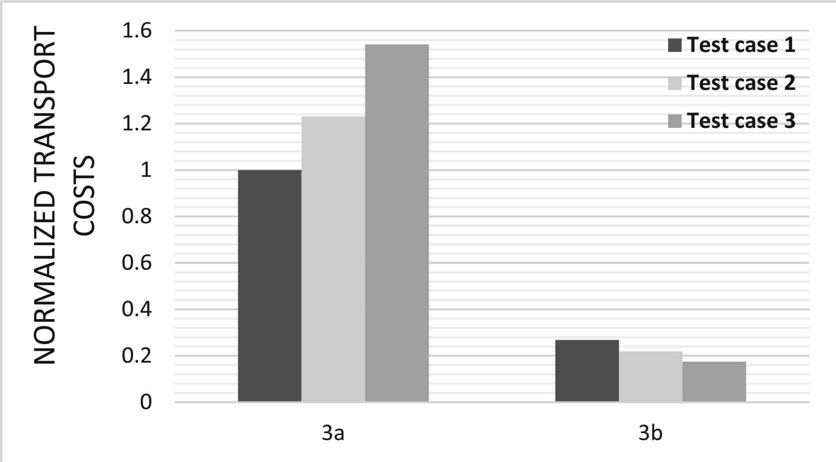

Fig. 3. Comparison of the amount of emergency transports in SZ3a and SZ3b in the three test cases

4 Conclusion and Further Outlook

By analyzing the effects of sensor-based quality data, this paper presents a simulation study for evaluation of using sensor-based, real-time quality data in logistic parts of automotive SCs. Possible effects for controlling SC of intermodal logistic processes are discussed in comparison to usual mechanisms like safety buffers and special transports (airplane). Sensors show a suitable opportunity in reducing stocks, especially for lower quality defect probabilities. This indicates a high sensor usage potential in nearly all product classes of automotive industry. Reductions in the range between 10 and 40 percent are possible and need to be transferred into practice. Thus, the results of the simulation study confirm the evaluation of real-time quality data for SC processes in case of environmental sensitive products and provide further research. In particular, special transports lead to better results with lower safety stocks but with higher transport effort through short reaction times. Therefore, further studies should focus on possible combinations and optimal conditions for usage. Additionally, researchers should focus on different areas of practical implementation. It is necessary to develop information architecture to reach higher transparency. Beside the possibility of real-time data transfer between different companies of a collaborative SC, terms like data security, data safety and data property have to be discussed. At the beginning, just closed loops are able for using sensors at packing units (e.g. special load carriers) getting control over physical sensors. Aiming fully added carriers in the global SCs, researchers and companies have to develop necessary standards and concepts of communication and data security.

Further research related to controlling mechanisms will validate the results of this study and evaluate the combination of using sensors and special transports in new controlling methods. Therefore, different methodologies and application opportunities need to be evaluated. Simulation studies can fulfill the need of evaluation, but business cases are relevant for practical implementations. The need of collecting real data is obvious. Furthermore, researchers have to focus on the sources of risks and the evaluation of real-time data for optimization. The scope of products needs further research regarding the usefulness of quality data including the connections between sensor data and quality data. Necessary quality models will help to get a wide support for decision-making processes in SCM. However, the simulation results indicates usage potential for all kind of products but in the beginning high-cost products and their global distribution networks will be the most interesting objects for real evaluation of real-time concepts. This relates to the high costs for implementing the infrastructure. Sensors need to be extended by concepts like context-based, local decision-making to face requirements like energy management and information speed. Lowering costs for technology (e.g. sensors, platforms, communication infrastructure) are also necessary to get the infrastructure for using the described opportunities. Based on this, innovative controlling methods help to optimize global SC by using real-time data.

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Retail Micrologistics: Chaotic Storage Taken to the Point of Sale

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Abstract. An overview of research questions and opportunities arising in the area of retail micrologistics is given. The latter is defined by assuming that w.r.t. a retail store environment, each item is tagged and individually traceable in real time, ordering principles and physical store layout are separated, and these principles are applied selectively to the point of sale (PoS), thus involving the consumer and primarily fast moving consumer goods (FMCG). Use cases are outlined.

Keywords: Retail · Micrologistics · Consumer logistics · Chaotic storage Augmented reality

1 Retail Micrologistics

Retail Micrologistics is given rise to by current developments in digitization and the assumed ubiquity of smart devices (Thoben et al. 2017; Zijm and Klumpp 2016; Stevens and Johnson 2016). Central to the research efforts proposed here is the assumption that the separation of physical and virtual, or digitally imposed ordering principles (i.e. chaotic/random storage, Hausman et al. 1976; Guo et al. 2015) can be selectively translated to the PoS in retail environments. This assumption and its implications are to be explored. Traditionally, retail stores have been designed along constraints of usability for both customers and employees, according to needs of storage, replenishment and marketing (Levy and Weitz 2012; Mentzer et al. 2001; Huebner and Schaal 2017). Much research has gone into organizing particular store layouts (Yapicioglu et al. 2012; Lee et al. 2013; Ozkan and Esnaf 2013; Pizzi and Scarpi 2016; Russell and Urban 2010), intended to influence customers to make as many 'unplanned purchases' as possible. More or less sophisticated approaches may usually consist in dispersing item categories which are elementary to most shopping trips (from the consumer's perspective) all over the shop floor, thus increasing time and distance travelled in store (Ghazavi and Lotfi 2016). Thus, complementarity of items from a customer's point of view can be seen as having been used to prolong shopping trips, whether or not this happened intentionally. Recently, advances in IT have enabled the disposal of static layouts or in any conceivable, straightforward way organized layouts in storage, rendering the obvious part of it 'chaotic', while leaving ordering to IT systems. Assuming the principle ('random' or

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'chaotic' storage; Hausman et al. 1976; Quintanilla et al. 2015) being transferred to the PoS, what are the consequences for retail store design and layouts, business processes and tasks, and user interfaces? While practicability of full chaotic store layouts has to be determined specifically per type of store, dropping the constraints on ordering principles promises useful insights into store design and architecture.

1.1 New Research Avenues in Retail Store Design and Architecture

Current developments in digitization (Thoben et al. 2017; Zijm and Klumpp 2016; Stevens and Johnson 2016) challenge preconceived notions in retail, with respect e.g. to store and warehouse layout (Vrechopoulos et al. 2004), functions, consumer behavior (Ghazavi and Lotfi 2016), and human qualification as well as related job descriptions and tasks. 'Chaotic' or random storage has re-gained attention (Hausman et al. 1976), and questions arise regarding the degree of transferability to the PoS. It is assumed that innovations such as RFID, ubiquitous smartphone use, availability of detailed purchase and tracking data as well as incentive provision via augmented reality-concepts make 'classic' order and categorization efforts obsolete to a degree.

The following collection of research questions arises from the stated assumptions. They vary in their degree of abstraction and more research opportunities are expected to be generated from further use cases. Given assumptions (i), each item is tagged and individually traceable in real time, (ii), ordering principles and physical store layout are separated, and questions arise in a number of areas once one considers (iii) applying these principles to a shop floor, thus involving consumers:

Considering store layouts/store architecture and observing their emergence: Assuming random item distribution, which additional assumptions are necessary to have a meaningful layout emerge? To what item categories, that is, subset of FMCG, does the concept apply? Which restrictions on item types, store size and customer count need to be implied?

Considering the consumer: First, consumer-centered approaches should be developed while keeping in mind that key behavioral measures of shoppers are in general heterogeneous (Sorensen et al. 2017; Inman et al. 2009). A theoretical justification to explore changes in store layouts and processes would be given with the help of straightforward cost reasoning from the consumer's perspective. E.g. feasibility is given if the total economic cost of a recurring (e.g. weekly) shopping trip with retail micrologistics concepts in place does not exceed the cost of one under 'classic' conditions, thus w/o assumptions (i)–(iii). As research on home delivery options shows, this is not straightforward (Kotzab and Teller 2005) and behavioral considerations may be of use (Ho et al. 2006).

Consumers are seen in the sense of Kotzab's and Teller's (2005) shoppers w.r.t. them being individuals procuring for their household rather than being synonymous to the latter. However, with mobile apps and augmented reality involved as incentives and tools, which by design are aimed at intrinsic motivation (Csikszentmihályi 1990), some form of consumption happens there as well. Consumers with a defined set of preferences are surely not expected to face a physically non-existent ordering of items and endure the related indefinite and unacceptable search. Since a virtual layout exists with the real time database on item locations, customers need access in a meaningful way. This means actual *requirements for user interfaces* need to be explored (Belay and McCrickard 2015). The concept of costs of a shopping trip to the customer can be used as guidance, as it implies finances and time spent as well as mental and physical resources invested in planning, shopping and transport. Planning can be thought of as compiling a shopping list, for instance, whether it be a one-time effort or exists as data on individual shopping history. Taking this comprehensive view at customers' costs yields a way to assess (customer-) efficiency of a store layout or any proposed retail micrologistics use case. By mapping goods and amounts to store locations, retail micrologistics solutions can be ranked by duration of customers' stay in store. Related to (i)–(iii) is the discussion of shifts in category management, namely towards categories comprised of complementary items (consumer-centered: items typically bought as baskets by consumer groups e.g. such as those defined in Granzin et al. (1997) should ideally form one category). Arguably this changes depending on time/day/season and other criteria.

Marketing: As Meyer and Kotzab (2017) remark, "…logistics literature – in contrast to marketing literature – does not include consumers as active members of a supply chain into their considerations". Since cost or effort considerations from a consumer perspective play a major part in retail micrologistics, consumers form an active and non-negligible element thereof. The above notwithstanding it has been noted that increasing time spent in store and maximizing exposure to its area positively influence unplanned purchases, and that "a better understanding of a shopper's prospective needs should also increase the accuracy and opt-in of targeted in-store promotions via mobile apps" (Gilbride et al. 2015; Hui, et al. 2013). This requires efforts in communication and orientation (mobile apps, augmented reality) and revisions of common store layouts (Alawadhi and Yoon 2016; Sorensen et al. 2017).

Further important implications hold for *user interface requirements* (consumer-centered approach) and all related *business processes* within the affected retail environment.

1.2 Design Framework and Exemplary Use Cases

We first briefly refer to the design framework we used to systematically explore questions in retail micrologistics, then give two use cases (Neukirchen and Klumpp 2017). Hevner et al. (2004) gave guidelines for conduct, evaluation and presentation of design science research. Design processes for the initial concept and its linkage to further theoretical development can be mapped according to *Concept-Knowledge theory* (C-K theory, Hatchuel and Weil 2003). The conceptual stage given with the use cases here (Nunamaker et al. 1991) consists of: statement of a research question, investigation of functionalities and requirements, understanding of system and procedures, and studying of relevant disciplines for new approaches and ideas. Within the framework of Vaishnavi and Kuechler (2007) this corresponds to the process steps problem awareness/description and suggestions, the matching outputs being a solution proposal and tentative design, respectively. Both our examples draw from several sub-disciplines of logistics, a C-K theory representation explains how recombining knowledge on replenishment, customer involvement, motivation, etc. in parallel to expansion of the initial concept (Fig. 1) has led to the current state of the consumer-involved replenishment-based game case, which now poses new theoretical questions regarding endogenization of store layouts, and store architecture as a whole, for instance, which have to be approached in the field as well. C-K theory is classically presented as a combination of two expandable spaces: Concept-Space, with concepts as undecidable propositions, thus logical limitations, and (newly generated) Knowledge-Space and their co-evolution (Fig. 1; Agogué and Kazakci 2014).

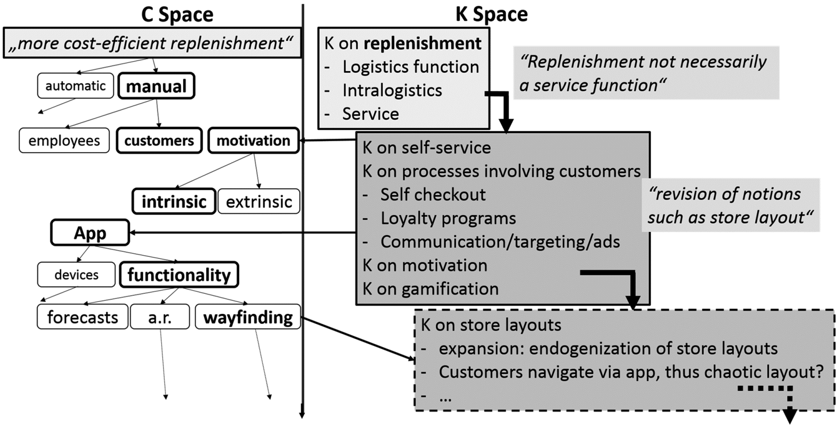

Fig. 1. Consumer-involved replenishment in the C-K-framework

Example 1 ***(Layout optimization/emergence):*** Individual shopping histories generated from data on tagged items and shelve locations reveals shoppers' paths through a given store layout which can be optimized: Data as an array $C(a, i, t)$, with a being amounts of items, i being consumers, and t referring to time, consumers' in store shopping data could be mapped to spatial coordinates of the shop floor, no matter if its layout is random or organized. Simpler, for a first approach to layout refinements, $C(a, i, j)$ with columns denoting individual items j, lines corresponding to consumers i and entries just $a_{ij} \in (0, 1)$. Thus, routes and potential for optimization/rearrangements of layout and store architecture are observable. With random layouts and app-based wayfinding, individualized marketing efforts can exploit routing options. An addition for wayfinding may be semi-autonomous shopping carts.

Example 2 ***(Blockchain shopping):*** Immediately upon picking (replacing) an item from the shelf, corresponding financial transactions using blockchain technology are induced. Possibly, this would dispose of all checkout functions though insurance aspects, for instance, need to be explored further.

Example 3 ***(Consumer-involved replenishment):*** This concept explores a marketing approach which does not only address consumers individually while in/near a store but integrates those who opt in into selected gamified replenishment activities. Motivating design of the apps and incentives used are critical, as is the use of augmented reality features (Neukirchen and Klumpp 2017). This example, as all related to retail micrologistics, rests on the assumptions (i)–(iii). Participation in a gamified replenishment process alongside the usual shopping trip may be integrated into reward schemes and the generation of in-store shopping routes, presumably raising the likelihood of unplanned purchases. The importance of optimized replenishment for sales volumes, customer satisfaction etc. has been receiving attention for decades, for instance by Urban (2002); Drèze et al. (1994); Ming-Hsien and Wen-Cher (1999); Huebner and Schaal (2017). The example presented here should be seen as one particular use case from the retail micrologistics field. Rather than covering a store's whole floor area, one might think of it as serving as an element for particular categories or consumer incentive activities integrated within mobile advertising, geared specifically towards intrinsically motivated participation should be aimed for (Klumpp et al. 2017).

2 Conclusion

Research avenues in retail micrologistics have been sketched out, exemplary use cases have been given. Retail micrologistics is distinguished from other consumer-involving or -centered approaches in that by having each item tagged and individually traceable in real time, ordering principles and physical store layout are separated, and these principles are applied selectively to a shop floor/PoS. Measures and innovations taken from there are conditional on involving the consumer, thus an understanding of logistics as principally inclusive of marketing thought is prerequisite.

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Forecasting Manufacturing Tardiness in OEM Milk-Run Operations Within the Industry 4.0 Framework

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Abstract. In a milk-run OEM pickup operation over an urban road network the manufacturing of components by suppliers is subject to varying tardiness on order release dates. Tardiness control by the logistic operators, when delivering parts and components to the OEM production line, which is assumed to work according with the Industry 4.0 procedures, must also follow the new paradigm. In this context, IoT will be extensively used in smart sensors in association with a Big Data repository of productive information for production and logistic planning. The required integration of manufacturing tardiness inference and logistic operations in the Industry 4.0 context is analysed in the paper.

Keywords: OEM · Milk-run · Tardiness control · Big data

1 Introduction

The deep integration of IoT and Big Data in the value chain is central in the Industry 4.0 context (Hermann et al. 2016). It involves the integration of machinery and complex physical devices with Iot sensors, Big Data, and algorithms acting in networks. It is also present in the OEM setting, where it is mandatory to eliminate all possible delays along the supplying process. The term OEM (Original Equipment Manufacturer) corresponds to those companies that acquire components from manufacturing suppliers and assemble them into final products to be sold to end customers. Stakeholders must develop integrated production and transport scheduling strategies as to reduce negative tardiness effects when supplying the main OEM production line (Novaes et al. 2017). Production scheduling, on the other hand, is one of the most important planning tasks carried out in the manufacturing process. Proactive uncertainty management that exploits inference techniques on unpredictable real-time events, are quite important in such a context (Stefansson et al. 2009). In the Industry 4.0 scenario, logistics OEM agents traditionally receive a pre-established schedule of supplier's components release times, but delays do occur in practice, with negative tardiness effects, such as penalties, assembly line interruptions, etc. The objective of this work is to investigate a model to permit the logistics operators to foresee, in a dynamic way, forecasts of supplier's orders release dates, thus reducing tardiness costs and operational faults in the OEM production line.

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2 Problem Definition

Within the Industry 4.0 paradigm, each production unit has to transform itself into predictive manufacturing, anticipating corrective actions to avoid disruptions in the system. During the manufacturing process, many situations may occur that affect production performance. They include machine breakdowns, demand fluctuations, setup interruptions, urgent orders, etc., as major production uncertainties (Stefansson et al. 2009; Azizi et al. 2015). In manufacturing, when a machine breaks down for example, it forces a modified flow shop program out of the prescribed state, and a new schedule is set up acting into the material flow, machinery allocation, tooling, and other possible actions.

The extensive adoption of IoT in the Industry 4.0 paradigm will set the essential structure of smart sensor networks in the new cyber-physical environment, associated with smart machines, and leading to a Big Data repository of productive information. Such increasing data availability along time can be harvested with data mining procedures, and with algorithms that will help to optimize product quality, reduce costs and lead time, save energy, as well as to improve equipment performance. Particularly in the OEM supplying scheme, an important parameter is the planned lead time at which component orders will be released to the logistics agents. When unforeseen disruptions such as machine breakdowns occur, the schedule is modified to maintain feasibility or to improve performance. To the logistics agent, who will collect OEM components at the supplier's premises, it is important to have a reliable prevision of order release delays in order to reprogram his work.

3 Preliminary Modelling

In the Industry 4.0 context, it is assumed that every supplier in the OEM milk-run setting will implement a robust (Roy, 2010) manufacturing tardiness estimation modelling, with a preliminary structure such as

(a) let $\tau_P^{(i)}$ be the lead time the supplier j is committed to complete an OEM order i; assume that a machine breakdown occurs at time $t^{(j)} < \tau_P^{(i)}$;
(b) the supplier j in question estimates that the adjusted lead time will be $\tau_C^{(i)}$. If $\tau_C^{(i)} > \tau_P^{(i)}$, a tardiness $\Delta^{(i)} = \tau_C^{(i)} - \tau_P^{(i)}$ will likely occur, and a fault diagnosis analysis will be performed with a robust algorithm, producing an estimate of the mean repair time $mrt^{(j)}$;
(c) let $Dt^{(j)} = \tau_P^{(i)} - t^{(j)} > 0$. The upper restriction imposed to $Dt^{(j)}$ is related to the resulting tardiness costs, including OEM production line interruptions, tardiness fines, inventory, labour and transport costs, etc. Depending on the $Dt^{(j)}$ value, the logistic operator will reorganize the routeing scheme and reduce the tardiness effect as much as possible in order to reduce such costs. If $Dt^{(j)}$ is too large, other correcting measures will be necessary.
(d) in many situations the delay may not affect the previous routeing scheme set by the logistics operator, leading to a zero tardiness cost;

But in general, $Dt^{(j)}$ is one of the variables correlated with tardiness magnitude. On the other hand, the mean repair time $mrt^{(j)}$ is another important variable influencing tardiness. Alternatively, the ratio $\alpha^{(j)} = mrt^{(j)}/Dt^{(j)}$ represents the mean repair time effect in a relative way, as compared with the magnitude of $Dt^{(j)}$. Since we have used a forward stepwise regression technique, the program will select the statistically significant variables to explain the value of the tardiness $\Delta^{(i)}$. A fourth element that seems to reduce tardiness values is the occurrence of idle time in the manufacturing process, i.e. when the supplier adopts an under-capacity scheduling scheme. Some authors refer to "idle time" as a proxy representation of "demand/production capacity", as used by Jansen et al. (2009). We assume a more accurate term "production load factor", which is defined as the ratio $\rho^{(j)}$ between the production output and the manufacturing capacity, within a given time period. In our preliminary analysis, four factors were beforehand assumed to explain lead-time tardiness values in component lead time: (a) the time interval $Dt^{(j)}$; (b) the expected machine mean repair time $mrt^{(j)}$; (c) the ratio $\alpha^{(j)} = mrt^{(j)}/Dt^{(j)}$; and (d) the ratio $\rho^{(j)}$ between the production output and the manufacturing capacity of supplier j, observed during the corresponding shift. A sample of 206 situations for one specific supplier j (machine breakdown faults, as an example), was submitted to a regression analysis. Variables $mrt^{(j)}$ and $\rho^{(j)}$ were not statistically significant, leading to the following tardiness inference function

$$\ln\left(\Delta^{(i)}\right) = -1.01086 + 0.9683\ln\left(Dt^{(j)}\right) + 2.1582\ln\left(\alpha^{(j)}\right) \quad (1)$$

with $R^2 = 0.87$, and *Student's t* statistics significant for all variables in (1). From (1) one gets the expected tardiness function for this specific case

$$\Delta^{(i)} = 0.3639\left(Dt^{(j)}\right)^{0.9683}\left(mrt^{(j)}/Dt^{(j)}\right)^{2,1582} \quad (2)$$

Analysing the available data, it was verified that the value of $\Delta^{(i)}$ was nil when $\alpha^{(j)} \leq 0.8004$. On the other hand, about 74% of the cases showed zero tardiness values (Fig. 1).

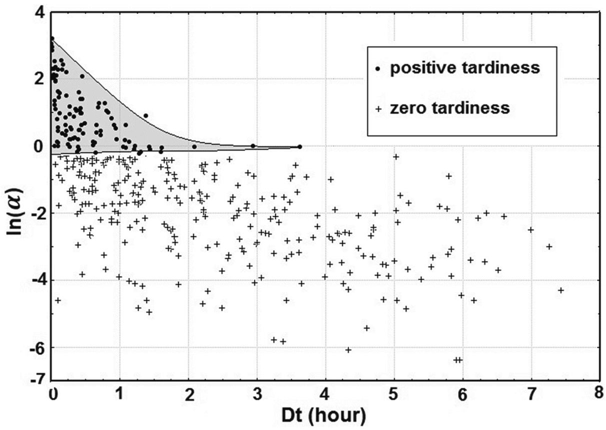

Fig. 1. Simulated occurrences of positive and nil production tardiness values generated by machine breakdown interruptions

4 Bayes MCMC Modelling to Forecast Manufacturing Tardiness

As long as Big Data information repository becomes extensively available in the Industry 4.0 context, the tardiness inference process can use successively observed data to get posterior distributions, with the objective of dynamically improving the causal inference among the operational parameters that modify the variables of interest. This is a typical inverse problem framework (Vogel, 2002). In this context, one can use Bayesian inference analysis. In Bayesian inference, the main object of interest is the posterior distribution, i.e. the probability distribution of the parameters estimated from observed results. The posterior distribution contains all information about the parameters, from which one can obtain point and interval summaries (e.g. mean, mode, variance). The general scenario of Bayesian inference is formed by an observed function $X = \left(X_1, \ldots, X_m\right)$, which is a vector of observed data, associated with a vector of unknown parameters θ, assumed to be a random variable with a prior distribution $\pi(\theta)$. The posterior distribution for inference, concerning the parameters s θ, in accordance to the Bayes formulation, is

$$f(\theta|X) = \frac{f(X|\theta)\pi(\theta)}{\int f(X|u)\pi(u)\partial u}. \tag{3}$$

The integral $\int f(X|u)\pi(u)\partial u$, does not depend on θ. In relatively high dimensional problems, such an integral can be difficult to evaluate, but one approach, the Markov Chain Monte Carlo (MCMC) method, associated with Gibbs sampling, is widely used to solve inverse technical problems (Azizi et al. 2015). Suppose $x_1, \ldots, x_m$ are sample values of the set of random variables $X = \left(X_1, \ldots, X_m\right)$ that characterizes the case being modelled. The expectation of a function $f\left(X_1, \ldots, X_m\right)$, with respect to the distribution over X, can be approximated by (Neal 1998)

$$E[f(X)] = \sum_{x_1} \cdots \sum_{x_m} f(x_1, \ldots, x_m) * prob(X_1 = x_1, \ldots, X_m = x_m), \quad (4)$$

$$\approx \frac{1}{N} \sum_{t=0}^{N-1} f\left(x_1^{(t)}, \ldots, x_m^{(t)}\right), \quad (5)$$

where $x_1^{(t)}, \ldots, x_m^{(t)}$ are the values, at stage t, of the inference process in a sample of size N. Writing $X^{(t)} = \left\{x_1^{(t)}, \ldots x_m^{(t)}\right\}$ for the set of variables at stage t, the corresponding Markov chain is defined by assuming an initial distribution $X^{(0)}$ for $t = 0$, and the transition probabilities for $X^{(t)}$ are dynamically calculated from $X^{(t-1)}$ by applying the Markovian transition probabilities. Bayesian inference using Gibbs sampling with the WinBugs software, for example, can generate posterior distributions that lead to a dynamic production tardiness forecasting procedure.

5 Conclusion and Future Research

We have discussed in this text a prospective framework for structuring, in a dynamic way, a Big Data, Bayes MCMC forecasting model of supplier's manufacturing tardiness values in an OEM supply chain, considering the process of delivering parts and components to the main assembling line according to the Industry 4.0 paradigm. At this stage of the research, no sufficient Big Data was available to effectively apply the MCMC approach to forecast order tardiness. This research effort will proceed further with more detailed model development, extensive data gathering, and a comprehensive application.

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Design of Emergency Response System for Disaster Management Using VANET

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Abstract. Catastrophic natural disasters have the strong negative impact on the economy and mankind around the globe. As transportation and communication play an important role in such situations, we develop an emergency response system for disaster management with the focus on land transport vessels and mobile rescue team members. We present a prototype of an emergency response system using Global Positioning System (GPS) and Vehicular Ad hoc Networks (VANETs), which includes a server (control room), that is used to collect the information about the disaster area and is also used to provide the desired services according to the request.

1 Introduction

Natural disasters such as earthquakes, hurricanes, tsunamis, typhoons, etc., lead to numerous deaths, injuries, and destruction of land/building, etc. When such disasters strike, effective rescue operations are required. There are two major points that are often considered at country level for the rescue operations. First is the cost of the rescue operations and second is the availability of communication. In standard situations, the latter relies on cellular mobile communication systems for coordination, which, however, may be destroyed as during the Jiji's Earthquake (Japan) [13]. Therefore, disaster relief workers face lack of information regarding e.g., the location of injured, the extent of first aid, types of equipment etc.

The cost of rescue operations depends on the severity and destruction during disaster, which has shown to be extremely high in terms of losing the life [2] and economic damages [3]. As a result, many new initiatives and programs in various countries throughout the world have been considered to control these issues [6,7].

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In catastrophic disaster's situation, selection of a proper technology and deployment of a temporary communication network may support rescue operations. Over the last few decades, new information and communication technologies arose, which can be utilized in responding to various kinds of emergencies to minimize disruptions, to minimize human and socioeconomic costs in specific scenarios [10]. Cost and infrastructure represent the biggest challenges during deployment of communication technologies.

Among the available choices, Vehicular ad hoc networks (VANETs) require no additional infrastructure, is comparably cheaper that provides good coverage. VANETs is the specialized sub-type of ad hoc networks and is one of the wireless technologies used by Intelligent Transportation Systems (ITS) [9,11]. This technology offers features like self-healing, self-managing and self-configuring etc., and also has capabilities to communicate in Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) [10]. In this paper, we leverage VANETs to propose an emergency response management system. The system is structured to gather information from multiple sources and locations, including from the point of incident in order to provide effective strategies and decisions to propagate the information to the nodes in real-time.

The remainder of this paper is organized as follows: Sect. 2 presents the existing solutions for emergency responses. Section 3 discusses the proposed application design, implementation of a testbed and expected outcomes. The last section provides concluding comments and suggestions for future work.

2 State of the Art

In each decade, approximately one million people died because of the natural disasters, and millions became homeless. Apart from it, when a disaster strikes, the first problem faced by authorities and emergency services is the breakup or disruption of communication links. In such situations as also observed in [13], the cellular communications systems were paralyzed which made the rescue operation extremely difficult and as result many lost their lives. The importance of emergency response systems has been increased due to massive destruction caused by Tsunami which came into being in Japan (2011) [2], and Earthquake which struck in Mexico (2017).

In the literature, the following failure sources that are directly/indirectly linked to land connectivity and communication networks have been reported, cf., e.g., [2,13,14]:

- Partial or complete crash of base stations
- Broken cables due to falling trees or break of trunks
- Partial or complete dis-connectivity of electricity
- Backup power generators failed
- Diversity in connectivity of communication networks
- Roads dis-connectivity and traffic jam due to collapse of buildings or land or bridges

Emergency responses and disaster management can be categorized into two types: First, dealing with emergency responses in early hours after the strike of disaster to 72 h [16]. Secondly, post-disaster recovery and reconstruction, which includes management of food, health, and relief operations, provision of basic necessities and reconstructions etc. [5,15].

To overcome the communication issue in the first 72 h, several methods based on different technologies have been proposed. In [8], the authors analyzed causes of dis-connectivity of the entire communication systems in Jiji/Taiwan Earthquake. The authors concluded that the loss of communication networks may have a catastrophic consequence and proposed the base of mobile ad hoc network (MANET) as rescue information system. Similarly, in [12], a design of P2Pnet was considered. In the disaster relief mission, the authors of [4] proposed an integrated communication system by combining wireless sensor network (WSN) and MANET. They used cost intensive satellite/cellular gateways to connect local network to satellite/cellular network.

To address the latter issue, researchers focus on communication and information management issues in health, food, and recovery operations. In [1], authors discussed methodological techniques to determine the location and severity of post-earthquake building damage and presented an algorithm based on the comparative analysis of a multi-temporal sequence of optical or Synthetic Aperture Radar (SAR) images, acquired before and after the event. In [2,3], the authors proposed a disaster management system using Intelligent Transportation Systems including VANETs, mobile and Cloud Computing technologies and evaluated in smart cities settings. The paper claimed for better evacuation results for demand and speed strategies.

This paper focuses on early hour issues. We proposed a simple application that can be fruitful even under catastrophic conditions to fulfill basic communication requirements.

3 Application Design and Implementation

In case of disasters, rescue teams, as well as un-organized volunteers, need to be coordinated despite communication network failures. To overcome the latter, a simple and distributed application may represent a solution, which requires:

- Basic functionality
- Simple and easy to use user interface
- Simple configuration and deployment
- Low power consumption

Regarding functionality, alert messages and required action can be categorized: First, high alert messages include first aid, ambulance or air-help. Second, medium alert messages that include general help issues, which allow for short delays. Third, low alert messages contain information about the location or land, cf., Table 1 for an overview.

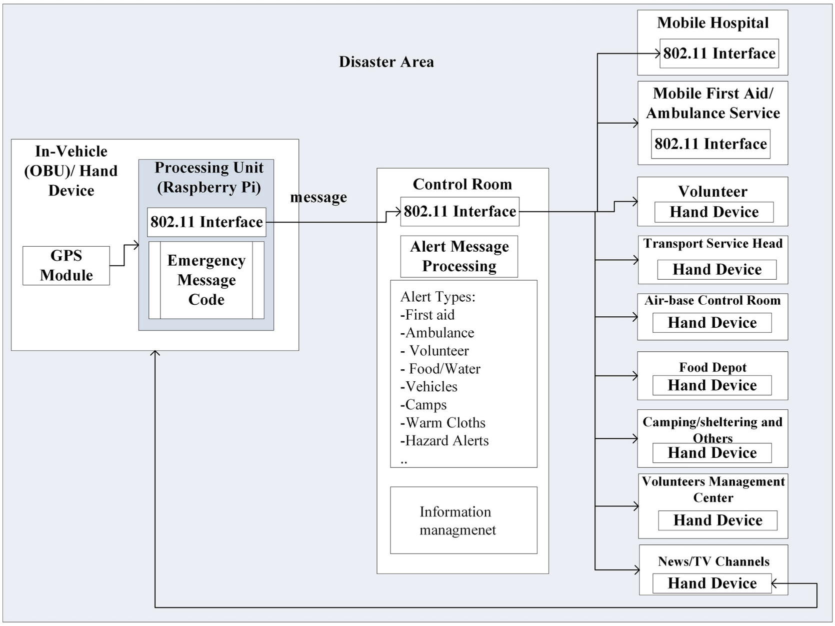

Fig. 1. Emergency control plan

Table 1. Alert messages, their types and transferred message codes

No.	Alert	Type	Message code
1	First aid	Emergency help call	01
2	Ambulance	Emergency help call	02
3	Air-help required	Emergency help call	03
4	Food/Water	Help call	04/40
5	Vehicles	Help call	05
6	Shelter/Camp	Help call	06
7	Volunteers	Help call	07
8	Warm-clothes	Help call	08
9	Collapsed land	Informative	09
10	Broken bridge	Informative	0A
11	Blocked road	Informative	0B
12	Collapsed buildings	Informative	0C
14	Voice message	Reserved(Optional)	Multimedia data
15	All OK/Clear	Informative	0D

For coordination, a centralized server (or control room) is included, which handles all alerts and maintains information about each participating entity in relief operations. Furthermore, it also collects information about the disaster area like collapsed buildings, bridges, road blocked etc. To deliver services, the control room is enabled to communicate with mobile nodes (hospitals, first aid teams, volunteers, expert-team-members for relief operations etc.). Figure 1 presents the plan of our proposed application.

Since in the disaster area, the major problem in gathering information is the partial or fully dis-connectivity of the already deployed network. When the emergency rescue teams are dispersed in the effected region for rescue operation, then the VANET enabled hand-devices or vehicle that are used in rescue operation turn into the wireless relay nodes for the message dissemination in the network. In addition to it, placing VANET enabled smart-devices on different location can also help to extend the coverage of the network effectively.

4 Hard-and Software for Testbed

To verify the proposed idea in a vehicular environment, we chose GoPiGo robot cars with IEEE 802.11 interface to configure ad hoc network and build a testbed. Each car was equipped with a single-board low-cost microcontroller, a GPS module for location information, a 16 button keypad for simple inputs and a 802.11n interface for the ad hoc mode networking.

Since designed application requires software implementation for the control room, which we termed server-side application, and for mobile users (vehicle/ handset/ infrastructure) representing the client-side application, that supposed to send alerts.

Considering the client-side application, a simple TCP application accepting keypad input is sufficient, cf. In order to give the simplest and abstract view of the application, we mapped each button with short message label of the alert message. Since small size packets are quicker and easier to transfer in the network as compared to multimedia messages [9], therefore, we mapped these alerts into codes. Figure 2 depicts the sketch of the interface and example messages format. Then we transfer these codes as presented in Table 1 into the network instead of whole text or media message. When a user needs to send the mapped message to the control room, the user presses mapped and OK buttons to confirm the message. If a user needs to specify the level of the required help i.e., a number of vehicles,; it first presses 5, then number sign followed by the number (# 3#) and then presses OK to confirm and send the message. The Fig. 2 presents the user interface and example messages format.

The relief operation may compose of several departments. Since the proposed system is centralized, therefore, the control room communicates with the local departments in case of an emergency alert received from team members. The server-side application is divided into three action types in accordance with the alert categories: For high alerts, the server takes quick action by sending messages to the respective departments. Regarding medium alerts, availability of resources

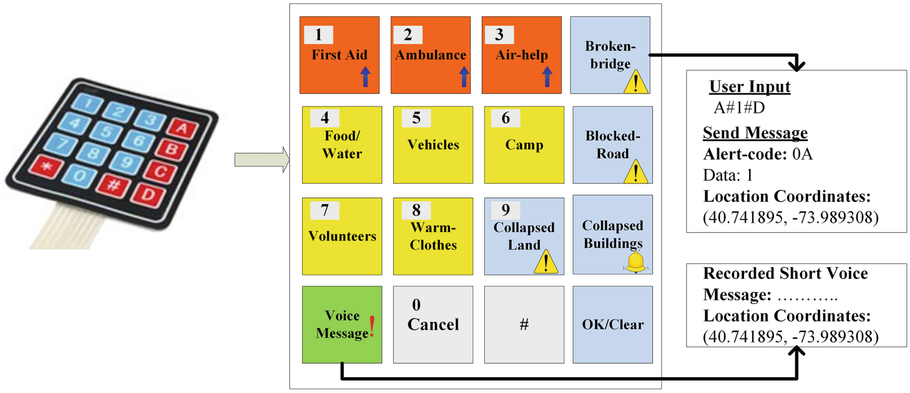

Fig. 2. Interface on client side and examples to insert data

is checked before taking action. Last, informative messages are only stored in the database. Here is the summary of these actions against specified code;

- 01: Send a message to first aid team nearest to the location
- 02: Send a message to hospital service
- 03: Send a message to the air-base control room (with additional requirements if there)
- 04/40: Send a message to the camping and accessories management head along location information
- 05: Send a message to the transport service head along location information
- 06: Send a message to the emergency camping/sheltering management head along location information
- 07: Send a message to volunteers management center for required volunteers at the specified location
- 08: message to the camping and accessories management head
- 09: Store this information into database and mark this location on the map
- 0A: Store bridge information into database and mark in the map
- 0B: Store roads information into database and mark in the map
- 0C: Store buildings information into database and mark in the map
- 0D: NO action, it's just an acknowledge message

The front-end of the server in control room displays a new alert, activity log, statistics and map of the disaster area to the quick overview of severity the incident area.

5 Conclusion and Outlook

In order to support safety and emergency applications in disaster areas, we devised an emergency system using VANET. The key point was to provide help services in early hours after a catastrophic disaster. Due to features of VANET, we chose this technology to design and implement a prototype of a respective application.

In our future work, the effectiveness of the proposed system will be demonstrated using robot-cars. These will be configured for ad hoc networks and put in a test-bed for evaluation. To show benefits derived from the adoption of our proposed system in terms of improved and balanced traffic flow and smooth evacuation, the system will be tested using use-cases, then compare the results according to the generated request.

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Enhancing the Cybersecurity of Port Community Systems

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Abstract. Major disturbances of large ports will most probably lead to tremendous negative effects to maritime supply chains and the whole economy. Beside physical threats, ports are also vulnerable to cyber attacks due to their dependency on information and communications technology. Port Community Systems (PCSs) are information hubs for ports integrating information from various sources for global supply chains, connecting systems of terminal operators, carriers, freight forwarders and authorities. In that way, Port Community Systems must be regarded as critical infrastructures – successful cyber attacks can lead to massive problems in port operation, in extreme cases even to a standstill, and thus – depending on the duration – to bottlenecks in the supply of industries and population and to severe consequences for the whole economy. The recent case of the NotPetya attack on Maersk, causing some central systems to be down for several days worldwide, is estimated to have caused a loss of about US$ 200–300 Mio. This paper presents ongoing work within the research project PortSec, aiming at improved resilience of PCSs with respect to cyber attacks.

Keywords: Cyber security · Maritime logistics · PCS
Port Community System

1 Introduction

Maritime transport is of central importance for the German economy. In order to ensure the smooth flow of cargo through the seaports, electronic data transmission systems for ports, commonly known as Port Community Systems (PCS), are used. PCSs can be seen as centralized information and data hubs for ports integrating and distributing information from various sources for global supply chains. They connect companies and authorities involved in maritime transport, such as shipowners, freight forwarders, terminal operators, carriers (ocean, road, rail, and inland waterway) and authorities like Customs, in particular by providing interfaces to their systems.

Major disturbances of large ports could lead to tremendous negative effects to maritime supply chains and the economy. Beside physical threats, ports are also vulnerable to cyber attacks due to their dependency on information and communication technology. PCSs are part of the Critical Infrastructure in traffic and transport – successful cyber attacks can lead to massive problems in port operation, significant transport delays, and in extreme cases even to a standstill. In that way, Cyber attacks on PCSs can – depending on the duration – even lead to bottlenecks in the supply of industries and population and severe consequences for the whole economy.

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Confidential data could be spied on or tampered with using manipulated user accounts in order to prepare for criminal acts like cargo theft or smuggling of drugs. Manipulation of data, for example in case of containers loaded with dangerous goods, could lead to storage without obtaining the legally required separation instructions. This may result in chemical reactions of hazardous substances and eventually lead to fire or explosion.

This paper describes first insights into intermediate results of the research project PortSec (PortSec 2017). This project, funded by the German Federal Ministry of Education and Research (BMBF), uses a software-centric approach in order to detect possible vulnerabilities in the field of cyber security for PCSs. The objective of the PortSec project is to develop a systematic and comprehensive IT risk management in port telematics, taking into account the underlying software architecture and including legal and economic security requirements. The software-based approach focuses on the prevention of attacks rather than their detection and defence. This approach is particularly innovative and has not yet been applied in existing procedural models and standards for the establishment of information security management systems (ISMS). One goal of the project is to develop an industry-specific security standard to prevent cyber attacks. This standard includes a certification scheme for PCSs.

2 Methodology

In order to create a catalogue of cyber security risks for PCSs, a structure to systemize these risks was created. In detail, each risk consists of the following items: a risk scenario, an asset and the motivation. The risk scenario describes the purpose of an attack on a PCS, e.g. a smuggler intends to create a Customs release for a container in order to receive the smuggled goods. An asset defines a system or a message which has to be modified, deleted or diverted in order to fulfil the attack. The motivation specifies the goal of the attack, e.g. the goal of a smuggler is to pick up a container with drugs without any Customs or other authorities' intervention.

In order to create the catalogue, the following steps are carried out:

(i) literature review on former cyber attacks on PCSs,
(ii) an analysis of business processes of a PCS,
(iii) brainstorming sessions on possible risk scenarios,
(iv) an analysis of the system and network structure of the PCS and
(v) an analysis of the vulnerability of the PCS software. By now, the first three steps have been carried out. The last two steps are in progress.

(i) In order to create a comprehensive overview on former cyber attacks on PCSs, a narrative literature review was carried out. Due to the fact that scientific literature for cyber attacks on PCSs is limited the literature review also includes magazines in the field of maritime logistics.
(ii) The business processes of the PCS were analysed. In detail, in several workshops with one PCS operator the business processes were analysed and modelled using

BPMN (Business Process Model and Notation). Therefore, the systems, interfaces and encryption of the different software components methods were documented.

(iii) The BPMN diagrams including the technical attributes for the systems and interfaces were analysed in order to detect possible risk scenarios. Later, during several brainstorming sessions, additional risk scenarios were identified.

(iv) Next planned step is the analysis of the system and network structure of the PCS.

(v) Software components of the PCS will be analysed in order to detect possible vulnerabilities.

3 Threat Analysis

Until few years ago, ports were mainly concerned about physical security. However, nowadays the highest risk lies in cyber attacks (Sensiguard 2017). Unlike conventional attacks, cyber attacks can be performed anonymously from a safe distance, possibly thousands of miles away. Attackers can monitor systems and collect information in order to detect vulnerabilities before performing an attack. In contrast to physical attacks, the detection of a cyber breach is far more difficult. Many respective cases even remain undetected. Another problem concerning lacking cyber security awareness is the fact that attacked companies refrain from reporting attacks, as they fear reputational damage.

With regard to the analysis of potential threats, scenarios are developed describing possible cyber attacks on PCSs. For this purpose, the domain-specific business processes in the area of port communication are analyzed. The security requirements of the processes and the processed data are assessed as well. The analysis is designed to identify possible weaknesses, primarily related to interfaces used for communication via the Internet. In addition, the systems are examined regarding protection factors like availability, confidentiality, and integrity.

Based on the results of the threat analysis, relevant attack scenarios will be defined, and associated economic and business risks will be evaluated with regard to potential damage. For this purpose, each individual scenario will be assessed with regard to the probability of occurrence, vulnerability and consequences in order to evaluate the effects and resulting damage of possible attacks on the PCS operator, the port industry, and downstream logistics processes. The impact of attacks and resulting effects on the economy will be examined as well. Previous similar attacks will be analyzed in order to complete the picture of the threat scenarios.

A further objective of the project is the development of a method by which domain knowledge can be transferred in a formal way into the knowledge database to be developed. A respective concept will be developed followed by the implementation of a procedure which facilitates the input of domain knowledge in an automated and formalized manner. Finally, the domain knowledge about the dangers and the resulting risks will be transferred to the knowledge database. In that way, the knowledge can later be used for testing procedures.

4 Literature Review

The literature review on the current situation on cyber security in ports shows that in the past ports were mainly concerned about physical security. However, nowadays the highest risk lies in cyber attacks, which can be executed from computers thousands of miles away (Ports&Harbours 2016). Unlike conventional attacks, cyber attacks can be performed while the attackers act from a safe distance. Attackers can monitor systems and collect information in order to detect vulnerabilities before performing an attack which could lead to major disruptions (Ports&Harbours 2015). In contrast to physical attacks, the detection of a cyber breach is more difficult. In addition, normal insurance policies do not cover cyber attacks (Portstrategy 2015a).

According to a study in 2013 published by the Brookings Institution, there is a relatively low level of cyber security awareness and culture in U.S. ports. Only one of the six involved ports has a cyber vulnerability assessment. None has a cyber incident response plan (DHS 2017a). Another problem concerning lacking cyber security awareness is the fact that attacked companies, like ports, refrain from reporting attacks, as they fear reputational damages. A better mindset in reporting cyber attacks could help other ports to be prepared (Portstrategy 2015a).

Different groups might target ports. The first group are criminals aiming on making money out of their cyber attacks. In general, criminal organisations are increasingly using cybercrime to facilitate cargo theft (Portstrategy 2015b). Thieves could try to retrieve data on the content of a container using a PCS in order to steal goods out of a container later. Besides information on the containers' contents, criminals are also interested in truck drivers' habits like regular routes and usual truck stops. Criminal organisations are able to use this information to identify the most vulnerable point in the supply chain which increases the effectiveness on their physical attacks (Portstrategy 2015b). Next, criminals could also encrypt the data of all containers in the port. In this case the port would have to pay a ransom fee in order to get access to its productive data again. The second group is commonly known as hacktivists. They are mainly interested in proving their abilities by detecting vulnerabilities in the systems of the port which could lead to major disturbances in port operations. The third group is Governments. Their objectives are espionage and the identification of possible vulnerabilities of foreign port systems which could be used for possible future attacks (Portstrategy 2015a).

Several attacks in the field of cyber security on ports and PCSs were reported. The most famous incident happened in Antwerp between 2011 and 2013. Hackers were recruited by an organized crime group. The group hid narcotics in containers used by legal shippers. In order to get access to the drugs later, the recruited hackers accessed the PCS of Port of Antwerp to retrieve the locations and security details of these containers. This enabled the criminals to send own drivers to pick up the containers before the legitimate owner arrived. At the beginning, the hackers used malware in order to access the IT systems. After the discovery of the malware they broke into the port premises and installed key-logging devices onto computers of the port (DHS 2017b).

In 2012, a cargo system operated by the Australian Customs and Border Protection was penetrated by a crime syndicate. This syndicate also used legal transports by other shippers for their drug smuggling. Due to the penetration of the system the criminals were able to check whether these containers were classified as suspicious by police or customs authorities. The crime syndicate abandoned containers which were classified as suspicious (Kochetkowa 2015).

In March 2017, the Port of Vancouver (Canada) was subject to a Denial-of-Service attack. According to the port's spokesman, the port regularly experiences this type of attack. In contrast to previous incidents, this attack was initiated from inside of the port by a virus which infected a computer of the port's network (CT 2017).

In Summer 2017, the shipping company Maersk was subject to a cyber attack during which the malware NotPetya was used. The attack resulted in severe damage of the container booking systems, causing a breakdown of operations in several container terminals worldwide for several days. The attack is estimated to have caused a loss of about US$ 200–300 Mio (Heise 2017b).

According to the German Bundeskriminalamt, in 2016 German Police in total investigated 83.000 cases of cybercrime, resulting in a damage of more than € 51 Mio in Germany alone (Heise 2017a). Nevertheless, the number of unreported cases is estimated to be high.

5 Automated Testing of Software

A comprehensive review of the IT security risks related to software has to identify basic security issues, e.g. with respect to software architecture, such as lack of encryption, incorrect authorization testing, or unprotected entry points. In particular, the architectural risk analysis must be based on the actual software implementation and not only on abstract descriptions, which are often incomplete. Since manual architectural analysis is often very complex and requires considerable expertise, this step should be supported by tools. Therefore, the PortSec project is based on a software-centric approach in which IT security risks are derived from the implemented software architecture in an automated way. First, the implemented software architecture is automatically extracted from the source code of the PCS, employing static and dynamic program analyses. The analysis of the software architecture enables the identification of fundamental security risks of the software with regard to possible cyber attacks. The redesigned software architecture in the next step is supplemented by descriptions of the network infrastructure in which the PCS is operated and by a formal representation of the business processes and corresponding legal and business requirements. On that basis, situations can be identified, in which unauthorized access to restricted business processes is possible and organizational control rules could be circumvented. At the same time, more general technical security risks are identified, e.g. insecure use of software frameworks or incorrect encryption.

6 Outlook: Creation of an Industry-Specific Security Standard

The German law for the security enhancement of information technology systems (IT security law), in force since July 2015, allows operators of critical infrastructures and their associated industries to define branch-specific security standards together with the German Federal Office for Information Security (BSI) (BSI 2017). Building on the results of the PortSec project, a sector-specific security standard for PCSs will be developed supporting the IT security law and ensuring compatibility with comparable and supplementary standards. Within the framework of PortSec, a respective audit and certification concept will be elaborated, considering PortSec results, which can be used by all operators of critical infrastructures in the area of maritime transport and traffic.

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Robotics in Logistics

Interval Superposition Arithmetic Inspired Communication for Distributed Model Predictive Control

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Abstract. In this paper, we combine an quantised communication approach for a distributed system consisting of holonomic robots with the set characterization to further reduce the communication load. To ensure collision avoidance among the robots, the trajectory is quantised and incorporated into a distributed model predictive control scheme. Combining this quantised approach with the set characterization to communicate only the lower and upper bound, the communication load is independent of the necessary horizon length while numerical results still show that target states are reached.

1 Introduction

Today, robots are suitable to fulfil many tasks as the computational abilities are capable to do also complex calculations online. For many applications, robots either have to collaborate, e.g. formation control [5], or, in non-cooperative scenarios, at least have to avoid collisions. As handling this problem in a centralised manner may be infeasible [9], a distributed control algorithm can be applied to divide the problem into subproblems, which could then be solved by each robot. Distributed Model Predictive Scheme (DMPC) turned out to be an appropriate method, which is able to steer a distributed system to a defined equilibrium [10], see also [1] for a detailed overview of the method. However, if a strong coupling among the subsystems exists, then communication is required [9].

Considering the communication burden in many robotic or automotive applications, wireless communication is used, see, e.g., [4]. Hence, the resources for bandwidth and throughput are limited. To incorporate the latter, we proposed a quantised communication scheme in [6], where optimisation is based on a continuous spatial set but communication is shifted to a quantised space. Here, the spatial set is quantised into a grid of cells and indexes of the occupied cells

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are used to exchange state information. This scheme allows for an extension to transmit only the altered cells instead of the whole prediction [8].

In this paper, we present an idea, which incorporates the set characterization from existing set-valued arithmetics [11] into the communication scheme. Instead of using the full prediction of quantised or altered cells, we transmit the lower and upper bound of the prediction of the robot. This leads to a fixed number of exchanged information as we have to transmit only two cells indexes for each time instant. We explore this approach numerically and compare the results to previously established schemes.

The remaining paper is organised as follows: First, we introduce the problem setting presenting the robotic model and give a short definition of the occupancy grid construction in Sect. 2. In Sect. 3, we present the set characterization adaptation for the communication among the robots and in Sect. 4 formulate the adapted DMPC algorithm which is executed by each robot. Before concluding our paper, we will present numerical results by utilising holonomic robots in Sect. 5.

2 Problem Setting

Here, we consider P mobile robots following a time discrete model

$$z_p^+ = f(z_p, u_p) := f_0\left(z_p\right) + \sum_{i=1}^{m} f_i\left(z_p\right) u_{p,i}, \qquad p \in [1:P] \tag{1}$$

with $z_p = \left(x_p, y_p\right)^\top$ as the current state of system p in the 2D-space, f_i denoting continuous and smooth vector fields $f_i : \mathbb{R}^d \to \mathbb{R}^d$, $i \in \{1, \ldots, m\}$ where each vector field is driven by a control variable $u_{p,i}$ and $m \in \mathbb{N}$. Here, we specialise this to a kinematic holonomic model

$$\begin{pmatrix} x_p \\ y_p \end{pmatrix}^+ = \begin{pmatrix} x_p \\ y_p \end{pmatrix} + \begin{pmatrix} 1 \\ 0 \end{pmatrix} v_p^x + \begin{pmatrix} 0 \\ 1 \end{pmatrix} v_p^y, \tag{2}$$

where each vector field is driven by a control variable v_p^x and v_p^y. The constraints are bounded by a convex set $\mathbb{U} \subset \mathbb{R}^2$ containing the origin,

$$\mathbb{U} := \left\{ u_p = \begin{pmatrix} v_p^x \\ v_p^y \end{pmatrix}, \|u_p\| \leq \bar{v} \right\}, \qquad \bar{v} > 0 \tag{3}$$

For a given prediction horizon N, we define a control sequence

$$\mathbf{u}_p = (u_p(0), u_p(1), \ldots, u_p(N-1)),$$

which is utilised to describe the predicted state trajectory of a robot via

$$\mathbf{z}_p^{\mathbf{u}}\left(\cdot; z_p^0\right) := \left(z_p^u\left(0; z_p^0\right), z_p^u\left(1; z_p^0\right), \ldots, z_p^u\left(N; z_p^0\right)\right).$$

To establish the quantised communication approach, we project the spatial set $[-\bar{x}, \bar{x}] \times [-\bar{y}, \bar{y}]$ into a grid $\mathcal{G} := [0 : a_{\max} - 1] \times [0 : b_{\max} - 1] \subset \mathbb{N}_0^2$ of squared cells such that each cell has a width (and height) c. Hence, we have

$$2\bar{x} = a_{\max} c \qquad \text{and} \qquad 2\bar{y} = b_{\max} c, \tag{4}$$

where $\bar{x}$ and $\bar{y}$ are both multiples of c. To quantise the position of a robot, we utilise the following function:

$$q(z_p) = (a_p, b_p) := \left(\left\lfloor \frac{x_p + \bar{x}}{c} \right\rfloor, \left\lfloor \frac{y_p + \bar{y}}{c} \right\rfloor \right), \tag{5}$$

The obtained quantised position can then be used to assemble a predicted trajectory in $\mathbb{R}^d$ over a horizon length N into a sequence of occupied cells via

$$\mathcal{I}_p(n) := \left(n + k, q\left(z_p^u\left(k; z_p^0\right)\right)\right)_{k=0}^{N}. \tag{6}$$

If a robot receives all sequences of occupied cells, it can construct the so called *occupancy grid*

$$i_p(n) := \left(\mathcal{I}_1(n), \ldots, \mathcal{I}_{p-1}(n), \mathcal{I}_{p+1}(n), \ldots, \mathcal{I}_P(n)\right). \tag{7}$$

If the states are mapped back to $\mathbb{R}^d$, the middle point of a cell is used as approximation for the true position of the robot

$$f_c((n, a, b)) = \underbrace{\left((a + 0.5)c - \bar{x}, (b + 0.5)c - \bar{y}\right)^\top}_{=:(x^c, y^c)}. \tag{8}$$

To derive collision avoidance constraints, we define a function $g_{q,k}^p$ to measure the necessary distance via the infinity norm

$$\begin{aligned} g_{q,k}^p &:= g\left(z_p^u\left(k; z_p^0\right), \mathcal{I}_q(n)(k), \mathcal{I}_q(n)(k-1)\right) \\ &= \left\| \begin{pmatrix} x_p^u\left(k; x_p^0\right) \\ y_p^u\left(k; y_p^0\right) \end{pmatrix} - f_c\left(\mathcal{I}_q(n)(k)\right) \right\|_\infty \geq 0 \end{aligned} \tag{9}$$

Hence, the coupling constraints are given by

$$G(z_p^u\left(k; z_p^0\right), i_p(n)(k), i_p(n)(k-1)) = \left(g_{1,k}^p, \ldots, g_{p-1,k}^p, g_{p+1,k}^p, \ldots, g_{P,k}^p\right) \geq 0. \tag{10}$$

3 Set Characterization

Instead of transmitting a sequence of cells (6), we now characterize the set of the positions of the robots as an interval rectangle, which are denoted by X_p for a robot p. Then, for the quantised set, we obtain

$$q(X_p) = \left\{\min \mathbf{z}_p^{\mathbf{u}}\left(\cdot; z_p^0\right), \max \mathbf{z}_p^{\mathbf{u}}\left(\cdot; z_p^0\right)\right\} \tag{11}$$

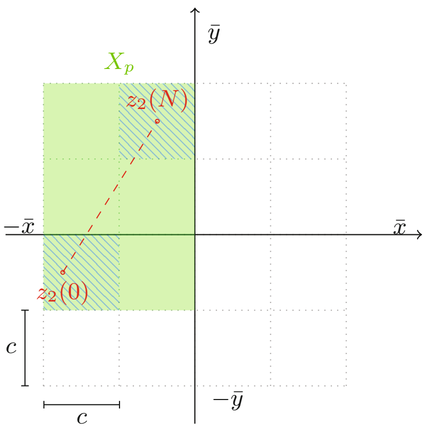

Fig. 1. Example with an occupied set X_p for robot p $a_{\max} = b_{\max} = 4$ with dashed cells for quantisation (11) and reconstruction by Algorithm 1.

by utilising the structure of the infinity norm in (9), cf. Fig. 1 for a sketch.

This allows to reduce communication as only the minimum and maximum cells for each robot are required. To reconstruct then the occupancy grid, Algorithm 1 can be applied.

Algorithm 1. Occupancy grid construction for (robot p) by received occupancy tuples from robots $q \in [1 : P] \backslash p$

Input $q(X_q)$
Set $a_{\min} = \min_a \{q(X_q)\}, a_{\max} = \max_a \{q(X_q)\}, b_{\min} = \min_b \{q(X_q)\}, b_{\max} = \max_b \{q(X_q)\}$
for $a = a_{\min}$ to $a_{\max}$ **do**
    for $b = b_{\min}$ to $b_{\max}$ **do**
        for $k = n$ to $n + N$ **do**
            Append $\mathcal{I}_q(n) := \mathcal{I}_q(n) \cup (k, a, b)$
        end for
    end for
end for
Set $i_p(n)$ according to (7)

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4 Distributed MPC

Each robot $p \in [1 : P]$ is equipped with a controller executing the DMPC algorithm as mentioned in [6]. Following the DMPC scheme, each robot solves in every time instant an optimal control problem over a finite horizon N based on the current state $z_p^0 = z_p(n)$ and received information $i_p^0 := i_p(n)$ by minimising a cost function $\ell_p : Z \times \mathbb{U} \to \mathbb{R}_{\geq 0}$, regarding given individual targets z_p^* and coupling constraints based on (9). This problem reads as follows:

$$\min_{\mathbf{u}_p} J_p^N \left(\mathbf{u}_p; z_p^0, i_p^0\right) := \sum_{k=0}^{N-1} \ell_p \left(z_p^u \left(k; z_p^0\right), u_p\left(k\right)\right) \tag{12}$$

subject to

$$\begin{aligned} z_p^u(k+1; z_p^0) &= f(z_p^u(k; z_p^0), u_p(k)), && k \in [0 : N-1], \\ u_p(k) &\in U, && k \in [0 : N-1], \\ G\left(z_p^u\left(k; z_p^0\right), i_p^0(k), i_p^0(k-1)\right) &\geq 0, && k \in [1 : N], \\ z_p^u\left(k; z_p^0\right) &\in Z, && k \in [1 : N]. \end{aligned}$$

Here, the modifications are concerning the communication. Therefore, the DMPC algorithm itself is given by Algorithm 2.

Algorithm 2. DMPC-algorithm for the overall system

Given feasible initial states z_p^0 for all $p \in [1 : P]$
for $p = 1$ to P **do**
  for $k = 1$ to N **do**
    Construct $\mathcal{I}_p\left(n\right)\left(k\right)$ based on z_p^0 by (7)
  end for
  Construct $q\left(X_p\right)$ by (11)
end for
Communicate $q\left(X_p\right)$ among all robots for all $p \in [1 : P]$.
for time instant $n = 0, 1, \ldots$ **do**
  for robot p from 1 to P **do**
    Receive $q\left(X_q\right)$ and construct $\mathcal{I}_q\left(n\right)$ based on Algorithm 1
    Solve OCP (12) and **Apply** $u_p^*\left(0\right)$
    Broadcast $q\left(X_p\right)$ based on (11)
  end for
end for

Here, we are not using terminal conditions, as this would require a sufficient long prediction horizon to match them, which would be not feasible in a large distributed system. Here, our approach is avoiding terminal conditions based on [1,2]. Regarding feasibility to ensure that the algorithm is not terminating unexpectedly, this is shown in [8].

5 Numerical Simulations

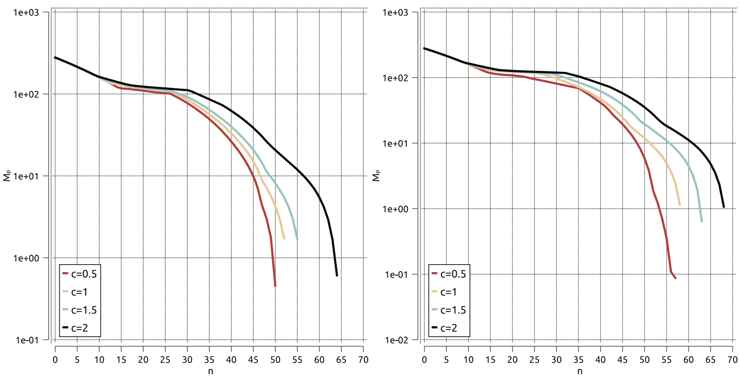
For the simulations, we consider a group of $P = 3$ mobile holonomic robots and set the state constraints $Z := [-6(\mathrm{m}), 6(\mathrm{m})]^2$. Regarding the controls, we set the bounds as $\sqrt{(\bar{v^x})^2 + (\bar{v^y})^2} | \leq 0.5$ (m/s), and $\bar{\nu} \leq 0.5$ (m/s) and $\bar{\omega} \leq 0.5$ (rad/s). Moreover, the minimum distance between the robots $d_{\min} = 0.5 + \varepsilon$ (m) was used, where $0 < \varepsilon \ll 1$ denotes a numerical safety margin. We obtained the minimum cell size $\underline{c} = 0.5$ (m) with $\underline{c} = \max\{\bar{v^x}, \bar{v^y}\} + \varepsilon = \max\{\bar{v}, \bar{\omega}\} + \varepsilon = 0.5(m) + \varepsilon$ based on (15) in [8]. The cell size was chosen as $c \in \{0.5, 1.0, 1.5, 2.0\}$. Simulations were conducted in C++ by utilising the NLOpt-Solver [3] with the gradient-free COBYLA-Algorithm [7]. The closed-loop costs were defined as

$$\ell_p\left(z_p, u_p\right) := \left\| \begin{pmatrix} \left(x_p - x_p^*\right)^2 \\ 5\left(y_p - y_p^*\right) \end{pmatrix} \right\|^2 + 0.2 \left\| u_p \right\|^2 \tag{13}$$

and initial and target positions were chosen as in [8, Table 1]. We investigated the performance of Algorithm 2 in terms of the cumulated closed-loop costs, which we defined for all robots for one time instant n via

$$M_P(n) := \sum_{p=1}^{P} \ell_p\left(z_p^{\mathrm{MPC}}(n), u_p^{\mathrm{MPC}}(n)\right) \tag{14}$$

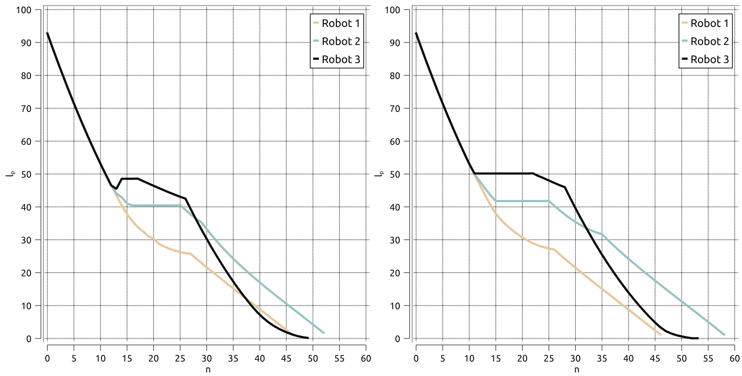
where $u_p^{MPC}(n)$ the applied control signal in Step (5) of Algorithm 2 at time instant n and z_p^{MPC} the resulting closed-loop trajectory. Figure 2 shows the numerical results of both communication schemes. We observe that although the limited communication induces less accuracy, the robots are still capable to arrive at their targets. For larger cell sizes, the difference of the simulation times decreases as larger cells attenuate the difference between the interval scheme and the communication of the prediction.



(a) Differential communication (b) Interval communication

Fig. 2. Development of M_P with $c = \{0.5, 1.0, 1.5, 2.0\}$ and $N = 8$

The comparison for the closed-loop costs for both schemes according to (13) is displayed in Fig. 3. The figure shows that the robots are following a straight



(a) Differential communication (b) Interval communication

Fig. 3. Development of $\ell_p(z_p, u_p)$ for $c = 1.0$ and $N = 8$

line as the transmitted cells constitute box constraints. Nevertheless, for robot 1 the arrival time is still the same, although the box constraints lead to larger detours. Therefore, the order of optimisation plays an important role for the arrival time of each robot.

6 Conclusions

In this paper, we used an DMPC scheme to steer distributed controlled robots to individual targets while the communication is inspired by an set characterization based quantisation. Here, only the minimum and maximum quantisation cells are transmitted. The numerical results show that the set characterization based quantisation and communication has only slight impact on the simulation time while for all investigated cell sizes the system still converges while the communication load is reduced drastically.

This approach should be validated by utilising a variety of feasible initial and target positions to provide a statistical analysis. Further research should investigate theoretical properties, priority rules and adaptations to traffic scenarios.

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Requirements for an Augmented Reality-Based Assistance System

Raising the Safety Level of Mobile Cranes

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Abstract. Commercial vehicles raise the efficiency of work processes in many fields of application. This is in contrast to a comparatively high number of accidents that are often associated with serious personal and property damage. Therefore, this contribution presents an approach to develop an assistance system for mobile cranes that raises the safety level in the working area. By applying Augmented Reality technology, the developed assistance system provides safety-related information directly in the field of vision of the crane operator. In this contribution, the authors present user requirements for the development of such an assistance system. On this basis, trajectories for the user-centered development for an Augmented Reality-based assistance system are revealed in the context of mobile cranes.

1 Introduction

In numerous economic sectors, human-operated commercial vehicles improve the efficiency of work processes. A wide variety of vehicle types are used which carry out their respective tasks with high efficiency, e.g. in the construction industry, in agriculture, forestry or transport. For moving and lifting heavy goods cranes are commonly used equipment. The appropriate installation and utilization of cranes allows more efficient and safer operations (Milazzo et al. 2017). However, in practice a comparatively high number of serious accidents occurs. Due to the severity of accidents in connection with cranes, e.g. falling cranes or loads, these accidents often have fatal consequences (Marquez et al. 2014). By analyzing near-miss and accident reports in relation with cranes, many studies identified human factors, e.g. inadequate training, attention deficits or errors of operator and signal person, apart from technical failures, as an important cause for crane accidents (Shapira and Simcha 2009, Mandal et al. 2015, Raviv et al. 2017). Therefore, approaches for real-time assistance for crane operators were introduced that support the operator directly during the lift (Zhang and Hammad 2012, Fang et al. 2016). Considering the current developments in human-machine-interaction

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technology, Augmented Reality (AR) provides a suitable technology to provide crane operators with work process-related information directly in the field of vision. The main advantages of the utilization of AR in this context are that the crane operator can be provided with safety-relevant information in every viewing direction as well as with context-sensitive information on the current work process, e.g. real-time image from the signal person or sensor-based warning signals due to persons or objects entering the working area.

AR combines real and virtual content, provides interactivity in real time and is registered in 3D (Azuma 1997). Therefore, the technology is well suited for mobile, work-process oriented assistance systems that can provide context-sensitive virtual information without distracting the user. To this end, technological requirements for the utilization of AR technology as well as the requirements of the specific field of application need to be considered (Quandt et al. 2017). On this basis, the authors present an approach for an AR-based assistance system that supports the crane operator in the work process. Therefore, the authors determined requirements for the development of such a system directly from crane operators by executing and analyzing semi-structured expert interviews. Subsequently, we describe the adopted approach for the assistance system design as well as the requirements from practice for the consideration of work processes, control instruments, environmental impacts, work safety and human influence factors.

2 Approach

Based on the described situation, our objective is to develop an assistance system for mobile cranes, which recognizes emerging hazardous situations at an early stage and draws the operator's attention to the danger. To allow the compensation of sensorimotor limitations of older employees, the system development is oriented towards the Design for all concept. This approach ensures the consideration of the requirements of older employees and aims to adapt machine operator workplaces to the requirements of demographic change. The successful implementation of such an assistance system is dependent on real-time capturing of the crane movement and the objects in the immediate environment. Only by providing the current situation in real time the safety level for people and machine can be raised. The information provision for the crane operator needs to be immediate and perceptible, and, at the same time, does not have to distract the operator. Figure 1 shows the mode of operation of the on-the-job assistance system for crane operators.

1. This includes the recording of the work situation by various sensor technologies (ultrasound, cameras, laser scanners, GPS, radar, motion tracker, etc.) which complement each other with regard to their specific abilities. In this way, a reliable and redundant data acquisition can also be carried out in the harsh and dirty working environment of construction areas.
2. This step describes the subsequent fusion of the different sensor data, which leads to a real-time picture of the working situation. This, in turn, is analyzed automatically in order to detect potentially dangerous situations and, in particular, to locate and classify people and objects in the work environment. By monitoring movements of

people and objects before entering the safety-critical area, the probable movement paths are predicted to avoid hazardous situations.

3. If several commercial vehicles are in close proximity to one another, a wireless exchange of relevant data is carried out. That way, the range of the system is increased and possible sources of accidents are eliminated.
4. Finally, the systems forwards all relevant information to the operator and visualizes those by applying AR technologies. The use of AR technologies makes it possible to extend the perceptions of the machine operator without restricting the immediate perception of reality. The real-time capability of the assistance system is the basic technological requirement to fulfill safety regulations and prevent from serious accidents.

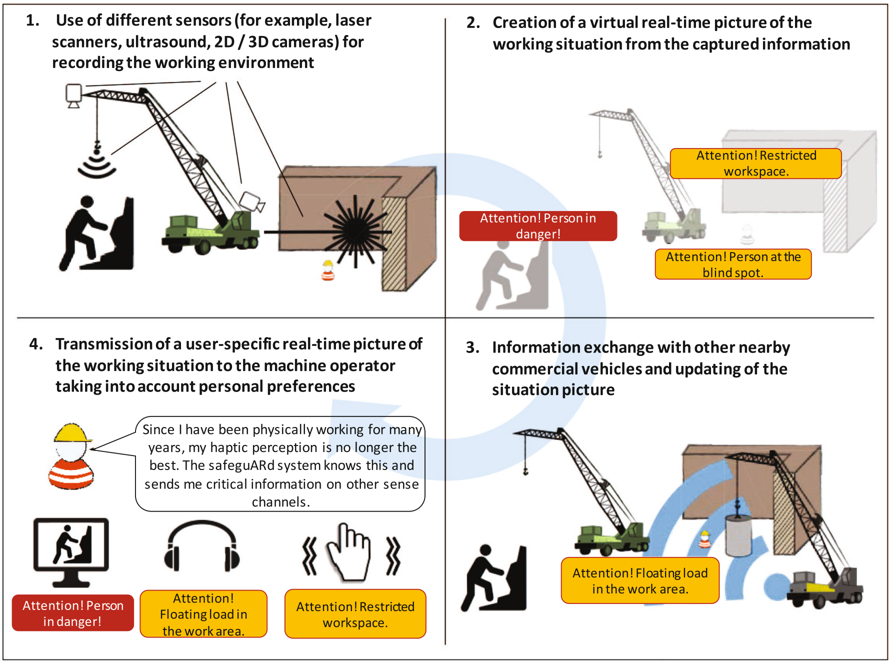

Fig. 1. Crane operator assistance system

3 Assistance System Requirements

For a successful development of the described assistance system, the requirements of mobile cranes, especially of the machine operators and their assistants, have to be considered. Therefore, the authors systematically gathered information from practitioners on work processes and machine related requirements. By analyzing this expert knowledge and the according technical literature, the authors derived the following categories for the identified requirements: work process, control instruments, environmental impacts, work safety and human influence factors.

3.1 Work Process

Work process related requirements for an AR-based assistance system primarily derive from a low degree of standardization of work processes during operation, which can be reasoned by the usual uniqueness and temporariness of construction projects (Al-Humaidi and Hadiprioni Tan 2009). Fundamental process steps for the positioning and preparation of the crane operation are defined usually considering an operational planning, e.g. equipping counterweights and securing the work environment. In contrast, the responsibility for the execution of the crane operation lies with the crane operator or with the assistants that instruct the operator in situations with obstructed vision on the load and for exact positioning of the load. Therefore, an assistance system for this field of application has to be applicable for different crane operations with crane operators and assistants as well as individual workflows during operation.

3.2 Control Instruments

Current mobile cranes offer various control instruments and visualizations of the most relevant parameters for crane operation. The manufacturers individually equip the operator cabins according to the customer´s requirements. Besides the basic control instruments that show information that is prescribed by law, e.g. maximum load capacity, current utilization or radius of the crane, several optional displays can provide e.g. a rear view from a camera or a view of the winch. Currently the design of crane cabins and instruments is based on specific experience of crane manufacturers and historical guidelines. However, the interaction of crane operators with control instruments does not fulfill objective criteria regarding ergonomics and safety (Spasojevic Brkic et al. 2015). As a consequence the demand of a controlled provision of additional information in the field of view of the crane operator should be investigated to avoid distraction during crane operation.

3.3 Environmental Impacts

For crane operations, the environmental conditions are non-controllable. Weather conditions or soil conditions can directly affect the operations (Al-Humaidi and Hadiprioni Tan 2009). In the context of the development of an AR-based assistance system, particular attention should be paid to lighting conditions to ensure the visibility of projected virtual content (Dini and Dalle Mura 2015). In this case, the lighting conditions are relevant for the machine operator in the operator cabin as well as for the assistants in the area of the load. The operators cabin is protected against solar radiation by special glazing, the area of the load can be as well outdoors or indoors. For the use of acoustical signals, the sound volume of the crane during operation and other sources of noise emissions in the work environment have to be considered.

3.4 Work Safety

Work safety regulations for the operation of mobile cranes do not exclude the utilization of AR hardware in the work environment. Automated methods for the observation of work areas on construction sites regarding hazardous situations are ascribed great potential to foster the development of safety engineering and management practices (Teizer and Cheng 2015). There are several regulations that do not have an immediate effect on the used hardware, e.g. safeguarding the work area. Regulations for work clothes have to be considered that include the obligation for assistants to wear a safety helmet. Therefore, the selected AR hardware needs to be integrated in the existing equipment.

3.5 Human Influence Factors/User Interface

The manufacturers meet the continual technical development of mobile cranes by simple and intuitive user interfaces. In many countries, crane operators need no special qualification to operate cranes apart from a short briefing on specific crane models. Furthermore, human factors play an important role as a cause of hazardous situations due to the different understanding of hazardous situations of crane operators and their assistants (Nævestad 2008). To date the requirements of older employees are not particularly considered. Therefore, an AR based assistance system in this field application has to be developed with significant participation of crane operators of all age groups to meet the requirements of future users and raise the safety level for all user groups.

4 Conclusion and Outlook

In this contribution, we provide an approach and empirical collected requirements for an assistance system for crane operators. The initial motivation are findings of accidents with cranes that often lead to severe personal and material damage. Crane operators are the cause for many of these accidents. Therefore, a support of crane operators is very helpful to raise the safety level of crane operations. Hence, a technical support in the area of human-machine cooperation is a promising approach. Based on this motivation, we have presented an approach for an assistance system based on AR technology. For this assistance system, we have provided empirically determined requirements. Therefore, it can be stated that the requirements of practitioners confirm the need of assistance systems that support a rising standardization of work processes and improve the safety level of crane operations. However, the challenges for the development of an AR assistance system in this context are the consideration of the requirements of all age groups of crane operators as well as the provision of additional virtual information without distracting or overextending the operator. Further research involves the determination of ethical, legal and social aspects and further development of the whole concept in the sense of Design for all.

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Evaluation of the Performance of Heuristic Algorithms in an Intersection Scenario

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Abstract. Autonomous vehicles are gaining more and more interest, as from the logistic perspective, transportation costs may be reduced and safety increased, if the underlying techniques and algorithms are capable to handle such complex scenarios. In this paper, we consider an intersection scenario with autonomous connected vehicles that cross an intersection without any central control or traffic lights. The intersection as the operation space is discretised into a set of equidistant cells. Therefore, to avoid collisions, the vehicles reserve cell indices which are communicated in each time instant. We evaluate analytical and heuristic path planning algorithms to measure the performance criteria in simulations with respect to system aspects, i.e. execution time and memory consumption, and solution quality.

1 Introduction

Recently, coordination of autonomous connected vehicles has become a large research field [6], as they are promising lower costs for transportation and may increase safety aspects due to possible smaller reaction times [9]. Ensuring safety aspects and adoption to a high dynamic environment, it is mandatory that respective algorithms are capable of providing a solution in appropriate time (real-time capability) and also regarding memory consumptions [4]. These requirements become an issue as no central entity is available in such a distributed scenario, which is capable to provide a solution in short time. Instead, the problem is divided into subproblems where each vehicle is considered as a multi-agent to solve the path planning regarding a given individual objective with respect to local and global constraints like speed limits or collision avoidance, respectively [7,12]. Nevertheless, appropriate algorithms have to be chosen to handle such complex scenarios in appropriate small time intervals and to ensure collision avoidance. To support the decisions, we evaluate for an intersection scenario different path-planning algorithms.

Path planning algorithms may be categorised into analytic or heuristic based methods. Moreover, one could distinguish static and dynamic algorithms, where the latter allow recalculation at runtime due to dynamic changes. Here, we will

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focus on performance criteria only. Many path-planning algorithms are utilising a graph model as data structure. A street system or connection between cities can be easily adapted into a system of nodes representing the cities and edges symbolising the streets. Mostly, directed graphs are used to account for constraints while the edges introduce costs to model travel distance or time effort. For analytical approaches, Dijkstra's algorithm or the algorithm from Floyd-Warshall are widespread methods [1,2]. Both are deterministic and static, i.e. the path is planned for the full problem until the target is found. The solution is always deterministic and optimal. Unfortunately, runtime is directly proportional to the number of vertexes, which renders these approaches intractable in real–time. To overcome these limits, many heuristic algorithms were proposed. While the respective solution is not always optimal, it may be calculated in shorter time. Algorithms using such techniques, are A^* as a static algorithm or $D^\star$ as an dynamic representative incorporating environmental changes and allowing incremental updates [3,5].

In this paper, we consider a quantised intersection, revealing a grid, which is crossed by autonomous connected vehicles, see [11]. The states are projected on this grid, see [8], revealing a graph structure to allow the applicability of path planning algorithms. Considering that the calculations are performed by the agents itself, certain criteria are necessary to judge the performance of such algorithms. As embedded systems may be limited in computational capability and memory, we include these aspects in our case study.

Notation: We abbreviate a set $\{0, 1, \cdots N\}$ with $[0 : N]$ and define for a vector $x \in \mathbb{R}^n$, $n \in \mathbb{N}$ the infinity norm $\|x\|_\infty := \max_{i\in[1:n]} |x_i|$.

2 Problem Setting

In this model, we utilise P vehicles following a time-discrete dynamics

$$z_p^+ = f(z_p, u_p) \tag{1}$$

where $z_p \in Z \subset \mathbb{R}^r$ is the state of vehicle p and $u_p \in U$ the imposed control, where $U \subset \mathbb{R}^d$ with d, r as positive integers. Here, we utilise a holonomic model which leads to

$$z_p^+ = \begin{pmatrix} x_p \\ y_p \end{pmatrix} + \begin{pmatrix} 1 \\ 0 \end{pmatrix} u^x + \begin{pmatrix} 0 \\ 1 \end{pmatrix} u^y, \tag{2}$$

where u^x and u^y are the imposed control in each dimension and constraint by

$$u_p = \begin{pmatrix} u^x \\ u^y \end{pmatrix}, \|u_p\| \leq \bar{u}, \bar{u} \geq 0.$$

Then, a trajectory containing the resulting states by the applied control with finite length N is defined as

$$\mathbf{z}_p^{\mathbf{u}}(\cdot; z_p^0) := \left(z_p^u(0; z_p^0), z_p^u(1; z_p^0), \ldots, z_p^u(N; z_p^0)\right). \tag{3}$$

Here, we quantise the operation space Z into a grid of equidistant cells with $[0, 1, \ldots, a_{\max}] \times [0, 1, \ldots, b_{\max}] \in \mathcal{G}$ to simplify the conversion of the intersection into a directed graph. The bounds of the spatial set $\bar{x}, \bar{y}$ are chosen such that $2\bar{x} = ca_{\max}$ and $2\bar{y} = cb_{\max}$ hold respectively, where c defines the size of each cell. The cell index is then given by

$$q = (a_p, b_p) := \left(\left\lceil \frac{x_p + \bar{x}}{c} \right\rceil, \left\lceil \frac{y_p + \bar{y}}{c} \right\rceil \right).$$

Then, for each given time instant n, the vehicles are broadcasting the reserved cells over a finite horizon N with

$$\mathcal{I}_p(n) = (n + k, a_p, b_p)_{k \in [1:N]}$$

to all other vehicles. The received information $\mathcal{I}_q(n)$ from vehicles q with $q \in P \backslash \{P\}$ is then used to enforce collision avoidance given by

$$\mathcal{I}_p(n) \cup \mathcal{I}_q(n) = \emptyset, \qquad \forall q \in \{P\} \backslash p$$

For each vehicle, an individual start $z_p^0 \in Z$ and target position $z_p^* \in Z$ is given. To ensure that the vehicles cannot skip a cell, a minimum cell size $c \geq \underline{c}$ is introduced in accordance with [8]:

$$\| q(z_p(n)) - q(z_p(n-1)) \|_\infty \leq 1.$$

In other terms, this property is known as Moore's neighbourhood [10]. Regarding a cost function $\ell_p : \mathcal{G} \times U \to \mathbb{R}_{\geq 0}$ judging the distance from the current state to the target, each vehicle is performing the following algorithm:

Algorithm 1. Algorithm performed by each vehicle

Given admissible, initial states z_p^0 for all $p \in [1:P]$
for $p = 1$ to P **do**
  Set $\mathcal{I}_p(0)(0) := \left(0, q\left(z_p^0\right)\right)$
  Broadcast $\mathcal{I}_p(0)$
end for
for $n = 0, 1, \ldots$ **do**
  for $p = 1$ to P **do**
    Measure $z_p(n)$
    if $n = 0$ **then**
      Receive $\mathcal{I}_q(n)(0)$ for $q \in [1:P] \setminus \{p\}$
    else
      Receive $\mathcal{I}_q(n)$ for $q \in [1:p-1]$ and $\mathcal{I}_q(n-1)$ for $q \in [p+1:P]$
      Assemble $\mathcal{I}_q(n)$, $q \in [p+1:P]$,
    end if
    Calculate feasible trajectory (3) according to the applied algorithm
    Broadcast $\mathcal{I}_p(n)$
    Apply $u_p(0)$
  end for
end for

Based on the chosen algorithm, either the full path (e.g. Dijkstra) is calculated or only a finite horizon (D*), but in all cases, only the first value of the solution is applied. This setting allows us to apply each path planning algorithm based on a graph structure. Here, we chose Dijkstra (analytic-based), $A^\star$ and D^*-Lite (both heuristic-based) to analyse their performance.

To evaluate performance, we considered the computational time for one vehicle until a valid solution is provided, the full execution time $n_\#$ and the memory consumption. Regarding the solution, we also considered the fastest arrival time of a vehicle $n^*_{min} := \min_{z^*_p} \left\{ z_p(n) = z^*_p \right\}$. Furthermore, we included the waiting time for the vehicles, which represents an indicator for the number of stops induced by the method.

3 Simulations

Considering the vehicle model (2) and an intersection setting with $Z = [-6, 6]\, m$, we quantised the latter into a grid with equidistant cells of size $c = 1.0$. The controls are bounded by $\bar{u} = 1.0$ and the cars have to cross the intersection except two cars which are placed in the middle of the intersection to enforce replanning. We measured the computational time by taking into account full calculation and assignment of a solution, i.e. Algorithm 1 between lines 8 and 16, cf. Fig. 1 for each algorithm for each vehicle. The full simulation time $n_\#$ involves the entire simulation, and results are shown in Fig. 2. For both measurements, the mean of 20 runs was taken. The results show that Dijkstra requires more computational time as compared to the heuristic approaches $D^\star$ and $A^\star$, which show improved performance even for quite small scenarios. Regarding the full simulation time, in both settings (4 and 8 vehicles), the analytical approach with Dijkstra demands more computational time. The values are quite narrow, as the scenario is small, but the growing tendency is apparent considering the 8 vehicles setting. In any case, the bottleneck of Dijkstra's algorithm is due the full exploration of the graph.

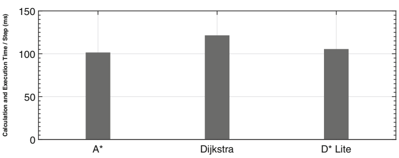

Fig. 1. Computational time (ms) for one vehicle

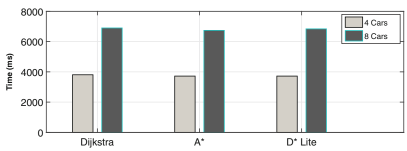

Fig. 2. Simulation execution time (ms)

For memory consumption purposes, the results are depicted in Fig. 3. Here, the differences between 4 and 8 vehicles were quite close, that is, why the results for 4 vehicles were skipped. Again, for Dijkstra the full exploration consumes more memory. For $D^\star$, the memory consumption is slightly higher. The reason for this behaviour is given by duplication of nodes if a replanning is necessary to avoid collisions. As the other algorithms are static and planning beforehand, this does not occur for those. Here, we considered replanning more closely and observed that these actions were only necessary in the first and second step of the scenario with 8 vehicles, cf. Fig. 4.

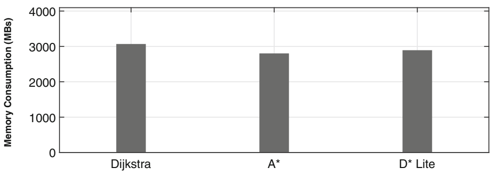

Fig. 3. Memory consumption in MBytes

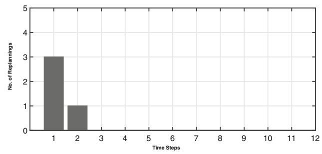

Fig. 4. Replanning counts for $D^{\star}$ for 8 vehicles

Considering the waiting time and minimal arriving time, the results are shown in Figs. 5 and 6. Although $D^{\star}$ induces one waiting time step more for the scenario of 8 vehicles, the minimal arriving time shows that the solution quality is identical for all algorithms.

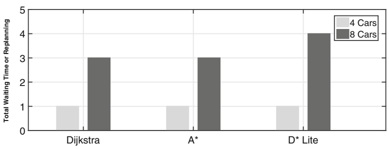

Fig. 5. Waiting time

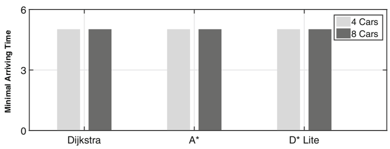

Fig. 6. Minimal arriving time

Summarising, we can conclude that for our case study the quality of the solution of analytical and heuristic algorithms is almost identical. Regarding system performance aspects, e.g. memory consumption and computational time, however, the heuristic algorithms are slightly superior.

4 Conclusions

In this paper, we evaluated analytical and heuristic path-planning algorithms for a small intersection scenario with autonomous, connected vehicles using a multi-agent approach. The applied algorithms on a quantised spatial set were evaluated using several performance criteria regarding quality of the solution (execution time, waiting time and fastest arrival) and system-specific criteria (memory consumption, computational time). The results indicate, that also in small scenarios heuristic algorithms are superior considering calculation time and memory consumption. For sufficiently small scenarios and available computational power, however, analytical algorithms should be revisited to gain insight into possible thresholds between these approaches.

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Big Data Analytics: A Case Study of Public Opinion Towards the Adoption of Driverless Cars

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Abstract. With the growth of textual data and the simultaneous advancements in Text Analytics enabling the exploitation of this huge amount of unstructured data, companies are provided with the opportunity to tap into the previously hidden knowledge. However, how to use this valuable source, still is not unveiled for various domains, such as also for the transportation sector. Accordingly, this research aims at examining the potential of textual data in transportation. For this purpose, a case study was designed on public opinion towards the adoption of driverless cars. This case study was framed together with the Danish road directorate, which is, in this case, the problem owner. Traditionally, public opinion is often captured by means of surveys. However, this paper provides demonstrations in which public opinion towards the adoption of driverless cars is examined through the exploitation of newspaper articles and tweets using topic modelling, document classification and sentiment analysis. These analyses have for instance shown that Text Analytics may be a supplementary tool to surveys, since they may extract additional knowledge which may not be captured through the application of surveys. In this case, the Danish Road Directorate can use these result to supplement their strategies and expectations towards the adoption of driverless cars by incorporating the public's opinion more carefully.

1 Introduction

The objective of this research is to assess the potential of textual data in transportation. For this purpose, a case study approach was designed in which the public opinion on the adoption of driverless cars, which is seen as one current challenge of the Danish road directorate, the problem owner, is examined. This case study is seen as highly relevant, since an adequate adoption of driverless cars may have a huge impact in logistics and the supply chain industry. Warehousing operations, outdoor logistics operations, autonomous loading and transport or the last mile delivery are only some examples of the potential of driverless cars (DHL 2014). The Danish transportation sector faces a range

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of challenges in the future with more cars on the roads, expected growth in congestion levels and increasing demands, from both companies and the public, for improved mobility (Regioner 2017). Additionally, the automation of transportation is also expected to grow, creating new demand patterns as well as opportunities for increased efficiency. Thus, adequately forecasting this future, including the expectations towards and adoption of driverless cars is a key priority.

2 Methodology

As the main method for conducting this research, a case study approach was selected since this approach is often used for explanatory investigations in which the variables are still unknown and the phenomenon not completely understood (Meredith 1998).

In the first phase, the adoption of driverless cars was framed as the initial problem together with the chief consultant from the Danish Road Directorate as the problem owner in an explorative meeting. Moreover, newspaper articles and Twitter have been selected as two relevant sources of examination. In the second phase, two analysis streams have been followed. Firstly, public opinion on driverless cars in the Danish newspaper coverage was examined. For this purpose, a data set including 1338 articles was generated using a Danish media database and topic modeling was selected as a suitable text mining technique in order to extract the main topics discussed in the context of driverless cars. The text pre-processing was conducted using the KNIME analytics platform version 3.3.1, following similar steps as employed in prior studies (Guo et al. 2017; Pereira et al. 2013; Tirunillai and Tellis 2014). Subsequently, the Latent Dirichlet Allocation (LDA) (Blei et al. 2003) algorithm was employed to extract topics from the articles. Secondly, public opinion on driverless cars on Twitter has been examined using a sample of 157.000 tweets which were collected in the period between the 1st of December 2016 and the 1st of April 2017 using the official Twitter API searching for tweets. The pre-processing of the tweets was carried out using KNIME. Following the pre-processing, sentiment analysis was applied, in order to scrutinize and evaluate the way people are tweeting about different themes in the context of driverless cars. For the sentiment analysis, the SentiStrenght software and sentiment lexicons were used (http://sentistrength.wlv.ac.uk; Thelwall et al. 2010). In addition, document classification on the tweets was conducted, following the same dictionary-based approach as for the newspapers.

In the last phase, the findings of the study have been evaluated and validated through a feedback session carried out with the problem owner. For this purpose, five experts working on the adoption of driverless cars for the road directorate have been involved in the interviews.

3 Empirical Findings on Public Opinion on Driverless Cars Identified Through Text Analytics

Demonstration 1: Topic Modeling of Newspapers

One of the problems which is found in the outline of knowledge above is that they rely on surveys wherein the researcher defines pre-set questions and categories based on their understanding of the problem. Topic modeling as an unsupervised clustering algorithm enables exploring concerns and benefits of the public, without a prior input. Table 1 illustrates the outcome of the topic modeling.

Table 1. Topic modeling output - word clusters.

Topic name	Keywords (translated to English)
1. Labour market effects	Artificial, intelligence, companies, jobs, robots, data, humans, technology, future
2. Technology description	Steering wheel, sensors, camera, automatic, systems, traffic, driver, automatic, driving
3. Technology testing	Road, municipality, collaboration, project, testing, trials, vehicles, producers, bill
4. Traffic and congestion	Traffic, space, congestion, roads, future, transport, world, technology
5. Unassignable	World, system, design, section, reality, billions, Copenhagen, photo, internet

Topic 1 and Topic 4, labour market effects and traffic and congestion, are considered as more interesting topics in contrast to topics 2 and 3, as these relate to some of the effects and impacts which driverless cars might have. The occurrence of these two topics indicates that in the context of driverless cars there is an interest in how their adoption will influence jobs and the labour market, and also whether they will lead to more or less congestion.

Demonstration 2: Document Classification and Sentiment Analysis of Tweets

Document classification and sentiment analysis have been conducted on the tweets, which offered an in-depth assessment of the themes as volumes indicate importance and sentiment scores indicate how concerned or beneficial a topic is being perceived. Table 2 summarises the number of tweets per category and their corresponding sentiment scores.

Comparing the importance derived from the tweets with those of the newspapers in Denmark, the four most important categories (congestion, labour market, legal liability, safety) are found to be the same which underpins the reliability of the findings. For assessing the sentiments of the tweets, the sentiment analysis is conducted on the level of the topics, and not on the aggregated level of the tweets, since on the aggregated level the scores do not add much benefit to the analysis. Though, by tracking the scores for the classified tweets it is possible to derive the sentiment of the public for specific themes.

Table 2. Number of tweets classified and average sentiment per topic

Topic	Topic volume	Sentiment score
Labour market	4098	−0,59
Safety	4065	0,00
Congestion	1716	−0,18
Legal Liability	998	−1,03
Hacking	790	−0,84
Environmental impact	189	0,03
Privacy	83	−0,04
Misuse (Terror)	42	−1,19

4 Conclusion

The objective of this paper was to assess the potential of textual data in transportation. For this purpose, a case study on public opinion towards driverless cars was conducted. The described demonstrations have presented three ways in which Text Analytics can be used to generate knowledge about public opinion. Firstly, topic modeling can be used to identify the key topics of a text corpus, secondly, document classification can be used to categorize the documents based on which topic they are concerning. Lastly, it is demonstrated how sentiment analysis can be applied to assess the affective state of a text and, thus, evaluate how the sender feels about the topic which they are discussing.

The analysis of the Danish newspapers shows that safety and congestion are the two most important topics but additionally labour market effects also stand out as an important topic. The analysis of the tweets illustrates a similar picture with safety, labour market and congestion as the most important topics. In contrast to the existing literature on public opinion about driverless cars the analysis of the tweets and the newspaper illustrate all a somewhat different picture of the public attitude towards driverless cars. The finding that especially stands out in this regard is, that throughout the analyses labour market effects are found to be a significant concern for the public, but it is only found to be a concern in the survey conducted by König and Neumayr (2017).

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Airships as a Possible Logistic Solution for the Transport of Special and Bulk Loads

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Abstract. The advent of new technologies has brought new opportunities and challenges due to the complexity and growth of the solutions. Increasingly large equipment needs to be installed in increasingly remote and displaced locations from increasingly congested industrial centers. These challenges have led to studies in areas of knowledge that were dormant, such as the potential of using "lighter than air" aircraft for cargo transportation. Airships have characteristics that could be used to transport special and bulky cargoes, for example, wind turbine generators. This article evaluates in a conceptual and qualitative way the use of airships as an alternative means of transport for special and bulky loads.

Keywords: Airships · Special and bulky loads · Logistics

1 Introduction

The implementation of a wind farm or communication tower installations (examples of special loads) requires a chain of studies, such as economic and technical feasibility based on wind speed and terrain resistance, on project deployment, transportation, assembly and maintenance of parts (Gouveia 2011). Special and bulky loads have dimensions or weights that exceed those determined by law for inland transportation. They may also present physical and operational characteristics that make safety difficult (Campos and Rissardo 1987). Depending on the location of the facility (such as in mountainous areas), the transportation of heavy loads and equipment can make the project costly or even unfeasible. The roads are built with infrastructure delimited for volume and weight of loads. Special situations require the use of special vehicles operating under special conditions and, in certain cases, also specific works to adjust the roads and access to an adequate safety margin (Gouveia 2011). This article presents airships as an alternative for the transport of special and bulky loads in difficult to reach situations. The analysis was done in a conceptual and qualitative way and the logistic budget of a wind farm built in Marmeleiro, Paraná, Brazil, was used as the basis (EIA 2015).

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2 The Resurgence of Airships

"Lighter than air" aircraft revolutionized technology in the early twentieth century. The great German Zeppelins were prominent in intercontinental transport and also as war reinforcement in both the First and Second World War (Machry 2005). However, the Giant Age of Heaven ended in 1937 with the fire of the Hindenburg, while flying over New Jersey, USA. Its use was restricted afterwards to secondary uses, such as the Good Year models used for advertising.

The use of the lighter-than-air vehicle for cargo transport was resumed in 1996 with the Cargolifter CL 160 design in Germany. The CL 160 model would need 1m3 of helium to lift every kilogram transported, while conventional jet aircraft burn a kg/km of fuel for each kilogram transported. The project would have payload capacity of 160 tons, reach of ten thousand km between origin and destination, cruise speed of 135 km/h in cruise regime at two thousand meters of altitude, fuel consumption at 100 km/h at 2,000 m altitude was 4.5 l/km. It was a relevant and innovative proposal, but the lack of financial resources made the project unfeasible in 2002 (Gomes and Mignon 2012).

Years after the discontinuation of the Cargolifter project, some companies resume the study of airships for various activities, including cargo transportation. In Brazil, Airship of Brazil carried out the inaugural flight of the ADB 3-X01 model on July 24, 2017, with a load capacity of 1.2 tons. The airship can reach 85 km / h with an autonomy of five hours. It is 49 m long and has a height of 17 m. The same Airship develops the ADB 3-30, cargo airship with capacity of 30 tons, 330 m3, 125 km / h and customizable autonomy. (Airship do Brasil, 2017)

Lockheed Martin in the United States develops the LMH-1 s, a hybrid airship (engine propulsion and partial airborne support for a gas lighter than air) scheduled to launch in 2018. The model can carry 19 passengers and cargo capacity from 21 tons to 111 km/h. It is the first of a family of hybrid leaders planned for the next 20 years. In 2006 the company had already performed a demonstrator flight with the P-791 (Norris 2016).

The SkyCat 220 and 220-ton lines belonging to the Advanced Technologies Group had great potential to the market, however, its assets were acquired by the English HAV (Hybrid Air Vehicles) in 2007. The SkyCat 220 had a payload capacity of 220 tonnes, maximum cruise speed of 176 km/h and 148 km/h, cruising altitude of 1,981 m and maximum range of 5,973 km. The HAV has evolved with new prototypes such as the Airlander 10 (a previous model re-release) and Airlander 50, payload of 50 tons, can be used for surveillance and also heavy lifting (QNB 2017), (Prentice and Knotts 2014), (World SkyCat 2017).

3 Applicability of Airships

The airship is faster than maritime modalities, road and rail, and much more economical in terms of fuel consumption and maintenance than conventional airships (Stockbridge et al. 2012).

Airships require smaller and less sophisticated infrastructure supports than other modes. They basically require anchoring and gas supply systems. Its vertical take-off and landing (VTOL) skills eliminate the need for large teams and maneuver infrastructure, such as fixed-wing aircraft, which still require airports with an extensive runway (Knotts and Prentice 2014).

Point-to-point vehicle configuration allows significant time reduction. The idea of picking up the cargo at the origin and transporting it to the final destination without the need for another modal for support is at least of great value for market gains (Pereira 2011). The dispensing of large landing structures without the need for prior preparation or the installation of ballast equipment and mooring towers, which can land on almost all types of terrain, makes it easy to reach remote areas that are difficult to reach. Care must be taken only to have clear areas of buildings, fences or dense trees that hinder the approach, anchorage and spawning of the load (Gomes and Mignon 2012).

Machry (2005) affirms that "For airplanes, airships have the advantage of not requiring large amounts of fuel to lift cargo to cruising altitude. In airships, what sustains weight is the physical property of buoyancy of the helium gas. The engines will only be used to drive horizontal shifts".

The resurgence of airships comes as the balance between rapid transportation and lower tax rates. The model has several market niches, vigilance and monitoring, rescue, emergency, fire-fighting and general, heavy, perishable and indivisible loads (Pereira 2011).

Airships can be an interesting alternative for the transport of special and bulky cargoes in situations of difficult access, reducing the logistics costs for this type of transport.

The transport of wind components is used in this article as a case study of special and voluminous loads, as this technology gains space on a world scale. The example becomes more representative when one considers that Brazil has a large deficit of logistics infrastructure, with problems such as long lines of trucks and ships in ports, high freight prices, poor road and railroad conditions, rare waterway and congestion of the air sector, with consequences in the increase of the costs with fuel and maintenance, that are transferred to the final price of the freight (PBLog 2013).

At the National Wind Energy Forum, held in 2013, the Brazilian Association of Machinery and Equipment Industry pointed out a perspective of 1,154 wind turbines that can be installed in 2018, a significant increase compared to 2017, according to Table 1 (Abimaq 2013).

Table 1. Travel numbers of trucks

Year	Increased power (MW)	Number of wind turbines	Number of truck trips
2015	2.549	1.275	12.746
2016	1.597	798	7.983
2017	625	313	3.127
2018	2.309	1.154	11.544
Total	7.080	3.540	35.400

For a check simulation of how many trips would be necessary for dirigible, the model used by Queiroz Galvão was an example, see Table 2 (Gueiroz Galvão, 2017).

Table 2. Components of a wind turbine

Component	Weight/ton	Length/m
Tower T1	58	11
T2	67	20
T3	72	27
T4	52	31
Total	249	89
Nacelle	84	*
Hub	56	*
Shovels (3)	24	60
Total	413	*

With the values in Table 1, in the year 2018, the transportation of one wind turbine by the modal route would require 10 trips.

The use of an airship in this case would reduce the amount of travel. Using as an example the information of the aforementioned SkyCat 220, it would take 2 trips to transport 1 wind turbine, due to its load capacity being 220 tons. The transport division could assume according to Table 2, the following scheme, T1, T2 and Nacele that sum a total of 209 tons and T3, T4, hub and shovels that has the sum of 204.

4 Case Study

The Environmental Impact Study of the Rosa dos Ventos Wind Farm I, II, III, estimated that the construction of the three projects would be R$ 376,274,420.00. 77% of the costs correspond to equipment and this equipment are described Transport is the second highest item in Table 3. The dirigibles would present a viable option to move the components.

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Table 3. Cost to equipments

Discriminatory	UN.	QNT.	Unit cost (R$)	Total cost
ALSTOM supply - 2.7 MW	uni	32,00	8.075.000,00	258.400.000,00
Transport	uni	32,00	475.000,00	15.200.000,00
Assembly	uni	32,00	237.500,00	7.600.000,00
Comissioning	uni	32,00	237.500,00	7.600.000,00
Total				288.800.000,00

The wind turbine model used to estimate the cost of the wind farm was Alstom's Eco 122. The rotor has a diameter of 122 m and a fiberglass blade of 59.3 m. 119 m (aerogenerator shaft) has a weight of 110 kg at the top tower (EIA 2015).

The rotor is produced in the Alstom unit of Camaçari, and the location of the Wind Farm is in Marmeleiro, Paraná. Using the SkyCat 220 information, a new transport value was obtained in Table 4.

Table 4. Cost to equipments - Airship

Discriminatory	UN.	QNT.	Unit cost (R$)	Total custo
ALSTOM supply - 2.7 MW	uni	32,00	8.075.000,00	258.400.000,00
Airship transport	uni	16,00	873.425,44	13.974.807,04
Assembly	uni	32,00	237.500,00	7.600.000,00
Comissioning	uni	32,00	237.500,00	7.600.000,00
Total				287.574.807,04

There was a significant reduction of R $ 1,225,192.96 in transportation with airships. Note that in the number of wind turbines has been reduced from 32 to 16, because the amount of load of the vehicle is 220 tons and the weight of wind component is 110 tons, in a trip it is possible to transport 2 wind turbines. In addition to the reduction in value, a significant reduction in the transport time of the wind components can also be achieved.

For the formulation of the unit cost was used, the data of Table 5 (World SkyCar 2017).

Table 5. Total costs – SkyCat 220

Total costs R$ - base of 4.500 h of flight	
Year (MUs$ 28,6–31,9) – R$	100.804.000,00
Flight/hour (Us$ 6.350–7.090) – R$	22.404,4
ton/km (Us$ 0,19–0,21) – R$	0,67

The airship has a cruising speed of 148 km/h, the distance traveled was approximately 2,885, 6 km, so the journey time was approximately 20 h. And the cost ton/km was obtained by (1 $\times$ distance traveled $\times$ cost ton/km $\times$ weight of the load). The unit cost of flight hour was R $ 448,088.00 and the cost per ton/km was R$ 425,337.44.

5 Conclusion

Using airships in the transport of special and bulky cargoes can bring significant reductions in both cost reduction and transport time. The vehicle's load capacity and flight autonomy may favor market gains. The results presented in Table 3 are expressive gains and that can also interfere in the construction of access routes. It is worth noting that the proposal is not to substitute modalities for airships, but to present as a possible solution in places of precarious and difficult access infrastructure, for example, the Amazon. Dirigibles do not require airstrips and can remain in the air for long periods of time and as they operate point to point so many costs can be avoided and regions that have logistical gaps and hamper development. This reduction means greater competitiveness for the transport industry. In addition, the return on investment in wind farm construction is faster, given the reduction in the time required to carry all the parts.

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Advanced Modeling Techniques

Predictive Control of a Job Shop System with RMTs Using Equilibrium Terminal Constraints

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Abstract. In manufacturing, capacity adjustment is one of the major effective measures to cope with demand fluctuations and machine breakdown. We propose a model predictive control (MPC) scheme to utilize the new type of reconfigurable machine tools (RMTs) for adjusting capacities within a job shop system. Our aim is to maintain a desired work in process (WIP) level and show stability of closed loop scheme by imposing equilibrium terminal conditions.

Keywords: Capacity adjustment · RMT · Stability · MPC

1 Introduction

Nowadays, manufacturers are confronted with the challenge to react to demand and market fluctuations quickly and effectively. This tendency renders the manufacturing processes to be more complex and dynamic [1]. To counteract the resulting performance degradation, capacity adjustment is one of the major effective tools [2]. Here, even a small modification during a high load period is sufficient to make a significant improvement in performance [3].

Typically, the capacity adjustment is done by purchasing new equipment, employing temporary workers, extending the working times, etc., which are all comparably expensive [4]. Here, however, we utilize the new type of reconfigure machine tools (RMTs) to balance capacities and loads. These machine tools are designed for a customized range of operation requirements, combining the advantages of high productivity of dedicated machine tools (DMTs) with high flexibility of flexible machine tools (FMTs). In particular, these tools are capable of adjusting capacity and functionality to meet product variety and production volume after a short reconfiguration time [5]. This flexibility can be exploited best within manufacturing systems with high product diversity at small lot sizes, which is the case, e.g., for job shop systems [2]. Focusing on this type of system,

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we study the impact of RMTs and respective control methods on performance measures of such systems. As job shop systems may suffer from high work in process (WIP) levels and therefore unreliable due dates and long lead times within production network [6,7], we follow the approach from [8] to directly control the WIP level by adapting the number of RMTs within the workstations separately. To this end, we impose a model predictive control (MPC) scheme to improve capacities and loads and show stability of the MPC closed loop by imposing equilibrium terminal conditions.

The remainder of this paper is organized as follows: The problem definition is given in Sect. 2. Thereafter, the basic MPC algorithm with equilibrium terminal conditions will be introduced in Sect. 3. In Sect. 4, an illustrative example of a job shop system with RMTs and DMTs is investigated and simulation results are presented. Last, conclusion and future research directions are presented in Sect. 5.

Notation: Throughout this work we denote the natural numbers including zero by $\mathbb{N}_0$ and the nonnegative reals by $\mathbb{R}_{\geq 0}$. The Euclidean norm is denoted by $\|\cdot\|$. Furthermore, we call a continuous function $\gamma : \mathbb{R}_{\geq 0} \to \mathbb{R}_{\geq 0}$ of class $\mathcal{K}_\infty$ if it is zero at zero, strictly increasing and unbounded. Similarly, a continuous function $\beta : \mathbb{R}_{\geq 0} \times \mathbb{N}_0 \to \mathbb{R}_{\geq 0}$ is said to be of class $\mathcal{KL}$ if for each $n \geq 0$ it satisfies $\beta(\cdot, n) \in \mathcal{K}_\infty$ and for each $r > 0$ it is strictly decreasing in its second argument with $\lim_{n\to\infty} \beta(r, n) = 0$.

2 Problem Definition

Job shop manufacturing systems provide a high flexibility in conjunction with cross-link information and multi-directional flow. These properties are beneficial for often changing products but may lead to bottlenecks in one or multiple machines or workstations. These bottlenecks, in turn, will cause high work in process (WIP), long lead time, low machine utilization, and low due date reliability for the whole system [9]. Here, we specifically focus on the operational layer, i.e. the sequence of orders to be processed is assumed to be fixed.

Instead of releasing orders earlier, which may destabilize the system [10], we utilize capacity adjustment to eliminate or periodically shift bottlenecks within the process. Here, we consider machinery–based capacity adjustment via RMTs, i.e. we adapt the number of RMTs assigned to specific tasks on the shop floor. As the WIP level is essential for all key performance indicators [11], we propose to control the WIP level directly. Hence, our aim is to allocate the RMTs within the job shop such that a certain WIP level is tracked.

Within this paper, we consider a simple flow model of a job shop system with n^{WS} workstations. The job shop is given by a fully connected graph $\mathcal{G} = (V, P)$, where the set of vertexes $V = \{1, \ldots, n^{WS}\}$ represents the workstations and P the flow probability matrix between the workstations. Each of the workstations features n^{DMT} DMTs, which are operating with production rate r^{DMT}. The number of RMTs is controlled by our input variable u and each RMT may operate with production rate r^{RMT}. Combined, the dynamics in the job shop system is given by

$$
\begin{aligned}
x(n+1) &= f(x(n), u(n), d(n)) && (1)\\
&= x(n) + P \cdot \left(n^{DMT} r^{DMT} + u(n) r^{RMT}\right) + d(n). && (2)
\end{aligned}
$$

Here, $x = (x_1, \ldots, x_{n^{WS}}) \in \mathbb{X} \subset X$ represents the WIP level of all workstations, $u = (u_1, \ldots, u_{n^{WS}}) \in \mathbb{U} \subset U$ denotes the vector of RMTs assigned to all workstations, and $d(n)$ represents the order input rates to the workstations. To incorporate possible constraints on the WIP level and the number of RMTs, we utilize the set notation $\mathbb{X}$ and $\mathbb{U}$ and call a state feasible if $x \in \mathbb{X}$ and a control $u \in \mathbb{U}$ admissible if $f(x, u, d) \in \mathbb{X}$ holds.

Our aim in this paper is to ensure that the WIP level x_j in each workstation $j \in V$ is asymptotically stabilizing a predefined reference value x_j^*, that is:

Definition 1. *Suppose a system (1) and a control $u(\cdot)$ to be given such there exists a forward invariant set $Y \subset \mathbb{X}$. If there exists function $\beta \in \mathcal{KL}$ such that*

$$\|x(n) - x^*\| \leq \beta(\|x_0 - x^*\|, n)$$

holds for all $x_0 \in Y$ and all $n \in \mathbb{N}_0$, then control $u(\cdot)$ is said to be asymptotically stabilizing.

In order to be stabilizable, we assume that for $x^* \in \mathbb{X}$ there exists $u^* \in \mathbb{U}$ such that $f(x^*, u^*) = x^*$.

3 Model Predictive Control

To achieve the goal of asymptotic stability, we propose to utilize a model predictive controller (MPC). The idea of using the latter is to approximate the solution of the infinite horizon optimal control problem

$$J_\infty(x_0, u) = \sum_{k=0}^{\infty} \ell(x(k), u(k))$$

subject to the dynamics (2) and constraints $x \in \mathbb{X}$, $u \in \mathbb{U}$. Here, we assume that the stage cost $\ell : X \times U \to \mathbb{R}_{\geq 0}$ satisfies $\ell(x^*, u^*) = 0$. Since this optimal control problem is typically computationally intractable, MPC approximates the respective solution via a three step procedure, cf. Algorithm 1: After obtaining the current state of the system, a truncated optimal problem with finite prediction horizon is solved to obtain a corresponding optimal control sequence. Then, only the first element of this sequence is applied and the prediction horizon is shifted, which renders the method to be iteratively applicable. Then computationally complex part is the solution of the truncated problems

$$
\begin{aligned}
\min J_N(x_0, u) &= \sum_{k=0}^{N-1} \ell(x(k), u(k)) && (3)\\
\text{subject to} \quad & x(k+1) = f(x(k), u(k), d(k)), \quad x(0) = x_0\\
& x(k) \in \mathbb{X},\ u(k) \in \mathbb{U}\ \forall k \in \{0, \ldots, N\}
\end{aligned}
$$

required in the second step of Algorithm 1. For simplicity of exposition we assume that a minimizer $u_\star(\cdot)$ of (3) is unique.

Algorithm 1. Basic Model Predictive Control Method

1: **Given** $N \in \mathbb{N}$.
2: **for** $n = 0, \dots$ **do**
3: Measure current WIP levels $x(n)$ and set $x_0 := x(n)$
4: Compute control inputs $u(n)$ by solving optimal control problem (3)
5: Apply $\kappa_N(x(n)) = u_\star(0)$ to workstations
6: **end for**

Yet still, optimality in each iteration is not sufficient to guarantee stability in the sense of Definition 1. From [12, Theorem 5.13], however, we obtain that we can utilize the optimal value function $V_N(x_0) = J_N(x_0, u_\star)$ to state the following:

Theorem 1. *Consider Algorithm 1 for the optimal control problem (3) with prediction horizon $N \in \mathbb{N}$ and the additional terminal condition $x(N) = x^*$. If there exist functions α_1, α_2 and $\alpha_3 \in \mathcal{K}_\infty$ such that*

$$\alpha_1(\|x - x^*\|) \le V_N(x) \le \alpha_2(\|x - x^*\|)$$
$$\alpha_3(\|x - x^*\|) \le \inf_{u \in \mathbb{U}} \ell(x, u)$$

holds, then κ_N is asymptotically stabilizing.

Given our dynamics (2), we can show the following:

Corollary 1. *Given system (2) and stage costs*

$$\ell(x(k), u(k)) = \|x(k) - x^*\|_2^2 + 0.1 \cdot \|u(k) - u^*\|_2^2, \tag{4}$$

the result of Theorem 1 holds with

$$\alpha_1(s) = \alpha_3(s) = s^2 \tag{5}$$
$$\alpha_2(s) = (1 + 0.1\|\Phi_1\|_2^2 + \|\theta_1\|_2^2 + 0.1\|\theta_3\|_2^2)s^2 \tag{6}$$

where

$$\Phi_1 = (2r_{RMT}^2 P^\top P)^{-1}(-2P^\top r^{RMT} + \frac{0.2P^{-1}}{r^{RMT}})$$
$$\theta_1 = 1 + r^{RMT} P\Phi_1$$
$$\theta_3 = \frac{P^{-1} + r^{RMT}\Phi_1}{r^{RMT}}$$

and the MPC feedback is asymptotically stabilizing.

To complement and check our theoretical findings, we next consider a numerical example to illustrate our results.

4 Case Study

Within this section, we consider the multi workstation system sketched in Fig. 1.

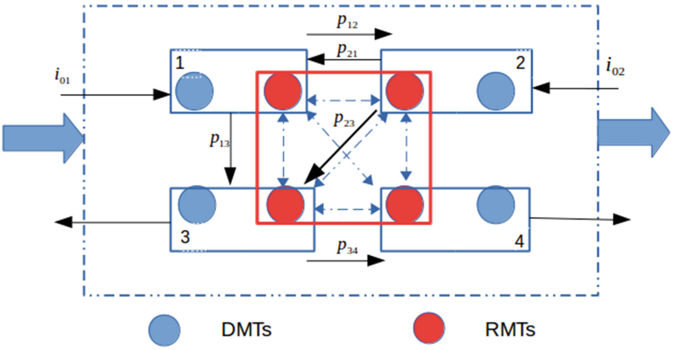

Fig. 1. Multi workstation multi product job shop system

The respective dynamics are given by (2) with parameters and initial values according to Table 1 as well as flow matrix and external input rates

$$P = \begin{bmatrix} -1 & 0.5 & 0 & 0 \\ 0.4 & -1 & 0 & 0 \\ 0.6 & 0.5 & -1 & 0 \\ 0 & 0 & 0.4 & -1 \end{bmatrix} \quad \text{and} \quad d(n) = \begin{bmatrix} i_{01}(n) \\ i_{02}(n) \\ 0 \\ 0 \end{bmatrix}$$

where

$$i_{01}(n) = \begin{cases} 10 + 3|\sin(0.1\pi n)|, & 20 < n \leq 30 \\ 10, & \text{else} \end{cases}$$
$$i_{02} = 6.$$

Table 1. The variables definition in the job shop system

Variable	Description
$x(0) = [40\ 40\ 40\ 30]^\top$	Work in process (WIP) level
$r^{DMT} = 3$	Production rate of DMT
$r^{RMT} = 2$	Production rate of RMT
$n^{DMT} = [5\ 4\ 5\ 2]^\top$	Number of DMTs for each workstation
$u = [2\ 1\ 2\ 1]^\top$	Number of RMTs for each workstation
$m = 6$	Maximum value of RMTs in system
$x^* = [25, 22, 25, 16]^\top$	Planned work in process (WIP)

Moreover, the target state x^* was chosen to satisfy our standing assumptions from Sect. 2.

Then, our goal is to steer the WIP level of each workstation to the desired value x^* while considering the state and control constraints

$$x(N) = \{x^*\}, \quad 0 \leq u_j(n) \quad \text{And} \quad \sum_{j=1}^{4} u_j(n) \leq m$$

To this end, we imposed the stage cost function (4), which satisfies the assumptions from Sect. 3 with

$$u^* = \frac{-P^{-1} \cdot d - \mathbf{1} \cdot n^{DMT} \cdot r^{DMT}}{r^{RMT}}.$$

In order to increase the basin of attraction and guarantee a large feasible sets, we chose $N = 16$ and obtain the simulation results sketched in Figs. 2 and 3. As expected in Fig. 2 we observe that the proposed method is capable of tracking the desired WIP value for each workstation along with the dynamic allocation of RMTs (see Fig. 3).

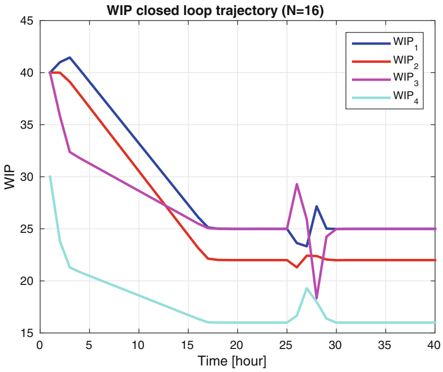

Fig. 2. Variations of WIP level

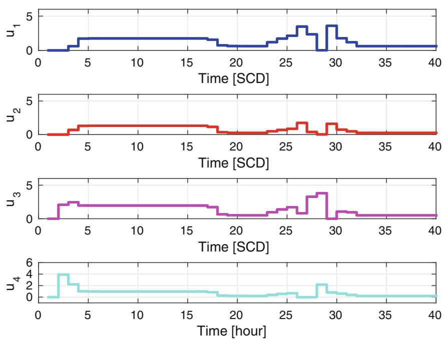

Fig. 3. Number of RMTs

5 Conclusion and Outlook

We have shown that RMTs effectively allow adjustment in capacity and functionality of a job shop system to cope with manufacturing process uncertainties concerning varying product quantities and types. To this end, we considered the WIP levels for each workstation, which we controlled by reallocating RMTs using MPC. Moreover, we showed asymptotic stability of closed loop for MPC with equilibrium terminal conditions.

The current case study represents a proof of concept, which we will extend to incorporate reconfiguration delays and transportation times as well as integer programming methods for the assignment of RMTs. It will be able to provide a guideline for manufacturers regarding the determination of the reconfigured RMTs to make the best decision for achieving respective control goals. Moreover, the proposed controller will be compared to other techniques such as PID.

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Economic and Social Advances for Geospatial Data Use in Vehicle Routing

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Abstract. Big data applications in transportation and logistics are much discussed before the background of mainly economic improvement potential. For the area of road cargo transportation, this contribution is discussing the use of geospatial data in truck routing especially in the context of autonomous driving and social sustainability concepts. Fleet management and cruise control systems have been established during the last decade in road transportation. However, the stationary vehicle routing before the actual travelled tour is subject only to planning and optimization based on a quite low level of information. For example, geospatial data regarding topography as well as speed limitations and trajectory as well as street elevation and bend characteristics are currently not used but have significant impact on truck speed, fuel consumption and driver workload. Therefore, a conceptual outline as well as a quantitative test simulation for applying geospatial big data in ex ante vehicle routing is provided. This does encompass obvious advantages in economic (reduced transport cost), environmental (reduced transport emissions) as well as social dimensions (reduced driver workload and working time). Further inquiries shall address detailed question as to how geospatial big data could be integrated into the daily routine and processes of vehicle routing in road transportation.

Keywords: Vehicle routing · Geospatial data · ex ante routing
Social sustainability · Driver workload · Autonomous driving

1 Introduction

Road cargo transportation is a cornerstone of land transportation, modern logistics and supply chains since the innovation of the wheel in ancient times. In most countries, vehicles on surface roads handle more than half of cargo transportation: For example, 54.7% in Bulgaria, 71.5% in Germany, 72.6% in Finland, 74.4% in Poland and 99.0% in Ireland (shares per ton kilometers for 2015); the EU-28 average resides with 74.9% – all data according to Eurostat (2017). Together with long-distance global sea shipping, road transport can be termed a backbone of logistics management: Without trucks most sourcing, production as well as distribution business models would not be feasible also under the restrictions of increased sustainability concerns as expressed by the future term of "co-modality" (Dalla Chiara and Pellicelli 2016; Pasaoglu et al. 2016; Zijm and

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Klumpp 2016; Zhu et al. 2014; Verma and Verter 2010). Trucks and road transportation do provide a high flexibility and cost-efficiency for logistics tasks; with specific sectors such as parcel delivery, just-in-time delivery for production as well as shipping small items in e-commerce settings, trucks are essential and cannot be replaced in an economically sound manner as indicated for example by Caballini et al. (2016), Abdallah et al. (2015), Nossack and Pesch (2013), or Wang and Yun (2013). Furthermore, high improvement potential is expected for the innovation areas of Physical Internet (PI) and autonomous driving concepts, though also risks may be involved (Klumpp 2017; Meyer et al. 2017; Pham and Jeon 2016; Kalra and Paddick 2016; Levin and Boyles 2016; Rodriguez-Castano et al. 2016; Talebpour and Mahmassani 2016). Research regarding success factors for the road transport mode is of importance to logistics practice. This contribution specifically looks into the question of using big data for truck vehicle routing problems. As automated truck transportation is at the doorstep (Koo et al. 2015; Weyer et al. 2015), this question is also of heightened attention especially in combination with questions of ageing and demographic change. In between rising transport volumes, ageing, and declining numbers of drivers, there is a dire need for improvement e.g. with human resource management instruments, leadership innovation as well as route optimization in order to mitigate cost and workload burdens by drivers themselves (Königs and Gijselaers 2015; Hasanefendic et al. 2015; Nuzzolo and Comi 2014; Verstrepen et al. 2009; Wu and Huang 2013). Therefore, also possible applications of geospatial data concepts have been explored, e.g. in the context and application area of road toll systems (De Jong et al. 2016; Vanoutrive 2016; Agarwal and Mo Koo 2016). This is linked especially to the mission to reduce carbon emissions from road transportation as outlined by De Gennaro et al. (2016). Regarding sustainability objectives, technological developments (Pasaoglu et al. 2016; Alises and Vasallo 2015) as well as the strategic problem of rebound effects have to be taken into account (Chai et al. 2016; Klumpp 2016). Rebounding indicates that though initially a decrease in e.g. carbon emissions can be achieved for example by route optimization or technological innovations (propulsion systems, efficiency enhancements), long-term emissions even increase as the gained efficiency leads to strong demand and usage increases in this case for road transportation. The specific research question regarding the conceptual area of future vehicle routing applications – connected to the core mission of logistics regarding competitive advantage (Kasarda 2017) – is:

- RQ: *How can an application of geospatial data to ex ante vehicle routing be conceptualized in order to improve the economic and/or social competitiveness of actors in the supply chain?*

Such analysis endeavors are connected to the developments regarding digitalization and the physical internet and industry 4.0 concepts. Obviously, datasets, data bases and applications are at the core of those developments, too (Montreuil et al. 2012; Montreuil 2011). The contribution is structured as follows: After this introduction, the second section outlines the specific research question and research method regarding the use of geospatial data in road route scheduling. Section three describes the simulation results for the selected example transport within Germany. Section four provides a detailed discussion for these results, touching restrictions and possible implications. Section five finally outlines conclusions and feasible further research questions.

2 Research Question and Research Method

2.1 Research Question for Geospatial Data Applications in Vehicle Routing

This second section addresses the question of how to quantitatively prove the existence of advantages in using geospatial data in vehicle routing. In order to achieve this, the question is put more specifically in a typical cargo transport context for a single transport mission: 20 tons of general cargo[1] have to be transported as a hypothetical task from the Port of Duisburg (address: Alte Ruhrorter Straße 42–52, 47119 Duisburg, Germany; GPS coordinates: 51° 27′ 9″ N, 6° 45′ 36″ E; altitude above sea level: 32 m) to Frankfurt Airport (ICAO-Code: EDDF; IATA-Code: FRA; Airportring, 60549 Frankfurt am Main, Germany; GPS coordinates 50° 2′ 0″ N, 8° 34′ 14″ E; altitude above sea level: 100 m). This transport task is very typical as the Port of Duisburg with a cargo transshipment volume of 12 million tons of freight annually is the largest European inland port and on the other hand Frankfurt Airport with a freight transshipment of 2.1 million tons is the largest cargo airport in Europe and the eight largest freight airport worldwide (Airports Council International 2017). Furthermore, typical transport routes of goods e.g. from Asia or America to the European market involve sea shipping into the ports of Amsterdam, Rotterdam or Antwerp (“ARA ports”), a short sea shipping trip to Duisburg (containerized) and further distribution of smaller cargo shipments (pallets, packages) via road, rail or air transport within the European free market. So for example this example shipment from Duisburg to Frankfurt for further European distribution via air cargo within Europe fulfills the typical scheme of distribution goods in the European market, e.g. electronics, fashion or healthcare products.

2.2 Research Method Simulation

As a research method, a simulated calculation of different transport routes is applied. The following routes are compared, also using geospatial data on route specifics:

(1) Standard google maps routing for road traffic without any further information (motorway number “A3”).
(2) Deviation routing (e.g. congestion on main road motorway A3) via A 45.
(3) Deviation routing via A 61.

The basic input data are perceived for a standard cargo truck, in this case a Mercedes long-haul tractor-trailer truck with the following characteristics (Mercedes-Benz 2017):

- Production Code: 963426 W5W F1M M3D M5M C1J V1W V1A V2A M5B

[1] No dangerous goods, no extreme volumes or other specifics, just standard cargo good as e.g. electronics and other fast moving consumer goods (FMCG), palletized for a dry cargo shipment on a truck trailer.

- Emission Class: Euro VI, with OBD-C
- Truck Cabin: L/ClassicSpace, 2,30 m, Level Ground
- Axle Distance: 3250 mm
- Motor type: OM471
- Motor volume [l]: 12,80
- Power [kW(PS)]: 375 (510)
- Torque [Nm]: 2500
- Transmission: G 281-12/14, 93-1,0
- Transmission rate i = 3,077
- Brake System: Disk Brake on Front and Rear Axis, with ABS & ASR
- Battery: 2 × 12 V/220 Ah
- Fuel tank: 290 l, left side, 650 × 700 × 750 mm
- AdBlue tank: 60 l, left side

This example truck also features the typical objective difference problem between optimized consumption on the one hand and power on the other hand. This leads to the situation where especially steep climbs or other driving situations (accelerating etc.) with the need for top power output are worsening the sustainability and emissions situation significantly.

3 Results and Limitations

3.1 Calculation Results

The following results are obtained regarding the required transport from Duisburg to Frankfurt. The specific calculation was focused on the relevant questions of “bend” and “steepness” of the three alternate routes (motorways) between Duisburg (inland port) and Frankfurt (airport) as these influence speed, fuel consumption as well as driver workload in a similar manner as the purely length (kilometers) of the routes. In comparison to this approach, standard navigation and route planning tools today only use distance in order to optimize route selection.

As results in Table 1 show, the two alternatives to the main A3 route (usually travelled but also frequently clogged with roadbuilding and congestion events), the A45 and A61 routes represent such a good example for route choice depending on the available data: As the A45 route would be *shorter* (264 km versus 291 km for A61), standard route planning software today would select the A45 route in case the main A3 route is not available (dynamic scheduling). On the other hand, the A45 alternative is significantly *steeper* with a total of 177 km with more than 1% increase versus only 137 km on the A61 alternative. For very steep sections with more than 5% – which requires heavy downshifting and therefore fuel consumption increase as well as workload for the driver – the difference is even higher with 29 km for A45 and only 15 km for A61, nearly double the length of very steep segments. In addition, there are more bend sections, which also may induce downshifting and therefore an increase in consumption as well as driver workload. Depending on motor characteristics (less power and torque than exemplified here) this may also lead to a decrease in travel time as the travel speed is lowered significantly during steep road segments depending on the gross weight of the vehicle. Therefore, a more enhanced geospatial data-based route planning algorithm could select the longer but less steep and with less bend sections applied route 3 (A61) in order to reduce fuel consumption as well as driver workload. This is at the same time a good example and proof that geospatial data i.e. on road characteristics may well be a very good benefit for route scheduling in road transportation.

Table 1. Calculation results for three routes DU-FFM

Route	Route kilometer	Bend sections[a]	Bend kilometer	Steep km (>1%)	Steep km (>3%)	Steep km (>5%)
1 (A 3)	247.62	33	15.99	134.717	46.525	13.081
2 (A45)	264.08	60	31.01	177.265	78.038	28.939
3 (A61)	291.13	50	27.92	137.297	52.412	15.387

[a]The applied calculation software always segmented the total route in 512 sections for calculation. Therefore, total length of individual sections is different for each route.

3.2 Method and Data Limitations

The implemented calculation is a one-time calculation for one single transport route in Germany. Therefore, several limitations apply as to the use and further interpretation of the data. It has to be kept in mind that the objective for the calculation was a "proof of concept" for the application of geospatial data in route planning for road transportation. Data was obtained from public sources in the internet regarding the map and geospatial data as well as routing and truck data. With possible more detailed data, especially regarding topographic conditions, the analysis could be implemented even deeper with more specific results. Furthermore, the applied calculation was restricted to the use of segmentation-based calculation software for route planning (i.e. using 512 sections of all three analyzed routes); this is also highly influencing calculation results, a smaller or larger segmentation may derive different results. This has to be evaluated and adjusted in future calculations. But nevertheless, even this first calculation draft has shown a possible conceptual superiority of route planning with enhanced geospatial data concerning routes travelled.

4 Discussion

4.1 Implications Regarding the Economic Cost Situation in Road Transportation

It has been exemplified that additional geospatial data regarding i.e. topographical characteristics of road tracks may enhance the accuracy of route calculations, especially in a dynamic setting regarding deviations for i.e. congestion situations on main roads.

This in turn may result in significant cost saving potential, as currently only travelled distance is taken into account for the main route planning tools. As i.e. fuel consumption for trucks is heavily dependent on further road characteristics and in especially the steepness angles, such data shall well be included in route planning in order to optimize the total cost situation. As shown in the example above, todays route planning algorithms may have selected the shorter but steeper second route (A45), which could have led to an increased fuel consumption due to steeper road segments compared to alternative No 3 (A61).

4.2 Implications Regarding the Sustainability Perspective Regarding Truck Emissions

Again, additional data on road characteristics enables the route planning to involve height level data – which in turn allows combined with specific truck propulsion data to determine possible excess consumption of diesel by trucks for different deviation routes. Compared to the current situation where only the mileage of different routings is taken into account, the error reduction may well be in the range of about 10–20%. As shown in the calculation example here, in deciding for specific routings as well as alternative routings in case of congestion and roadwork, the question of steepness and connected to that also fuel consumption of truck transportation is very important. This is a commonplace question in the logistics sector with a high relevance for many corporations and truck driver employees in the sector. Furthermore, selection less steep routings may also enable trucking companies to downsize their propulsion and power inventories of trucks; in the past, the trend was to increase motor volumes for increased power and torque outputs (i.e. from 280 to 420 to more than 500 PS powertrains in trucks). However, in the future given the ability to select less steep routes for the trucks, companies may well decide to use cost as well as environmental saving potentials by using less powerful trucks in combination with less steep routings. This would enable them to save costs (less costly propulsion systems and trucks) as well as emissions from the travelled routes.

4.3 Implications Regarding the Social Dimension of Truck Driver Workload and Stress

Obviously, geospatial data allows for a completely new dimension of measuring driver workload in truck driving. As known previously, different road characteristics put different sorts and levels of stress and workload on the professional driver i.e. in a truck. For example, steep road stretches with frequent gear shifting (if not done by automated systems as ‘predictive, GPS-based cruise control systems’) are representing a higher workload than normal even driving, be it on the motorway or on country roads. Therefore, in the following Table 2, a first draft for a grading scheme is suggested with 7 different categories and providing a scoring system from 1 to 5 points regarding the workload level of a given stretch of road (calculated by kilometer). This could be implemented into an automated rout planning system based on geospatial data for all roads in a given area. Furthermore, this would then provide an option to calculate driver workload beforehand while planning and comparing possible routings.

Table 2. Suggested driving workload scheme with geospatial data

No	Driving operation	Workload points per km
1	Normal driving on motorways	1
2	Steep climb[a] driving on motorways (shifting, overtaking etc.)	2
3	Normal driving on country roads	2
4	Steep climb driving on country roads (shifting)	3
5	City[b] driving with traffic lights	3
6	Steep climb or downturn driving with strong bends on narrow country roads, potentially low bridges etc.	4
7	Driving and navigating within factory or pedestrian zones	5

[a]E.g. with a road angle of more than 3%.

[b]Within city limits of a town with more than 5,000 inhabitants.

The classification may start with a normal drive on a motorway stretch, representing one workload point. Additional workload is represented by the two subsequent classes of "steep climbing driving on motorways" (No 2) or "normal driving on country roads" with 2 points in the measurement scheme. Steep climb driving on country roads and city driving represent 3 workload points per kilometer. The highest workload with 4 and 5 points are represented by "steep climb or downturn[2] driving with strong bends on narrow country roads" and "driving and navigating within factory grounds or pedestrian zones" as here the attentional and coordination requirements for drivers are usually at the highest.

Such a classification in combination with the above outlined data application in route planning may enable route planning software to measure diver workload in advance and take this into account for route evaluation and selection.

5 Conclusion

This contribution has shown quantitatively the possible advantages of a use of geospatial data regarding truck transportation routing and road dispatching. There are categories of cost, sustainability as well as social advantages in terms or reduced workload for truck drivers to be identified. This leads to the concept of a balanced triple bottom line approach for forwarders and logistics service providers (Klumpp 2017), as well as a future importance of especially social and security dimensions in road transport (Anund et al. 2017; Nowakowski et al. 2015; Ohlson and Osvalder 2015; Meech and Parreira 2011).

In addition, this is closely connected to the question of autonomy in truck driving as with increase automation and support systems, among other reasons, as the requirements for drivers will change dramatically – up to the point where new tasks and additional processes for drivers "in situ" are envisaged. This implies that the selected routes and

[2] It has to be kept in mind that downturn stretches are stressful because they represent a personal danger to the driver in terms of accidents due to not sufficient or malfunctioning brakes, therefore heavy downshifting is required.

streets travelled are not too complicated and a diver "override" is not necessary too often. Otherwise, the proposed alternative occupations and tasks for drivers would not be feasible as duration of application and awareness by drivers are not sufficient enough to complete the tasks or the number of tasks required.

Further research could address for example the questions of linkages to e.g. further dispatcher and truck driver training (e.g. in line with Todorova et al. 2016) as well as the further calculation of sustainability improvements compared to the current situation (e.g. emissions simulation and reduction based on existing simulation models like Valverde et al. 2016 or Zhang et al. 2016).

Finally, it can be stated that the field of data applications in transportation and especially in road cargo transportation is of high importance due to the large transportation mode share, the large number of people and businesses involved (more than 3 million truck drivers in the US, 3.5 in the European Union) as well as the large economic, social and environmental impacts of this specific sector.

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Applying Process Mining in Manufacturing and Logistic for Large Transaction Data

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Abstract. Process mining is a promising approach to extract actual business processes form event logs. However, process mining algorithms often result in unstructured and unclear process models. Moreover, sufficient data quality is required for accurate interpretation. Therefore, adopting process mining for the field of manufacturing and logistics should take into account the complexity and dynamics as well as the heterogeneous data sources and the quality of event data. Therefore, the objective of this work is to study the application of process mining in the manufacturing and logistics domain with real data from manufacturing companies. We propose a methodology to improve the limitations of process mining by using a Markov chain as a sequence clustering technique in the data preprocessing step and apply heuristic mining to extract the business process models. Finally, we provide results from an experiment with real-world data in which we successfully improve the quality of discovered process model in the regards of replay fitness dimension.

Keywords: Process mining · Clustering process model
Manufacturing · Logistics

1 Introduction

Business processes in manufacturing and logistics are characterized by a high degree of complexity and dynamics. The causes of complexity are manifold, such as complexity of the products themselves, the high number of participants in business processes, and unforeseen events. Moreover, the business processes have to be adapted over time according to the structural changes that impact the execution of the original business processes. As a result, improving business processes efficiency is utmost important. Thus, enterprises strive to improve and manage business processes to stay competitive in the market.

To improve business process performance, knowledge is a major factor [1]. A good understanding of the existing business processes is vital their successful implementation and also for future process improvement. Knowledge leads to

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solutions for solving problems, learning, and the creation of core competencies [2]. Furthermore, a proper understanding enables organizations to provide better automated support for their business processes in terms of flexibility [3,4].

A promising way to get insight in existing business processes is process mining. It is associated with business process management, business process analysis, business process improvement, and knowledge management. It has been successfully deployed in many domains for process analysis and discovery, such as health care, software development, and education. In manufacturing and logistics, process mining has been deployed in several works as a part of broader studies. For example, process mining has been used as an input for decision making in business process management [5,6]. Another work focuses on applying process mining as a service to improve business process performance [7].

However, these works do not intend to identify and study the application of process mining in the manufacturing and logistics domain. Even though process mining is an efficient approach assuming that all necessary data is available and well structured, there are some issues in reality that need to be considered. Processes in manufacturing and logistics are subject to frequent changes and tend to be less structured. The reasons are short product life cycles, a high number of involved companies, and fragmented processes due to frequent handover of goods. Consequently, one of the particular problems is the quality of the event logs. It is required to have sufficient data quality for mining, which is usually not the case for manufacturing and logistics event logs. The main reasons are: (1) data are semi-structured or unstructured because the event data are not collected from a process-aware system, but rather for completely different purposes, such as billing or tracking of goods. (2) Different pieces of data describing the same process exist in diverse formats due to the high number of parties involved, who all maintain their own, proprietary databases. (3) The amount of data is very large, because in the light of digitization in industry, data is collected by many entities (e.g. machines, storage facilities, transport equipment). With regard to these challenges, very few works have studied process mining with actual event logs and a large volume of data which overwhelms the traditional data analysis and makes it more difficult to conduct data analysis effectively. Therefore, a large amount of data needs new methodologies to explore and automatically discover knowledge.

As a result, the goal of this work is to study the application of process mining in the manufacturing and logistics domain. This work focuses on process discovery, which is the extraction of process models from raw data and also the most known and common application within process mining. We propose a methodology to improve the performance of traditional process mining which delivers poor results when applied to complex and unstructured event data. A Markov chain is applied as a sequence clustering technique for the data preprocessing step to reduce the complexity of the process data. Subsequently, the heuristics mining algorithm is used for conducting process discovery to present the general behavior of business processes. We experiment in our study with real-world event data from manufacturing companies. Finally, we compare our methodology with traditional process mining by measuring replay fitness, one of the well-known indicators to validate the quality of discovered process models.

2 Background and Related Works

2.1 Business Process Discovery

Understanding the actual processes in a dynamic environment can effectively assist in reducing risks, creating strategic advantages, and improving processes. In theory, companies first plan and design their processes before they implement them. However, in reality, a proper process design is either not happening or companies work with legacy processes, which have never been documented. Therefore, acquiring insight knowledge of actual processes is vital for fulfilling business goals. The knowledge can be acquired from a large amount of data which is generated from systems and software. Process discovery is a useful approach for discovering real business processes. In traditional process analysis and design, process models are developed from a top-down representation of predefined process models and are afterwards implemented in reality. Business discovery is the bottom-up approach. It is an automated construction of processes from the actual processes. In the modern business, such business activities or events are recorded by information systems and make it possible to analyze these logs. Process discovery extracts knowledge from these event logs.

Event logs are a set of process executions capturing business process activities [8]. An event log may contain activities information such as resources (i.e. persons or machines), start time, and end time [8]. Generally, all event log records also carry a case id, which is used to specify process instances [8]. This case id can be a manufacturing order, a sales order, a customer id, etc. The event logs contain records with ordinal as well as nominal attributes. Furthermore, additional information can be extracted from the logs. This information can be, e.g., the number of events per case, unique events, unique paths, the similarity among cases, process variants, and the performance of different activities. Therefore, the event logs can be the start point of process discovery and analysis. For several years, great effort has been devoted to the studies of developing new process modeling and process automation techniques. However, only few works have been done in the area of process discovery and analysis, particularly with large amounts of data.

2.2 Process Mining

Process mining is a research discipline associated with machine learning and data mining. The process mining applications are discovery and analysis of business processes to improve the actual processes by extracting knowledge from event logs [8]. Event logs are generated from many sources such as enterprise resource planning (ERP) systems, manufacturing execution systems, or workflow systems. Process mining uses event logs to conduct three type of process mining:

(1) process discovery, (2) conformance checking, and (3) process enhancement. A discovery technique is used to produce process models from event logs without a-priori information [8]. For example, the α-algorithm is able to construct Petri nets from event logs without additional knowledge about the processes. The second type is conformance checking. The purpose of this type is to confirm the modeled process with the actual observed (mined) process [8]. It can be used to detect, locate, and explain deviations. For example, the analysis of events can determine potential fraud by measuring the alignment between specified model and reality [8]. The third type of process mining is process enhancement. The aim of this type is to improve business processes. It can be done in various ways such as altering process models, adding new perspectives to a process model to be better reflect the reality. It can be used to show bottlenecks, service levels, throughput times, and frequencies [8].

2.3 Related Works

The application of process mining in manufacturing and logistics has been addressed in research, but it has never been fully elaborated so far. In the work of Becker et al., the authors propose a Process Maintenance System by applying process mining to continuously update process models in an automated fashion [7]. The study combines the proposed process maintenance system with the application of process mining to constantly update process model and check for business processes changes in highly dynamic logistics processes [7]. The result of the study shows that process mining is capable of process discovery in manufacturing and logistics systems. The authors suggest that it is considerable to apply numerous heterogeneous data sources from real world processes. In a subsequent work, Becker et al. [9] test clustering methods to group similar process instances. They apply k-medoids clustering with different similarity measures to enhance the process mining approach.

Enhancing process discovery and analysis has been given the attention with regard to managing unstructured data and complex process. Wang deployed process mining for the analysis of logistics process at a Chinese port in a case study [10]. The applied methodologies covered event log extraction and data preprocessing as well as the execution of exploratory, performance, and conformance analysis. Process mining was able to identify a set of significant process deviations. However, the authors mentioned major challenges related to the quality of data and the selection of event instances for preprocessing, which was virtually impossible without logistics domain knowledge. They concluded that domain experts play an important role in such an analysis [10].

To conclude, the application of process mining in manufacturing and logistics, process mining is able to enhance the capability of enterprises by providing useful knowledge. However, process mining needs improvement to handle real world processes and data, particularly in highly dynamic and complex areas, such as manufacturing and logistics. To enhance the performance of process mining, this paper investigates a methodology to use real world data for discovery, which are noisy and unlabeled.

3 Methodology

The research methodology is composed of three main steps: preprocessing data, process discovery, and evaluation.

3.1 Preprocessing Data

The objective of this task is to group similar business process instances with the aim of reducing complexity. In order to group the similar sequences, a Markov chain is deployed as a clustering technique. We have adopted the technique from the work of [1]. Since the Markov chains are unknown in the beginning, Expectation-Maximization (EM) is applied to generate the transition matrix for each cluster. EM is an iterative algorithm for likelihood estimation in problems with missing data [11]. The algorithm in preprocessing data step consists of four phases: initialization, expectation, maximization, and summed distance calculation.

Initialization Step. In the first phase, transition probability matrices are randomly created for each cluster c_k. A Markov chain is defined by a set of transition states. The likelihood for a transition from a current state into the next state depends only on the current state (memorylessness characteristic) and each transition has an associated transition probability. The probability of the observed sequence belonging to a given cluster depends on the Markov chain associated with that cluster. A Markov chain is represented as a $n * n$ matrix, where n is a number of states. For example, let x_r be the random sequence for initialize transition probability matrix and $x_r = start, m_1, m_1, m_1, m_1, m_2, m_3, end$. The probability of initial state $\rightarrow m_1$ is 1. The probability of $m_1 \rightarrow m_1$ happens 3 times in 4 times and $m_1 \rightarrow m_2$ happens 1 time in 4 times. Consequently, the probability of $m_1 \rightarrow m_1$ is $3/4 = 0.75$ and $m_1 \rightarrow m_2$ is $1/4 = 0.25$. The transition probability matrix derived from x_r is a square matrix of the following,

$$\begin{array}{c} \\ start \\ m_1 \\ m_2 \\ m_3 \end{array} \begin{array}{c} \begin{array}{cccc} m_1 & m_2 & m_3 & end \end{array} \\ \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0.75 & 0.25 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \end{array}$$

Expectation Step. As given the transition matrices, each sequence in the event logs can be assigned to the highest probability cluster. Let $x = x_0, x_1, x_2, x_L$ be a sequence of length L. The begin state x_0 and end state x_L are introduced to simplify the probability equation. The probability that the sequence is associated with cluster C_k can be expressed as [1,12].

$$p(x|c_k) = p(x_0, c_k) \times \prod_{i=1}^{i=L-1} p(x_{il}|x_{i-1}, c_k) \times p(x_L, c_k) \tag{1}$$

where $p(x|c_k)$ and $p(x_L, c_k)$ are the transition probabilities of the start state x_0 and end state x_L in the Markov chain associate with cluster c_k and $\prod_{i=1}^{i=L-1} p(x_{il}|x_{i-1}, c_k)$ is the transition probability from state x_{i-1} to x_i. For example, let trace $=\{m_1, m_1, m_2, m_3\}$, then $p(x|c_k) = (m_1|x_0, c_k) \times (m_2|m_1, c_k) \times p(m_3|m_2, c_k) \times p(m_4|m_3, c_k) \times p(x_L|m_4, c_k) = 10.750.2511 = 0.1875$

Maximization Step. In the third step, the transition probability matrix for each cluster is updated by the newly assigned members. Then we compare the previous transition probability matrix with the updated one for each cluster. If they are equal, the algorithm will go to the next step; otherwise, the algorithm will repeat step 2 and 3.

Summed Distance Calculation. In the last step, this clustering result is validated by calculating the total distance between the centroid Markov chain and each trace member to evaluate the similarity. The total distance between C_k and T_n, where n is the number of traces in C_k, is defined as [13]

$$D(C_k, T_n) = \frac{1}{2} \sum \left[P(S_i^{C_k} \times M_{ij}^{C_k}) - P(S_i^{T_n}) \times M_{ij}^{T_n} \right] \tag{2}$$

Let $M_{ij}^{C_k}$ and $M_{ij}^{T_n}$ be the elements in the transaction matrix of cluster C_k and S_n respectively, $P(S_i^{C_k})$ and $P(S_i^{T_n})$ are state-space distributions of each cluster and trace respectively. The smaller $D(C_k, T_n)$ is, the more similar are these Markov chains. The probability of S_i in C_k is given by

$$P(S_i^{C_k}) = \frac{\sum S_i(T_r)}{\sum r|T_r|} \tag{3}$$

where T_r of length $|T_r|$ is a sequence that is assigned to cluster C_k. For example, cluster k_1 contains two traces: $\{m_1, m_1, m_1, m_2, m_3\}$ and $\{m_1, m_1, m_2, m_2, m_3\}$, then we have $\#m_1(T_r) = 5, \#m_2(T_r) = 3$ and $\#m_3(T_r) = 2$. Therefore, $P(m_1^{C_1}) = \frac{5}{10}, P(m_2^{C_1}) = \frac{3}{10}$, and $P(m_3^{C_1}) = \frac{2}{10}$.

3.2 Process Discovery Algorithms

The next step is to run the process discovery approach. The process discovery in process mining also refers to the control flow perspective which aims to derive the actual process model from event logs. There are a variety of process discovery algorithms, such as α-algorithm, heuristic mining, fuzzy mining, and genetic mining. Each algorithm has its strengths and weaknesses. The α-algorithm is one of the first process discovery algorithms to discover the behavior of traces. It scans event logs for particular patterns. There are limitations to deal with the noise and completeness of the event logs. However, there are other algorithms that overcome the weaknesses of the α-algorithm which are the variants of the α-algorithm or other different algorithms. Fuzzy mining is an another widely used approach which can deal with unstructured processes by extracting confusing behaviors into simplified models [14]. It integrates abstraction and clustering techniques and limits the amount of information by emphasizing on the most important or desired details. Another algorithm that is an improvement of the α-algorithm is the heuristic mining algorithm. It is able to capture the frequency of the sequences, detect short loops and skipped activities. In this study, a heuristic mining algorithm is adopted since it focuses on presenting general behavior of work flow or the most frequent path instead of every detail of the behavior of business process [15]. Moreover, it is a relative robust algorithm which can cope with noise and exceptions.

Evaluation. In the last step, the discovered process models are evaluated by measuring replay fitness. The replay fitness refers to the measurement of missing tokens when replaying an event log in the discovery process model [16]. We use the measurement method proposed by [16]. The fitness metric f is defined as follows:

$$f = \frac{1}{2}\left(1 - \frac{\sum_{i=1}^{k} n_i m_1}{\sum_{i=1}^{k} n_i c_1}\right) + \frac{1}{2}\left(1 - \frac{\sum_{i=1}^{k} n_i r_1}{\sum_{i=1}^{k} n_i p_1}\right) \tag{4}$$

Let k be the different sequences from the event logs and $i(1ik)$ an index for each sequence, n_i is the number of process instances combined into the current sequence. m_i is the number of missing tokens, r_i is the number of remaining tokens, c_i is the number of consumed tokens, and p_i is the number of produced tokens during log replay of the current trace. The value of f ranges between 0 and 1. If there are no tokens missing nor remaining, then the result of fitness is 1. In contrast, if every produced token is remaining or every consumed token is missing, then the result of fitness is 0.

4 Analysis and Results

The analysis and result section is subdivided into three parts. The first part explains the context of the real data and general statistics. The second part demonstrates the result of process discovery algorithm presented by petri nets process model and presents the evaluation of fitness between the set of traces from original data and traces from clusters.

Events Logs. The event logs are collected from the manufacturing execution system of a manufacturing company. There are 3,508 manufacturing orders containing 63,558 operations (events), executed on different 50 machines. The length of the observed process instances is from 1 to 31. The event logs present the manufacturing processes which comprise of an order id, a machine id, and a time stamp. The order id represents the case id to integrate other machine ids in the same process instance. The time stamp is used to order all events that belong to a specific order by execution time. Table 1 demonstrates an example of an event log. Order id 1 is composed of 7 machines. The machine ID represents

Table 1. Example of the event logs

Order ID	Machine ID
1	2, 3, 4, 5, 6, 1, 2
2	36, 29, 30, 6, 31, 32, 13, 12, 17, 1
3	19, 9, 9, 1, 7
4	9, 4, 1, 7

the activities in an instance process which means that the order ID 1 has the machine ID 2 as first activity and following with machine ids 3, 4, 5, 6, 1, and 2 respectively.

Sequence Clustering. This part illustrates the result of the sequence clustering with the real event logs from a company. We use the Markov chain and EM for clustering process instances as data preprocessing. Different numbers of clusters k are tested and evaluated by the total number of distance between the centroid Markov chain and its members. Figure 1 presents the total distance result for k = 5, 10, 15, 25, 30, 35, 40, 45, 50, 60. As expected, the total distance decreases with k. We select the k = 50 as it shows the minimal total distance. However, the clustering technique with Markov chain ignores the length of traces. As a result, a single cluster can be composed of a wide range of the sequence lengths.

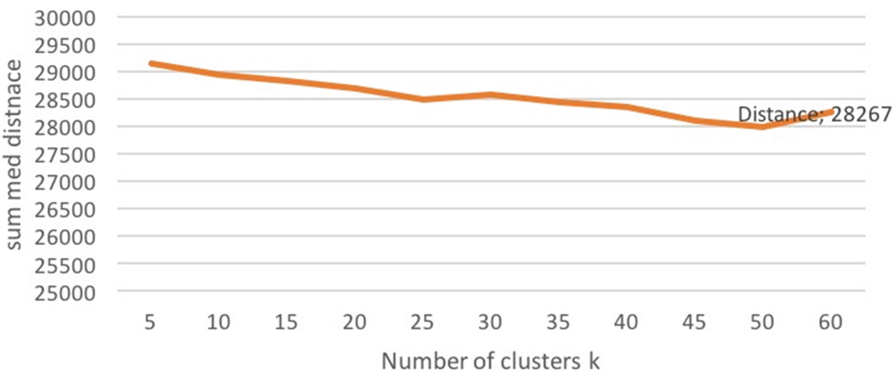

Fig. 1. Summed distance between Markov chain centroids and traces

Process Discovery. In this section, we deployed the result from the previous step to the ProM 6.6 software. Figure 2 depicts the process model from the largest cluster at k = 50. The model has been generated using the Heuristic mining algorithm. The fitness of the original and clustered event logs are close to 0 and 0.5992 respectively. The fitness replay result show distinct differences between the original and the clustered process model. The replay fitness of the

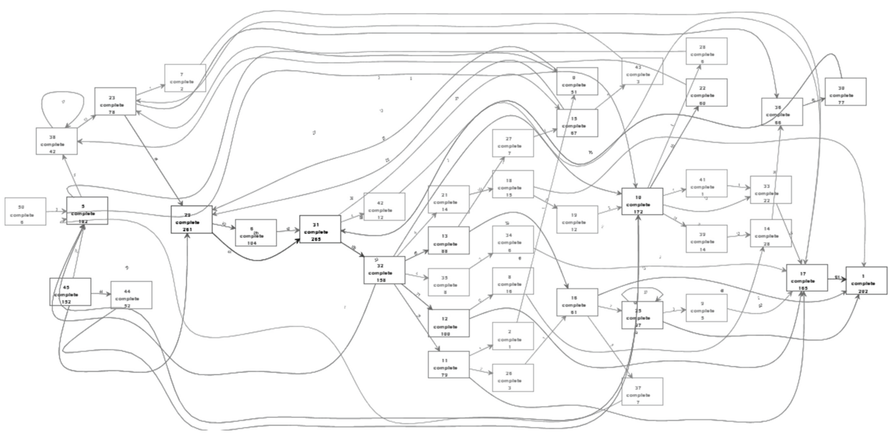

Fig. 2. Heuristics net from the Heuristic Miner in ProM

original has a number of missing tokens and remaining tokens, because the real-world processes tend to be less structured and exhibit a higher variance. Since the Heuristic mining algorithm aims to identify general behavior and frequent paths, the derived processed model does not consider every detail of every business processes instance. The process model derived from clustered event logs distinctly increases the replay fitness, since it groups the similar processes. As a result, the number of missing and remaining tokens is smaller than compared to the original logs. Therefore, conducting clustering as preprocessing is able to increase the fitness of the resulting process models.

5 Conclusion and Discussion

In this paper, we introduced the challenges of process discovery in the highly complex and dynamic environment of business processes in manufacturing and logistics. The main contribution of this paper is the exploration of a practical process mining application in the specific domain by using real-life process data from industry. The result shows that solely applying traditional process mining is not competent to handle the real-world data since the replay fitness of the discovered process model is poor. In particular, we propose the methodology to enhance the performance of traditional process mining by adopting a Markov chain clustering approach to perform sequence clustering in the data preprocessing step. Our contribution here is applying sequence clustering technique and declaring the way of finding the number of clusters by measuring the summed distance between a centroid Markov chain and trace members. The result indicates that the methodology successfully improves the discovered process model quality by the measurement of replay fitness dimension.

However, our study has only been conducted with a single source of data and a single dimension of process model quality. In the future works, we aim to enhance the robustness of process mining in logistics and manufacturing domain by proposing methodologies to handle heterogeneous data sources, as the real-world data is from a broad range of data sources. Furthermore, to manage to a large volume of data, which is usually semi-structured and unstructured, the evolution of methodologies should be able to handle the processing demands caused by a large amount of data which required to be updated frequently in order to reduce processing time, and provide proper interpretation. Particularly on Markov chain as clustering method which demands processing time to cope with a large amount of data and a high degree of complexity. In addition, it would be advantageous to not solely consider replay fitness, but also other quality dimensions such as simplicity, soundness, generalization, and precision.

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Enforcing Structural Robustness for Vehicle Routing Plans Despite Stochastic Demands

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Abstract. In this paper we propose an approach to derive a structurally robust solution of the capacitated dynamic vehicle routing problem with stochastic demands. The approach designs an a priori plan that minimizes transportation costs while allowing to accommodate changes in the demands without losing structural properties such as number of vehicles or optimality. We compare the proposed approach with stochastic programming with recourse. Considering a benchmark dataset, computational results show that the robust approach outperforms stochastic programming with recourse.

1 Introduction

Vehicle Routing Problems (VRP) play a crucial role in logistics and many variants have been proposed in the literature during the last decades, cf. [9]. One of the most commonly used formulations is the Capacitated Vehicle Routing Problem (CVRP), which aims to minimize the delivery costs for a single product from depots to customers by means of a number of capacity constrained vehicles [3]. In the classical CVRP, also called static and deterministic CVRP, it is assumed that the demands are known. However, in reality uncertainties arise in the demands. Therefore, the Capacitated Dynamic and Stochastic Vehicle Routing Problem (CDSVRP) was designed to better reflect these applications. For recent surveys, cf., e.g., [6,8]. In this type of problem, only distribution requests are known initially, while true orders become available during the execution of the plan only. To integrate this aspect, a two-stage solution was devised. First, an optimization is performed based on a priori information, computing the a priori plan of routes. Then, when demands are revealed during the execution of the a priori plan, the plan is adapted to accommodate for these changes, cf., e.g., [5,7,9].

Due the existence of stochastic variables within the problem, demand realization might exceed the vehicle remaining capacity, which leads to a route failure and requires a recourse action [6]. To accommodate for the stochasticity, in this paper we propose a robust approach by means of an L_1 type cost function to

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integrate stochastic variables using simulation. Here, robustness implies that the solution allows to accommodate changes in the demands without losing structural properties and optimality.

In the following Sect. 2 we introduce the problem formulation considered in this article. Thereafter, we show our robust solution approach in Sect. 3. In Sect. 4, we numerically compare our approach to stochastic programming with recourse before drawing final conclusions in Sect. 5.

2 Problem Formulation

Within this paper, we consider set of vehicles V with restricted capacity $C > 0$ each and a fully connected graph $G = (N, A)$ with $|N| = \overline{n}$ and $|A| = \overline{a}$ to be given. Here, $|N|$ is the set of vertexes representing customer locations (0 is the depot of vehicles), and $|A|$ is the set of arcs representing travel times between connected vertexes. If demands are random variables $d_n : \Omega_n \to \mathbb{R}_0^+$ for all $n \in N$ with sampling space Ω_n, and costs $c_{ij} > 0$ are fixed for all $(i, j) \in A$, then

$$\min_x J_V(x) := \min_x \left\{ \sum_{v \in V} \sum_{k=1}^{|x^v|-1} (c_{ij} \mid i = x^v(k),\, j = x^v(k+1)) \right\} \tag{1}$$

$$\text{ST. } x^v(1) = x^v(|x^v|) = 0 \qquad \forall v \in V \tag{2}$$

$$x^v(k) \neq x^v(k') \qquad \forall v \in V,\ \forall k, k' \in \{2, \dots, |x^v| - 1\} \text{ with } k \neq k' \tag{3}$$

$$x^v(k) \neq x^{v'}(k') \qquad \forall v, v' \in V \text{ with } v \neq v' \text{ and } \forall k \in \{2, \dots, |x^v| - 1\},\ k' \in \{2, \dots, |x^{v'}| - 1\} \tag{4}$$

$$x^v(k) \in V \setminus \{0\} \qquad \forall v \in V,\ \forall k \in \{2, \dots, |x^v| - 1\} \tag{5}$$

$$\sum_{k \in \{2, \dots, |x^v| - 1\}} d_{x^v(k)} \leq C \qquad \forall v \in V \tag{6}$$

is called capacitated dynamic and stochastic vehicle routing problem. Within this problem, x^v denotes the route of vehicle $v \in V$ in x, $|x^v|$ the length of the respective route and $x^v(k)$ the k-th vertex visited by vehicle v.

Here, Eq. (2) presents the initial and terminal conditions. The deadlock free condition is represented in (3). The tour arc conditions are expressed by (4) to avoid overlaps and (5) to ensure return to depot only once. Last, Inequality (6) states that the total capacity of vehicle $v \in V$ must not be exceeded.

Our aim, however, is to compute a robust solution, which minimizes the real and not the planned costs. The real cost ($\hat{J}_V(x)$) is split into two stages: the planned costs c_{ij} (first stage) and the additional costs F for vehicles to cover costumers, who were not serviced by the first stage (second stage). Unfortunately, we can evaluate $\hat{J}_V(x)$ only a posteriori, i.e. upon completion, or via stochastic analysis. In both cases, the focus relies on analyzing the costs. Here, however, we focus on structural properties such as, e.g., length and sequence within a route and also number of routes. More precisely, we want the computed solution to retain its structure despite possible deviations from the plan induced by revealed information. To anticipate the costs and the spread of costs induced by the latter, we propose to utilize an L_1–norm like cost functional.

To this end, we suppose a set of $\overline{s}$ scenarios

$$S := \{s_j = (d_1(j), \ldots, d_{\overline{n}}(j), c_1, \ldots, c_{\overline{a}} \mid j = 0, \ldots, \overline{s}\}$$

to be given, where s_0 is the nominal scenario and $F : G \times S \to \mathbb{R}_0^+$ is a measure for the second stage costs. Now, we want to compute a set of closed subgraphs $x = \{x^v\}_{v \in V} \subset G$ minimizing

$$\overline{J}_V(x) := \sum_{v \in V} \sum_{k=1}^{|x^v|-1} (c_{ij} \mid i = x^v(k),\, j = x^v(k+1)) + \omega \sum_{s \in S} \frac{F(x, s) - F(x, s_0)}{\overline{s} - 1} \tag{7}$$

subject to the constraints (2)–(6) of the CDSVRP. In comparison to the cost function (1), the additional term in (7) accounts for the spread of the solutions. Thus, certain disturbances in demand can be compensated. The weight ω represents a parameter of choice for managers to modify the importance of the two aspects in the cost function: optimality and robustness. Note that we do not characterize a certain tolerable bound on the disturbances, which would lead to a worst case solution. Instead, we let the optimization mechanism decide, which (modified) minimum is robust in a structural sense. For this reason, we will not state explicit bounds on tolerable disturbances, and if disturbances are too large, they will be handled by replanning or extra tours.

3 Robust Solution Approach

For the problem described before, we develop a robust solution approach, which consists of four stages. In the first stage, we fit a probability distribution distribution (PDF) to demand data of each costumer separately. Thereafter, we use these PDFs to generate S scenarios. For scenario 0, we assume that the demands are equal to the mean of all PDFs ($d_{iS_0} = E\,[d_i]$). The remaining scenarios are constructed by sampling the PDF using Monte Carlo Simulation, i.e., for every scenario a value is generated for each customer demands (d_i). Hence, every scenario has a different set of deterministic values. In the third stage, a static and deterministic instance of the CDSVRP is defined using equation

$$\overline{d}_i = d_{is_0} + \omega \sum_{s \in S} \frac{d_{is} - d_{is_0}}{|S| - 1} \qquad \forall i \in N. \tag{8}$$

The latter equation is formulated using the robust cost function (7). Every ($\overline{d}_i$) is calculated by a linear combination of the scenarios with the weight ω, which accounts for the deviation from the nominal value (d_{iS_0}). Hence, it is possible to decide how conservative a solutions should be. Finally, in the last stage we solve the static and deterministic CVRP. For that we use three heuristics: Clark Wright Savings (CWS), 2-opt Local Search and Simulated Annealing (SA). Using Clark Wright, proposed first by [2] savings parallel version, we generate a initial plan of routes. Then, we apply a 2-opt Local Search, first introduced by [1] to remove crossing of links in a route, while preserving the orientation of the routes, which reduces the transportation costs. Given the result of the improvement heuristic, we utilize SA [4] to further improve the result. The result obtained after this stage represents a structurally robust plan of routes.

4 Simulation Results and Comparison

To compare the effectiveness of our approach, we consider stochastic programming with recourse (SPR) as a two-stage approach as a reference [10]. In SPR, both the cost of the a priori plan designed in the first stage and the expected cost of the corrective actions performed in the second stage are minimized. A failure arises when the vehicle capacity is depleted during the execution of the a priori plan, and a commonly used recourse actions is a preventive restocking. Since it may be less costly to travel to depot to refill the vehicle from the latest customer than to wait for a route failure at a location further away from the depot, in PR a vehicle is refilled before a route failure may occur.

For comparability of both approaches, we used Clarke Wright savings to calculate the a priori plan and preventive restocking as the corrective action. With PR a decision must be made every time a vehicle reaches a customer. To decide if a corrective action is required, we calculated the customer success rate, which is the probability of serving the customer without having a route failure. Then, if the success rate is lower than 80% we analyzed the distance. If the distance from the next customer to depot is lower than the distance from the latest customer to depot, then the vehicle visits the next customer. Otherwise, it goes to the depot to be refilled.

To compare both approaches, we developed three test problems (TP1, TP2 and TP3) with different number of customers (30, 50 and 100). In all test problems the customer locations are distributed in a 2000×2000 square in a Euclidean plane, and the transportation costs between customers are equal to the corresponding Euclidean distances. We considered the costumer demand $d_{TP,i} \sim U(a, b)$ to be uniformly distributed. For all test problems we changed the parameter a and b for every customer, in this way each customer demand has a uniform PDF.

Table 1 shows the computational results. Column (1) lists the test problems, column (2) through column (7) report the performance of the benchmark approach SPR, while column (8) through column (13) of our robust approach using $\omega = 10$.

For all test problems, SPR calculated a priori plans with smaller number of routes as compared to our robust approach. Hence, the cost of the a priori plans designed by SPR were lower. However, regarding the final plan, the robust approach outperformed SPR. The final plan is the real plan executed to deal with the real demands, i.e. it includes the costs for not anticipated recourse actions. This cost ($\hat{J}_V(x)$) is lower – and consequently the number of routes is smaller – for the plan designed by the robust approach. Besides that, the difference between the cost of the a priori plan of routes and of the final plan of routes is also lower using the robust approach. Since *diff.* means the plan needs less detours to depot to deal with the real demands, this indicates that the solution drawn by the robust approach can handle changes better than the SPR solutions. Considering computational time, the performance of both approaches are alike.

Table 1. Results for the test problems considering performance measures

Test problem	Stochastic programming with recourse						Robust solution approach					
	Routes (initial)	$J_V(x)$	Routes (final)	$\hat{J}_V(x)$	Differ.	CPU time	Routes (initial)	$J_V(x)$	Routes (final)	$\hat{J}_V(x)$	Differ.	CPU time
TP1	4	6,504.0	7	9,865.1	3,361.1	0.0043	5	6,610.0	6	7,929.0	1,319.0	0.0050
TP2	9	14,141.0	15	21,633.0	7,492.0	0.0354	11	18,360.0	13	20,461.0	2,121.0	0.0627
TP3	19	31,419.0	27	44,223.0	12,804.0	0.4879	23	34,184.0	26	42,683.0	8,499.0	0.5110

5 Conclusions

In this paper, we have proposed a robust solution approach to solve the capacitated dynamic and stochastic vehicle routing problem. The proposed solution minimizes the transportation cost while permitting small changes in the demands without changing solution structure and losing optimality. Using the robust approach, the dynamics and stochastic problem was reduced to a static and deterministic one, which allows to use simple algorithms. The computational results show that our approach performs better than stochastic programming with recourse.

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Big Textual Data in Transportation: An Exploration of Relevant Text Sources

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Abstract. With the emergence of Big Data and growth in Big Data techniques, a huge number of textual information is now utilizable, which may be applied by different stakeholders. Formerly unexplored textual data from internal information assets of organisations, as well as textual data from social media applications have been converting to utilizable and meaningful insights. However, prior to this, the availability of textual sources relevant for logistics and transportation has to be examined. Accordingly, the identification of potential textual sources and their evaluation in terms of extraction barriers in the Danish context has been focussed in this paper.

1 Introduction

Big Data is increasingly considered as an opportunity for decision makers in public (Munizaga 2017) and private (Waller and Fawcett 2013) transportation sectors. However, some challenges in the application of Big Data in transportation remain. Firstly, sensor-generated and geo location data is being heavily focussed. Secondly, the question of data ownership and confidentiality (Munizaga 2017) as well as methodological considerations in the automation of transportation-related Big Data (Kinra et al. 2017; Munizaga 2017; EU Group Transport Advisory 2014) are not extensively solved. Lastly, data comparability problems and the integration of different sources constitute further challenges. These challenges raise questions on the relevance of further Big Data sources.

User opinions for instance are considered as a highly valuable source for enhancing the evidence base in different areas of transport. These user opinions are only one example of the availability of "Big Textual Data" in nowadays-digital world. Under "Big Textual Data" different textual sources are summarised, including user-generated-content published on social media platforms, traditional online content, information assets of companies such as emails or customer complaints and non-publically available data such as consultancy reports. In order to exploit this Big Textual Data, text mining which is considered as one of the emerging approaches of Big Data, has to be

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applied. The application of text mining techniques enables the unveiling of the formerly untapped source of textual data and can enhance evidence-based decision making. The objective of this paper is to identify the relevant textual sources in a first step; and secondly, to examine the potential extraction barriers. Both analyses have been conducted with the focus on Denmark.

2 Textual Data Sources in Transportation

A prerequisite for textual data analysis is the availability of textual data. Accordingly, it is required to identify potential sources and to evaluate the sources, which may contain content relevant for decision makers in logistics and transportation. Four main steps have been conducted in order to identify potential relevant text sources. Firstly, the literature on the usage of textual data in transportation was reviewed, and all sources which were used in this context have been included. Secondly, the availability of text in social media based sources has been examined, applying the mapping study of Chaniotakis et al. (2016). These sources have been down-selected in the Danish context by considering the social media usage in Denmark (Kulturstyrelsen 2015). Lastly, media platforms and publications used by the different stakeholder were scanned in order to identify additional sources. Following this process, overall, three categories of relevant text sources have been identified. The first group of sources are social media based sources including Twitter, Facebook, Trustpilot, Google+ and Google maps reviews as well as LinkedIN. The second group are traditional textual sources including research articles, newspaper and magazines, company annual reports and press releases, consulting firm reports, government reports, user association and NGO publications and lastly public responses to bills (Høringssvar). The third group includes intra-organisational sources, such as customer service logs. However, these sources are usually non-public, and accordingly, not accessible and therefore, the third group of sources is neglected in this research. The importance of the identified sources was additionally evaluated in the context of an intensive workshop on textual data in transportation and logistics for the Danish logistics and transportation sector. Overall, the potential of social media based sources for logistics and transportation has been supported. In particular, Twitter and Facebook are assessed as relevant sources by the stakeholders.

In a second step, the identified sources have been evaluated with regard to the extraction strategy and technical extraction barriers. The assumption in this research is that data availability itself is not useful for organizations. Different criteria have to be considered while examining the potential of Big Textual Data for transportation such as the barriers to the accessibility of different sources. Table 1 illustrates the result of the evaluation of the social media based sources.

It is not possible to find general regulation for the sources belonging to the same category. For instance, comparing social media based sources; it is notable that there is a difference in accessing the data from Twitter and Facebook, in contrast to LinkedID. While the first two mentioned sources are partly accessible through their official API's, extracting content from LinkeID requires the permission of the individual user.

From a technical point of view is it also evident that there are boundaries to the exploitation and that these are specific to the individual sources. Most of the social

Table 1. Evaluated social media based sources

Data source	Amount of data	Extraction	Technical extraction barriers
Twitter	Very large	Official Twitter API	No access to historical data older than 7 days Official API returns sample of tweets (≈1 pct.)
Facebook	Very large	Official developers API	Extraction is limited to one URL at the time Keyword search not possible
Trustpilot	Medium - Large	Official Trustpilot API	Unable to explore
Google+ & Google maps reviews	Medium - Relatively high	Google Places API	Unable to explore
LinkedIn	Little	Official LinkedIn API	Unable to explore

media based sources are accessible through their official API. However, often the API's do not grant full access to the content and the decision maker is limited to certain functionalities. For instance, Twitter's API allows only accessing data seven days back in time, and only access to 1pc of total Tweets is granted (Morstatter et al. 2013). In cases in which no API exists, web crawlers are used for extracting the targeted content. However, using a web crawler, legal aspects have to be considered carefully. Furthermore, the structure of the targeted websites needs to be examined in order to configure the crawler to the given structure, which may be a further challenge. The individual configuration of each website may be time and resource intensive. Traditional sources are often spread across different publishers, or saved in different formats which require manual extraction of the content. The evaluation of the traditional textual sources is summarised in Table 2.

Table 2. Evaluated traditional textual sources

Data source	Amount of data	Extraction	Technical extraction barriers
Research articles	Large	Elsevier API among others	Data is spread across various databases
Newspaper & magazines	Large	Infomedia API	None once access is granted by Infomedia
Company annual reports & Press releases	Large	Web crawler	Each report will have different structure which has to be accounted for
Consulting firm reports	Medium	Manual extraction of PDF documents	Each report will have different structure which has to be accounted for

(*continued*)

Table 2. (*continued*)

Data source	Amount of data	Extraction	Technical extraction barriers
Government reports	Medium	Manual extraction of PDF documents	Each report will have different structure which has to be accounted for
User association/NGO publications	Little	Web crawler	Dependent on specific site but each site will be structured differently which limits automatized crawling
Public responses to bills (Høringssvar)	Little	Manual extraction of PDF documents	Text is provided in various picture formats which require manual conversion

The identification of the textual sources and the examination of their exploitation underpin the following two points. Firstly, in the context of transportation and logistics, textual data is available both in large volumes and in variety, which demonstrates the potential of text analytics in obtaining access to this valuable information asset. It also demonstrates when working with textual data and text analytics, it is an essential step to focus the source identification process carefully, including the differences in accessing and extracting content from the individual sources.

3 Conclusion

This paper has showcased the potential of Big Textual Data for transportation and logistics by pointing out several crucial issues in incorporating textual data in transformation. Firstly, one relevant step prior to the actual analysis of the textual data is the identification of relevant textual sources in the field of transportation. This first step is highly relevant since, despite a flourishing amount of Big Textual Data available on different platforms, it is still unsure which sources should be taken into account for transport problems, as there is no certitude on whether some data may be more relevant over the other. The paper has made a first and significant step in this direction and provided a series of potential textual data sources for transportation, also taken their strengths and weaknesses of accessing the data into consideration. However, these sources and potential of further sources have to be evaluated in future work, and a methodology on how to assess their relevancy for transportation problems will be developed, accordingly.

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Building Fast Multi Agent Systems Using Hardware Design Languages for High-Throughput Systems

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Abstract. While being from various domains, Multi Agent Systems and Hardware Design Languages rely on the same core concepts: parallelism, separation of concerns as well as communication between independent entities. This paper introduces the idea of utilizing the benefits of HDLs, with their focus on fast simulation and correct timing, to implement multi agent designs. Consequently, the massive advantages can be taken into account, which have been gained by decades of research in the field of electronic design, concerning the analysis, the evaluation as well as the optimization.

1 Introduction

Since several years, *Multi Agent Systems* (MAS) have been frequently used to model logistics systems. They offer flexibility, a clear separation of concerns for the actors of a system, allow for a wide range of simulation parameters and system setups to be tested and quickly provide both, high-level and in-depth results for a given design. *Hardware Design Languages* (HDLs) have been in use for decades to design and test hardware systems – the development of state-of-the-art computers, embedded designs and integrated circuits of all kinds relies heavily on the workflow offered by HDL environments.

However, despite their conceptual differences, they hold some intriguing similarities, which suggest that they could be used to design systems. In fact, this application is the counterpart they were originally designed for. This paper introduces the idea of implementing MAS using established HDLs, which allow MAS designers to utilize decades worth of optimization from the electronic design industry while keeping the established multi agent paradigms.

2 Multi Agent Systems

Since the 1980's, MAS have been part of various research activities and, thus, have gained more and more interest over the years. Mainly, this is due to the

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fact that they are interpreted as a software paradigm, which can easily deal with massive open distributed systems appropriately [10]. They are used in different contexts like logistic: Whenever it is necessary to model systems with several actors that, while acting autonomously, communicate and perceive their surroundings to determine their courses of action. Depending on the focus or the perspective of research, there have been a lot of different definitions for MAS. If one aims at simulating MAS to prove their validity, they all have the following things in common (cf. [9] or [3]):

- *Agents* act autonomously due to their tendencies (objectives, goals), perception of their environment (communication with other agents, passive recognition of changes in the environment) while this environment is only partially represented and their given resources.
- *Environments* constitute a dynamic system (without autonomous behaviour), which the agents are situated in, perceive their inputs from and output their actions to.
- *Coupling* of agents and environment to, finally, model the desired MAS. This mainly addresses the problem of relating agent's perceptions and actions with environmental changes in a time-accurate manner.

As MAS are often very complex, it can be difficult to verify their properties and correct behaviour formally [5]. Therefore, simulations of those MAS are strictly required to ensure that they work as intended. Since the beginning of the 1990's, various frameworks have been developed to simulate MAS in different domains. They aim usually at either the study of complexity or distributed intelligence or aim at Software MAS [9].

Nevertheless, as agents (and also changes in the environment) naturally happen simultaneously, a simulation of an MAS requires parallelism. Some work has been done in that regard with tools like Gensim [1], JADE [2] or Spades [7] as has been surveyed in [10] but they focus on software level.

Using MAS gives engineers the ability to (somewhat) easily model, simulate and evaluate arbitrary logistic processes. These applications range from small factory models over more complex, conceptually and novel manufacturing chains, e.g., a high throughput material developing approach [4], to vast supply networks.

3 Hardware Design Languages

On the other hand, HDLs serve a very different and specific purpose: the design of electronic systems. In order to deal with the vast complexity of current hardware designs, these languages provide a layer of abstraction. This layer allows designers to implement modular systems at the so-called register-transfer-level.

Hardware modules can be defined as simple machines, which hold an internal state (i.e. some kind of storage). These machines processes an input usually referring to signals, i.e., connections to other modules, and produce some kind of output usually referring to various connections to other modules. Both, the current state and the output depend on the input as well as the previous state.

The advantage of this approach is, however, not just that dedicated synthesis tools realize the translation from the HDL to descriptions, which can later be manufactured, but also the simulation forming a core feature. With hardware manufacturing processes being both, expensive and time-consuming, simulating a design in software is the state-of-the-art in order to quickly test certain changes or evaluate ideas. However, with current computers still being typically sequential machines, the simulation framework has to take care of (simulated) parallelism and the communication between modules.

4 Merging the Concepts

The interesting point is the similarity of these core features of the framework. While the original application is quite different, the core issues of simulating either hardware or multi agent systems is very similar: independent entities, which operate concurrently, must be simulated on a single sequential machine. Even the required parts for the actual simulation are quite similar on a second glance: retrieving some kind of (sensory) input, sometimes storing something depending on this input and finally acting (setting the output) based on both, inputs and the internal state. Thus, it should be possible to map one of these concepts to the other.

Hardware development has always been a hot research topic, with countless hours having been poured into the various tools and workflows. Additionally, HDLs have always had performance as a core issue. Current hardware systems consist of billions of gates, which have to be simulated in order to generate test sets being applied in both pre- as well as post-silicon tests and, at least important, realizes various verification tasks. Thus, theoretically, HDLs should be a promising foundation, if it comes to the execution of fast simulations.

This remainder of this paper introduces the concept of *MAS-via-HDLs* (MvH), implementing concepts of MAS and simulations using the established HDL frameworks.

With concepts such as schedulers, events, event queues, communication etc. all being readily available, HDLs contain everything, which is required for an fully operational framework. With modularization, processes, modules etc., HDLs provide structure similar to what MAS libraries implement to build the agents themselves.

One major difference between HDLs and MAS is that the former explicitly prohibit altering any structural features after the simulation has started. This not only means that, assuming agents are considered to be mapped to module structures, i.e., no further agents can be instantiated after the simulation has commenced, but this extends to the communication structures: While wires (or signals) are considered to be part of the (fixed) hardware in HDLs, i.e., they can not to be altered on a finished design, MAS often rely on communication being initiated and then later finished and cut between two or even more agents.

However, this shortcoming can be addresses by introducing the required maximal amount of agents before the simulation starts. This is like a pool containing enough members, which are activated and deactivated as required and all these member are connected according to the given profiles – if needed using, e.g., bus-like communication structures establishing the message exchange between parties.

Apart from this conceptual difference, however, the concepts are indeed quite similar allowing HDLs to be orchestrated by MAS frameworks effectively.

5 Case Study

As a case study, the Party example from the JADE [2] framework was adapted to SystemC [6]. SystemC is a high-level system design framework, which is based on C++, which has become an industry standard [8] for electronic system design.

The Party example illustrates how agents communicate and how this mechanism is used to distribute information. Two agent types are implemented as follows:

- The *Guests* are being introduced to each other. Out of all guests, one starts to share a rumor with the party. As soon as two guests are introduced of which, at least one, knows the rumor, the rumor is spread among them.
- The *Host* steadily introduces guest agents to each other and tells initially a guest the rumor, which has been randomly selected by the host.

The scenario is done as soon as all guests are aware of the rumor.

The Java classes for the agents inherit the existing JADE classes:

```
public class HostAgent extends Agent { ... }
public class GuestAgent extends Agent { ... }
```

The implementations for the SystemC adaption on the other hand implements agents as hardware modules, relying on the according C++ macros:

```
SC_MODULE(HostAgent) { ... }
SC_MODULE(GuestAgent) { ... }
```

More precisely, JADE comes with the so-called DF, the Directory Facilitator, which operates as a hub between agents (and is often referred to as the system's "yellow pages"). While SystemC does not provide a functionality that works exactly like JADE's DF, it *does* have a strong focus on communication between modules, often in the form of buses or more complex structures. The adapted implementation gives the host the role of the hub, requiring guests to register at the host. As communication connections have to be modeled explicitly, the host requires as many communication sockets as there are potential guests:

```
tlm_utils::simple_initiator_socket<HostAgent> socket[COUNT];
```

TLM is short for Transaction Level Modeling, a framework integrated into SystemC, which is used to pass messages between modules in a generic way while providing better simulation performance than pin-accurate signals. Most importantly, TLM messages contain arbitrary "payload" fields, allowing users to easily attach any given data to the message.

Similarly, when the guests are instantiated, they have to be connected to the given socket in order to be able to exchange messages with the host:

```
initiator = new HostAgent("HostAgent");
guests    = new GuestAgent*[COUNT];
for(int i = 0; i < COUNT; i++) {
  guests[i] = new GuestAgent("GuestAgent");
  initiator->socket[i].bind( guests[i]->socket );}
```

Beside this loop, which connects the host's ith socket to the ith guest's socket, the rest of the modeling remains conceptually similar to the JADE blueprint. The most obvious difference is due to the fact that hardware simulation frameworks (such as SystemC) do not allow modules to be removed from the design after the simulation has started. This means that the modules have to keep track by themselves whether they are currently active or not. In this example, this is not an issue as agents are only removed when the final state (of all agents knowing the rumor) has been reached, at which point the simulation is finished anyway. However, while this may be an issue concerning how the simulation is planned and executed (due to dynamic instanciation being restricted), this should not pose an issue as *(a)* user-defined types may still be instanciated at will and *(b)* sensible communication protocols should be able to disregard inactive parts. The only issue that might arise is memory, as all participating parts must be created before the simulation starts and held in the RAM afterwards.

When these designs are executed (with the JADE implementation being modified to no longer rely on user inputs but instead running by itself), the difference between the given approaches is striking: JADE required 6.895 s to spread the rumor across 1000 guests, the SystemC adaption merely 0.054 s (executed on an Intel i5-3320M with 12 GB RAM). While this example of course only provides a single measurement, scalability should not be an issue as long as the system is run on a single host system. As HDLs are built very performance-centred while at the same time focusing on reproducibility, they do not provide measures to route communications across separate machines – thus, as soon as this would be required for larger simulations, scalability might become a problem.

Keep in mind that this comes at the cost of increased implementation effort: There is no graphical user-interface to investigate the communication, although SystemC does offer sophisticated logging features. Furthermore, the C++ foundation does not offer garbage collection, thus, the designers have to free allocated memory by themselves, and the communication channels have to be modeled explicitly. However, the proposed MvH technique leads to a significant performance boost compared to conventional MAS development workflows – in particular, a computation time less than ten seconds are perfectly fine for most the investigated use cases. This means that the application of the proposed MvH technique has to be considered, especially, when building systems with lots of agents or a vast amount of communication, which -in the first place- allows to design highly optimized MAS.

These optimized MAS are strictly required, if the system relies on a high throughput of elements (such as manufacturing chains of very small, independent, interacting items) and, therefore, should be deliberately analysed.

Future work should look into the details of whether or not certain criteria have to be fulfilled for the difference to remain this vast, if the performance-gaining points of SystemC are projectable to other HDLs as well. Furthermore, it should be investigated whether or not these driving forces can be transferred into a dedicated MAS framework that is built on top of these faster frameworks.

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System Dynamics of Dependent Requirements Variations in Automotive Supply Networks – Insights on a Horizontal Bullwhip Effect

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Abstract. Addressing the root causes of schedule instability, particularly the unreliability of suppliers' production processes in a supply network, can help to curtail short-term demand variations and increase the overall supply chain efficiency. Hence, we introduce a stylized automotive supply chain with two suppliers and a single original equipment manufacturer (OEM). This supply chain can be disrupted by a shortage occurring at one of the suppliers due to random machine breakdowns, what consequently creates dependent requirements variations (DRV) affecting both the OEM and the other supplier. Using a System Dynamics (SD) simulation which contains the said mechanism causing schedule instability, comparative simulation scenarios were carried out to gain theoretical insights with regard to the nature of DRV. As a result, the simulation study shows that the Bullwhip Effect is not just detectable on a vertical supply chain level under demand uncertainties, but also on a horizontal supply chain level when production risks are present.

Keywords: Automotive supply chains · Schedule instability
Systems dynamics simulation

1 Introduction

Generally, companies become more affected by the risks of other companies when cross-company dependencies increase (Hallikas et al. 2004). Consequently, risks from uncertain customer demand and deliveries can be transferred between companies which operate within the same supply network. In this context, Ivanov et al. (2015) state that operational risks like demand fluctuations are typically studied under the conditions of the Bullwhip Effect. So far, risks from uncertain customer demand and their impact on schedule instability, particularly the Bullwhip Effect, have been studied intensively. Here, suppliers respond on volatile demand schedules at short notice while such demand disturbances magnify as they pass upstream (Childerhouse et al. 2008). In contrast to that, the risks from disruptions affecting schedule stability have been studied rarely although the research interest in investigating supply chain disruptions grew in recent years (Ivanov et al. 2014).

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Specifically, Sivadasan et al. (2010) describe schedule instability as a mutual interaction between the adjustment of the customer's orders and the production planning of the suppliers. As the current concept of schedule instability cannot answer the question how schedule instability spreads horizontally in more complex supply networks and to which extent unreliability of a certain member within that network affects schedule instability, the concept of DRV is set in a SD simulation model. In this context, simulation can be used to improve the understanding of a supply system by extending the general theoretical concept of schedule instability (Davis et al. 2007). Therefore, the paper at hand is structured as follows. The next section covers the literature background, leading to the model development based on the identified research gap. Subsequently, Sect. 3 contains the scenario analysis, and finally, Sect. 4 briefly concludes this paper.

2 Literature Background

SD simulation is generally seen as a probate instrument to analyze problems with dynamic complexity in a wide range of settings (Sterman 2000). Particularly in automotive supply chain settings, continuous simulation approaches are common instruments (Thierry et al. 2010). Tako and Robinson (2012) also investigated a wide use of SD simulation as decision support tools in Supply Chain Management. In this context, the use of SD modelling mainly focuses on inventory management and demand amplification under the conditions of the Bullwhip Effect (Angerhofer and Angelides 2000). For instance, Özbayrak et al. (2007) provide a SD model representing the operations of a four-echelon manufacturing supply chain focusing on inventory, backlogged orders, and customer satisfaction. In recent years, several authors also used experimental settings to investigate causes of the Bullwhip demand amplification. For instance, Croson et al. (2013) conducted an experimental study based on the Beer Distribution Game to investigate schedule instability related to the ordering behavior of supply chain members. Here, they considered the use of strategic safety stocks to decrease coordination risks. Based on the study by Croson et al. (2013), Sterman and Dogan (2015) analyzed the effects of Hoarding and Phantom Ordering to explain the remaining schedule instability. They realized that Hoarding and Phantom Ordering behavior can be triggered by external influences such as supply disruptions or demand increases. Moreover, Huang et al. (2012) addressed supply risks in a SD model to examine the impact of supply disruptions. They investigated a supply chain under disruption risks considering a backup supplier to close possible inventory gaps. Building on this existing literature, our study intends to contribute by analyzing DRV between the OEM and its supply network caused by uncertain supply.

3 The Simulation Model

Using VENSIM as simulation software, we consider an assembly network supply chain in which two suppliers are providing different parts to a single OEM for the assembly of a final product. Short-term capacity shortages occurring at the supply side trigger demand variations across the supply network because of the supplier's inability to ship the required part. This forces the OEM to re-schedule the production to avoid a standstill. Accordingly, the OEM increases the requirements for other suppliers' parts on a short notice. At the same time, the requirements for parts in short supply are reduced. This creates horizontal ties between the suppliers; these ties are manifested in an indirect relationship between demand variations at the nodes which supply non-complementary products. This kind of relationships can be described as DRV (Gruchmann and Gollmann 2017). Consequently, DRV are likely when disruptions occur, especially under a Just-In-Time procurement with single sourcing. The related causal loop diagram (Fig. 1) is presented next, indicating positive (+) and negative (−) relationships. A positive relationship means that if the cause increases (decreases), the effect increases (decreases). On the other side, a negative relationship means that if the cause increases (decreases), the effect decreases (increases).

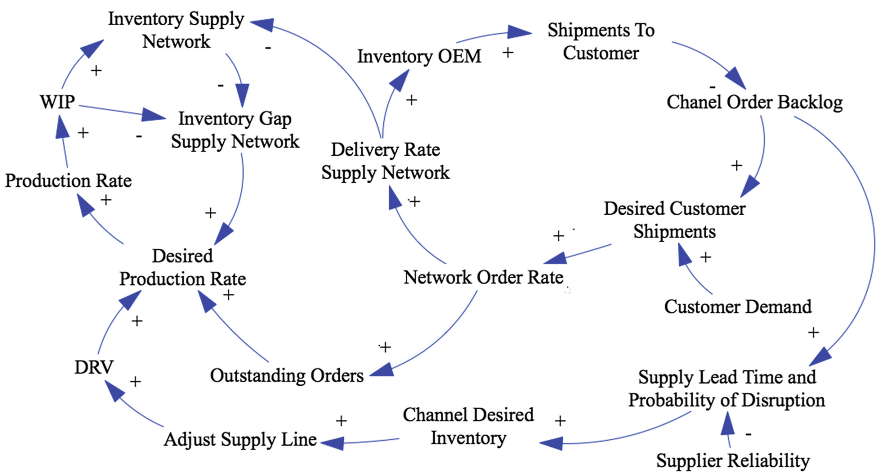


Fig. 1. Causal loop diagram of OEM's and supply network's interaction

In particular, we model the operation as follows: The OEM provides its suppliers forecasts (Customer Demand). If a manufacturing disruption at unreliable supplier 1 (S1) occurs, the missing parts turn into backorder (Inventory Gap Supply Network). In contrast, the fully reliable supplier 2 (S2) is able to increase its capacity at short notice following the shortage and the subsequent rescheduling by the OEM (Network Order Rate). Specifically, while S1's part is unavailable, the OEM dedicates a higher portion of its capacity to the assembly of S2's part and increases accordingly its requirements for it (DRV). After supplier 1 having recovered its backlog (Delivery Rate Supply Network), the OEM will dedicate a higher portion of its capacity to the assembly of S1's part and decreases its requirements for S2's part accordingly. The related stock and flow diagram (Fig. 2) to this operation comprises four stock variables, which capture the quantity demanded (Network Order Rate), supplied (Inventory Supplier S1, Inventory Supplier S2), and stocked (Inventory OEM). The exogenous demand

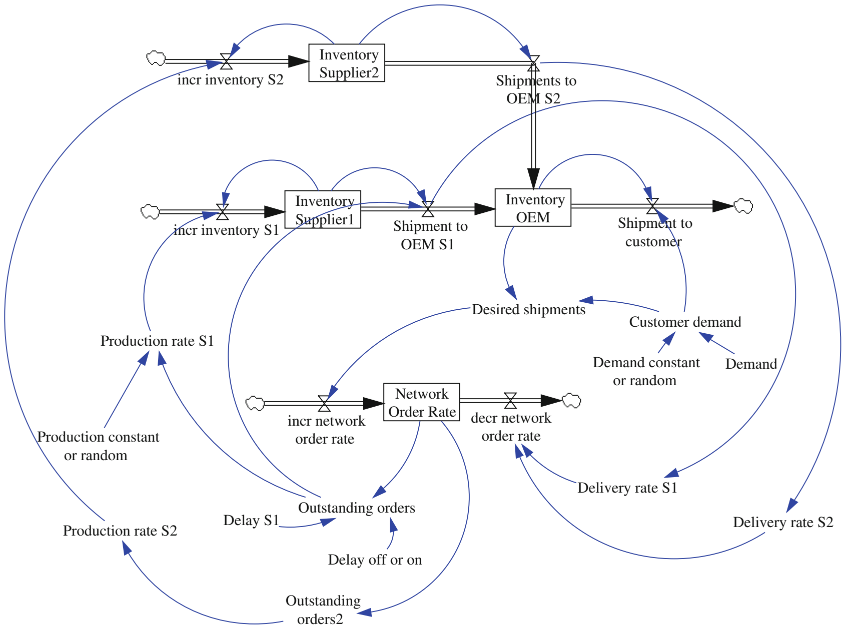


Fig. 2. Stock and flow diagram of OEM's and supply network's interaction

variable may be constant or random normally distributed. Moreover, the suppliers' production of goods to be delivered to the OEM may happen instantly or with delays. Finally, production quantities of supplied goods may be constant (ideal case meaning no production disruptions or quality issues) or random normally distributed (representing production risks). Desired shipments are the result of final customer demand and the OEM's inventory leading to outstanding orders for S1 and S2. Hence, the overall objective is to satisfy final customer demand for the OEM's products. The model-related simulation parameters and functions are displayed in Table 1.

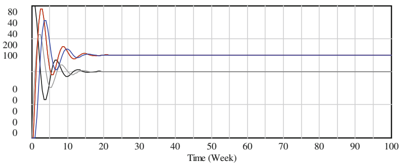
Now, selected scenarios, including a baseline scenario for constant demand and production rates with no delays (Fig. 3a), the effect of random demand (Fig. 3b), the effect of random production rates of S1 and constant demand (Fig. 3c), the effect of random demand and random production rates of S1 (Fig. 3d), random demand and delayed production at constant production rates (Fig. 3e), and random demand and random production rates with delayed production (Fig. 3f) are presented.

The baseline scenario (Fig. 3a) shows that the whole supply system is able to operate on a stable basis when constant demand and production rates are assumed. If demand or production rates are random (Fig. 3b and c), the inventory rates will oscillate within a limited interval after initially high amplitudes. If both demand and production rates are random (Fig. 3d), the oscillation of inventory levels add up and cannot be significantly dampened throughout the simulation period. In case that the production of S1 is delayed and demand is random (Fig. 3e), S2 is confronted with even higher order variations and consequently more volatile inventory levels compared to S1. Finally, if demand and production rates are random and production at S1 is

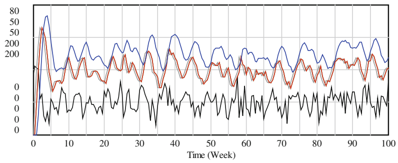
Table 1. Simulation variables, parameters and functions

Variables and parameters	Functions
Inventory Supplier1	= INTEG (incr inventory S1-Shipment to OEM S1, 0)
incr inventory S1	= IF THEN ELSE(Inventory Supplier1>Production rate S1, 0, Production rate S1-Inventory Supplier1)
Shipment to OEM S1	= MIN(Inventory Supplier1, Outstanding orders)
Inventory Supplier S2	= INTEG (incr inventory S2-Shipments to OEM S2, 0)
incr inventory S2	= IF THEN ELSE(Inventory Supplier2>Production rate S2, 0, Production rate S2-Inventory Supplier2)
Shipments to OEM S2	= Inventory Supplier2
Inventory OEM	= INTEG (Shipment to OEM S1+Shipments to OEM S2-Shipment to customer, 0)
Shipment to customer	= MIN(Customer demand, Inventory OEM)
Desired shipments	= Customer demand-Inventory OEM
Customer demand	= IF THEN ELSE(Demand constant or random=0, Demand, RANDOM NORMAL(0, 200, Demand, 15, 0))
Demand	= 100
Demand constant or random	[1; 0]
Network Order Rate	= INTEG (incr network order rate-decr network order rate, 0)
incr network order rate	= MAX(Desired shipments, 0)
decr network order rate	= Delivery rate S1+Delivery rate S2
Delivery rate S1	= Shipment to OEM S1
Delivery rate S2	= Shipments to OEM S2
Outstanding orders	= IF THEN ELSE(Delay off or on=0, Network Order Rate, DELAY3(Network Order Rate, Delay S1))
Delay S1	= 5
Delay off or on	[1; 0]
Outstanding orders2	= Network Order Rate
Production rate S1	= IF THEN ELSE(Production constant or random=0, 0.5*Outstanding orders, RANDOM NORMAL(0, 200, Outstanding orders, 5, 0))
Production constant or random	[1; 0]
Production rate S2	= 0.5*Outstanding orders2

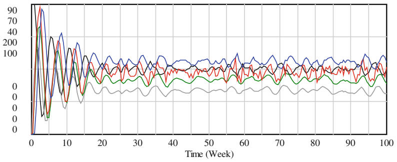
delayed (Fig. 3f), the OEM is regularly not able to fulfill customer demand in certain periods as demand amplifies over time, while in other periods the OEM will be increasingly overstocked. In this latter scenario, S2 again experiences higher amplitudes of order variations. Accordingly, scenario 3f shows the characteristic Bullwhip pattern, also on a horizontal level.



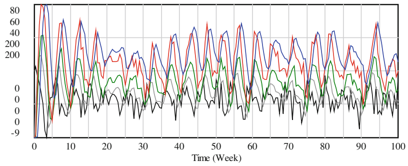
(a) Baseline scenario



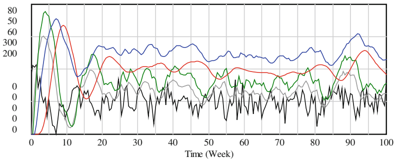
(b) Random demand



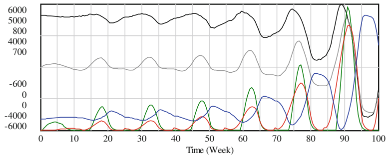
(c) Random production rates of S1



(d) Random demand and random production S1



(e) Random demand and delayed production S1



(f) Random demand and random, delayed production

Legend: Inventory OEM (blue), Inventory Supplier1 (red), Inventory Supplier 2 (green), Network Order Rate (grey), Desired shipments (black)

Fig. 3. Scenario analysis and results

4 Conclusion and Future Research Directions

Following the roadmap by Davis et al. (2007), the presented simulation model gives first theoretical insights into the effects of DRV on demand and production rates of single supply chain members. Particularly, the consequences of delayed production of an unreliable supplier leading to order variations for another supplier in the supply network were examined. It could be seen that risks from demand and supply side add up (Fig. 3d) and become even harder to manage if additional risks such as a delayed production (Fig. 3f) destabilize the system. In this line, the simulation study shows that the Bullwhip Effect is not just visible on a vertical supply chain level under demand uncertainties, but also on a horizontal supply chain level when production risks are present. As practical result, OEMs should consider within their sourcing decisions not just the effects of supply risks for just themselves, but also for their whole supply network. Especially reliable suppliers suffer from additional network risks while unreliable suppliers have no incentive to improve their performance. Future research steps after this study include thorough model validation, e.g., by means of an expert survey, and its empirical validation using primary data collected from case companies. To gain further insights, the model could be extended such that more than two suppliers are included or a second OEM is modeled. To account for a holistic approach to supply chain sustainability, the effects of employing additional capacities at the suppliers due to DRV on economic, environmental, and social performance could be further evaluated.

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Utilizing Domain-Specific Information in Decision Support for Logistics Networks

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Abstract. This paper introduces the implementation and utilization of domain-specific information in a decision support system (DSS) for logistics distribution networks. This information is used to steer an evolutionary algorithm's search for promising configurations of the network. Results show that utilizing this information improves the performance of the DSS.

Keywords: Logistics distribution network · Decision support system
Domain-specific information · Domain-specific language
Evolutionary algorithm

1 Introduction

The management of complex logistics networks is a challenging task. Managers take actions in order to increase the service level or to reduce costs, e.g., by increasing the stock of a stock keeping unit (SKU) or shifting an SKU to a central warehouse. A decision support system (DSS) has been developed for determining and suggesting promising actions to the managers (Rabe et al. 2017b). With the size of the logistics network increasing, the number of possible actions grows exponentially, resulting in longer simulation runs. In this paper, the use of domain- specific information (DSI) is investigated to improve the DSS's performance.

2 Related Work

2.1 Decision Support System

In the literature, DSSs are mostly focused on supply chains in the automotive sector (Liebler et al. 2013). The authors have developed a DSS, that is focused on logistics distribution networks and has already been presented in Rabe et al. (2017b). Therefore, it will only be briefly introduced in this paper. The simplified architecture of the system is presented in Fig. 1. The logistics network's data is automatically transformed into a data model for a data-driven discrete-event simulation (DES) tool. The model is stored in a MySQL database that contains the complete parameterization of the logistics network.

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Since the DSS uses a simheuristic approach (see Juan et al. 2015), the performance of the logistics network, e.g., costs and service level, is evaluated by a DES. In each simulation run, the simulation model is dynamically instantiated from the database. Therefore, actions to the logistics network can be applied as changes to the model in the database. Once the heuristic unit (HU) registers a complete simulation run, it can try to improve the performance of the logistics network by applying actions. An execution engine is decomposing the actions into corresponding changes to the underlying database (Rabe et al. 2017a). This process may be repeated iteratively to determine the most promising actions, which are then provided to the decision maker.

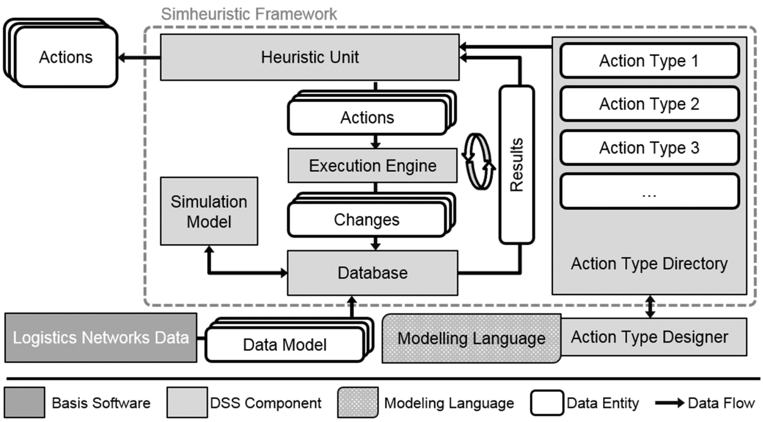

Fig. 1. Simplified architecture of the decision support system (based on Rabe et al. 2017b).

To increase the flexibility of the DSS, it can be extended by user-generated action types (Rabe et al. 2017a). An action type is a generic description of similar actions, e.g., an action type might describe the possibility of changing the stock of an SKU at a site in a generic way. A corresponding action specifies the SKU, the site and the value for the new stock level.

Action types are created within an action type designer (see Fig. 1) by users composing constructs of a domain-specific modeling language (Rabe et al. 2017b). Available action types are stored in an action type directory. The HU can access the action type directory to select action types and derive actions by adding parameter values.

2.2 Domain-Specific Language

A computer language that focusses on a specific problem domain and that has limited expressiveness, which is easy to understand by a human but still executable on a computer, is called domain-specific language (DSL). A DSL is typically used to increase the productivity and understanding when writing a program (Fowler and Parsons 2011). By focusing on a restricted application and through appropriate notations and abstractions, less low-level detail needs to be specified, which decreases the complexity of a program (van Deursen et al. 2000).

The previous usage of a DSL in supply chain design was mostly focused on modeling supply chains in the automotive sector (Parlings et al. 2015), whereas the authors propose to use a DSL for modeling actions in logistics distribution networks.

2.3 Evolutionary Algorithm

The analyzed problem is a combinatorial optimization problem, since the solution, representing actions to be implemented, is constructed from a finite set of actions. Such problem is proposed to be solved using an evolutionary algorithm (EA) (Cabrera et al. 2016). The EA mimics the biological evolution process, in which each generation consists of a number of individuals representing a suggested problem solution. The quality of an individual solution is evaluated by a fitness function, which influences the evolutionary process. Individuals in the successive generations are formed by selecting individuals based on their fitness, using cross-over and mutation mechanisms.

3 Usage of Domain-Specific Information

3.1 Integrating Domain-Specific Information in Action Types

An action type requires functional data for describing the changes to the underlying database, and informal data for supporting the user understanding. The authors propose to add domain-specific information as a third category. Such information might be a list of correlations with other action types. For example, when an assortment from multiple sites is shifted to a central warehouse, increasing the safety stock of affected SKUs in the central warehouse might be a promising candidate for further actions. Each correlation entry consists of a reference to the correlating action type and a correlation factor indicating the correlation's intensity.

Additionally, the user may add information to differentiate whether the action type represents structural changes, e.g., shifting an SKU to a central warehouse or configurational changes, e.g., increasing the stock of an SKU. This supports the HU, because, typically, structural changes should be applied prior to the configurational ones.

Furthermore, the user may add information about the frequency or the success of an action type based on experience from the real system. The success indicates the average percentage reduction of costs in the logistics network after applying a corresponding action, e.g., actions for storing an assortment A, B, C in a central warehouse may reduce the cost of the logistics network by 0.9%, 0.4%, 0.5%, respectively. This leads to an average success of 0.6% representing the projected impact of that action type on the logistics network's performance.

3.2 Implementing DSI in the Evolutionary Algorithm

The heuristic unit in the DSS utilizes EA in its search for the most promising actions. The search space consists of all actions that can be derived from the implemented action types. The DSI of an action type is combined in a unified score value. Hence, the creation of the initial generation, crossover and mutation operations in the EA have been adapted to utilize the score value of the actions. For the first generation, actions with higher score values have greater probability of being selected, hence forming individuals. Therefore, the selection of actions is biased by their score value. In crossover operations, two selected individuals are used to produce two new ones. The exchange of actions between two individuals now depends on their score value and a generated random number as follows:

- Swapping actions when the random number lies between both score values,
- dominating higher score value action when the random number exceeds the higher score value (both individuals receive the same action), and
- no change otherwise.

In mutation operations, randomly selected actions are replaced by other actions. As the score value decreases, the probability of an action being replaced by another randomly selected action from the search space increases.

For testing the new approach, the implementation of the HU utilizing EA has been investigated. EA parameters have been set as: initial individual length 4, number of individuals per generation 10, cross-over probability 70%, mutation probability 30%, maximum number of generations 50, maximum experiment run time 2 h, and stagnation on the best solution found for 10 generations. The search space consists of 240 actions derived from four action types: increase stock, decrease stock, increase safety stock, and decrease safety stock. Two experiments have been run to test the introduced approach on small size logistics distribution networks consisting of five distribution centers, 30 SKUs and 103 customers. Each experiment has been run ten times. Individual's fitness has been measured as total distribution cost and service level, which is needed to be decreased and increased, respectively. The experiments' results are recorded in Table 1. The experiments showed that better solutions are found by the EA utilizing DSI; the best found solution achieved 1.6% better cost values in average.

Table 1. Comparison of the average performance of best found solutions by the EA approaches.

Experiment	Utilizing DSI	Ø Cost	Ø Service level
1	Yes	65524.045 €	84.81%
2	No	66619.644 €	84.75%

4 Conclusion

The authors have included DSI in the definition of action types in logistics networks. An EA is utilizing this information to increase the search for promising actions. Experiments showed that this approach improves the solution. Currently, the authors are extending the approach by including further DSI, such as correlation and frequency.

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A Tool for an Analysis of the Dynamic Behavior of Logistic Systems with the Instruments of Complex Networks

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Abstract. It is known that the whole is more than the sum of its parts. In production for each machine a lot of information is available due to today's integration of automatic data recording. In this context, one way of representing the whole is the modeling as a complex network. Yet, present complex network analysis tools can either not manage the amount of data of such systems or neglect their dynamic behavior. Therefore, we present a tool, which meets these requirements of the logistic field, and demonstrate its abilities for a real-world example.

1 Introduction

Many real-world phenomena can be modeled as a complex network. These can be, e.g., a computer network in computer science, networks of friends in social sciences, prey-and-predator networks in ecology, or material flow networks in logistics. Unlike other applications the analysis of different time points is not only easily feasible in logistics, the inclusion of the time scale into the analysis delivers insights beyond static properties. Yet, the available tools including the dynamic aspect are not suitable for the amount of data available in logistic and require as input graph representations [2,8,14].

The following approach integrates the graph transformation into the analysis tool and can handle the amount of raw data in the typical size for logistic. These advantages and possible interpretations of network characteristics will be shown for an exemplary real-world data set which describes the material flow in a production. Therefore, the needed transformation into a time-dependent complex network will be presented in the second section. Next, a selection of network characteristics, their theoretical background, and their possible interpretation

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in the context of material flow networks are presented. Finally, some analysis results of a real-world example will be discussed.

Figure 1 shows a screenshot of the created tool. The user interface is separated into an analysis and a control panel. The created tool will be freely available as python implementation[1]. The implementation is based on the NetworkX package [9] and the user interface from Sayama [12,13].

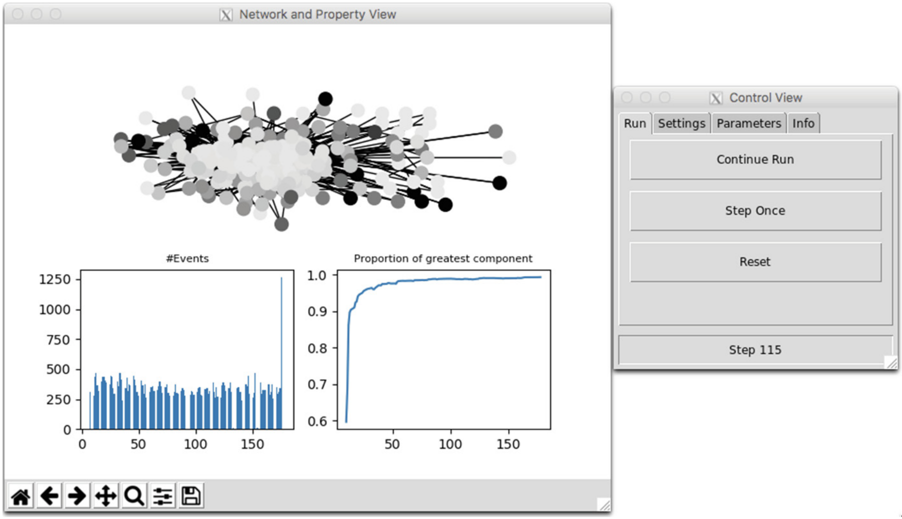

Fig. 1. Screenshot of the presented interactive tool showing the control panel and the analysis view with the network characteristics number of events per day and proportion of greatest component over days included.

2 Material Flow Networks and Definitions

As a first step time-dependent complex networks are defined and the used transformation of completion confirmation data is explained.

A real-world phenomenon modeled as a graph of sufficient size and complexity can be termed as complex network. Depending on the context, the resulting graph is directed or undirected, weighted or unweighted, and either containing self-loops or not. The choice of graph type is therefore a choice of level of detail of the model. In a material flow network, e.g., weighted edges can express the intensity of the material flow between two work stations, while unweighted edges can only indicate if a material flow between two points exists or not. In any case, a graph $G = (V, E)$ consists of a set of vertices V and a set of edges E. It may own an edge weighting function $w\colon E \to R$, which assigns each edge $e \in E$ a weight $w(e)$. To extend this concept to a time dependency, a family of complex networks is regarded, each modeling different time points of a real-world phenomenon.

[1] https://github.com/funket/dyneta.

Based on this definition of a time-dependent complex network, the generation process from completion confirmation data into a time-dependent complex network can be explained. The information is commonly stored in a tabular fashion. Each record contains several pieces of information and as smallest denominator the following is required in our approach: order ID, machine ID, start time, and end time. If the records are sorted by start time in ascending order, two consecutive lines from the same order can be interpreted as material flow from the first machine to the second machine [3,4]. Therefore, the machines and the material flow are modeled as vertices respectively edges in the complex network. Due to the possibility of having multiple material flows between the same tuple of machines, edges are weighted by the amount of material flow. An edge with weight one between two vertices is created in case of a first material flow between machines. Each additional material flow between these machines increases the edge weight by one.

An example snapshot of the full transformation is displayed in the Fig. 2. Typical real-world cases are based on hundreds of thousand lines of raw data and have around the same size of possible time points to view. We call the resulting time-dependent complex network a material flow network.

Order id	Machine id	Start	End
10	A	09:00	10:00
10	B	10:00	11:00
10	C	11:00	12:00
11	C	09:00	10:00
11	A	10:00	11:00
11	B	11:00	12:00

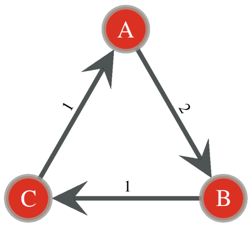

Fig. 2. Transformation of exemplary completion confirmation data into a complex network. The order 10 correspond to the edges from A to B and B to C, whereas order 11 adds the edge from C to A and increases the weights of edge (A, B) to 2.

3 Inspected Network Properties

To further explain the advantages of the presented approach, a closer look at possible properties of complex network, a suitable way of displaying time-dependent characteristics, and a potential interpretation in the context of material flow networks is needed. The formal definitions and further characteristics can be found in reviews or introductions of the complex network field [1,5].

In this case only a selection of properties relevant for material flow networks is presented and primarily ordered accordingly to different display types.

Network properties can be classified in three categories: global properties, distributions and local properties. Global properties summarize a certain aspect of a complex network into a single number like the number of vertices. The local properties assign each vertex or edge a value like the degree of each vertex. In between are distributions, which summarize local values into a global function, like the degree distribution.

Table 1. Selection of network characteristics relevant in context of material flow

Characteristic	Description	Possible interpretation
Global properties		
Events per time unit	Number of lines or weights added per time unit (day/week)	Productivity per time unit
Density	Ratio of numbers of actual edges by number of possible edges	Likelihood that two random machines interact
Degree assortativity^{w}	Tendency of vertices to connect with vertices of the same degree [11]	Tendency of machines connecting to machines with similar number of interacting machines
Proportion of the greatest component^{w}	Ratio of number of edges in the greatest connected component by the number of total edges	Importance of the biggest interacting subsystem
Diameter^{*,w}	Longest shortest path	Indicator for the global topology like hub-and-spoke-distribution paradigm [6]
Average shortest path*	Mean of the length of the shortest paths	Mean interaction distance between two machines
Efficiency^{w}	Mean of the reciprocal of the length of the shortest path between two vertices [10]	Quantification of the exchange of goods across the production
Average local clustering coefficient^{+}	Mean of the local clustering coefficient (see below)	Measurement of the number of alternatives or detours in the production
Average local efficiency^{w}	Mean of the local efficiency (see below)	See average local clustering coefficient
Distributions		
In-/out-/total-degree distribution^{w}	Distribution of In-/out-/total-vertex-degree	Overview of connection distribution in production and indicator for small world phenomenon [7,15]
In-out-degree difference distribution^{w}	Distribution of difference between in- and out-degree	Values distant to zero correspond to sinks or sources in the production
Local properties		
Local clustering coefficient^{+}	Measurement of connectivity between neighbors	High values could indicate the existence of manufacturing cells
Degree-/ Closeness-/ Betweenness-centrality^{w}	Measurement of centrality based on the degree/inverse distance to all other vertex/proportion of shortest path through this vertex	Quantification of importance of a machine in the total system

*connected graph, $^{+}$undirected graph, ^{w}weighted & unweighted variant available.

Beside the level of detail supplied, the three categories own different challenges for displaying actual and historic information. The global properties can be plotted as line charts or histogram either over natural time units or over the number of included events. The distributions are displayed as line charts plotting the complementary cumulative distributions (CCDF) on a loglog scale, i.e. for a distribution X the function $f(x) = P(X \geq x)$ is rendered and both axes omit a log scaling. For example, the CCDF of the degree distribution at k is the fraction of nodes with a degree greater or equal k. An advantage of this display style is the indication of a power law distribution by a straight line in the plot [7]. One or more historical distributions are presented as additional lines in the same plot to enable an analysis of dynamic behavior. The last type of network characteristics are local properties which are defined for each single vertex. These properties can be represented as shape, coloring, or size of each vertex. The feasibility of displaying all vertices with local properties depends on the system size. The example of the next section with around 200 machines is on the edge of readability.

A summary of all implemented network characteristics with a possible interpretation in the context of material flow networks is included in Table 1. In general, our approach is not limited to the presented properties or display options and can be easily extended.

In total, the presented network characteristics highlight different aspects. Furthermore, an observation of network structure and network characteristics over time offers new possibilities for analysis.

4 Exemplary Results for a Material Flow Network

With the knowledge of the data transformation and the network characteristics some results of an example will be presented and be interpreted in the context of production. The following results are based on a real-world data set from a job-shop production. The raw data contains about 100.000 lines and describes a period of one year. Due to the availability of around 30 network characteristics, just some typical findings are discussed. The order of the results goes from global properties over distributions to local properties. All values are calculated per day, discarding a ramp-up period to prevent skewing the plots with the first data.

The plots of the first two properties are included in the screenshot in Fig. 1. The histogram of events group by days shows a strict division into five working days and two days off. From this pattern a few weeks differ with some additional day without any event, which is expected to be caused by public holidays. Another single outlier is a day with roughly two times more events than any other day. The simulation in Fig. 1 was just stopped after this outlier and the outlier is clearly visible in the lower left plot. Taking a look at the underlying data, at this day an unusual amount of data seems to be recorded manually. This is a hint towards a possible error in the raw data. The second plot in Fig. 1 is the proportion of edges in the greatest connected component. It shows that after the first weeks most machines belong to the greatest component. With this information the restriction to connected graphs of some networks characteristics in Table 1 can be lowered. The respective calculation can be restricted to largest connected component. With this method the theoretical well-understood network characteristics can be applied with caution to real-world complex networks.

Knowing that the greatest component is representative after the first weeks, we take a look at development of its average shortest path. The plot in Fig. 3(a) shows the fast decreasing to an average around 2.5 machine-machine steps. Despite the network's growth during the whole observation period, the system becomes and stays well connected. An even stronger effect of the same form can be seen, if the weights are included into this consideration. Another plot including the weight information is the weighted in-out-degree difference in Fig. 3(b). As expected, a narrow normal distribution around 0 can be viewed at any time. But the presents of a few outliers with a high input or output only shows that a few machines take the functions of sinks and sources. Taking a closer look on the dynamic behavior, reveals that not all outliers diverge from zero and some converge again to zero. Some machines seem to fluctuate in their behavior and can take both roles as source and sink in the logistic system.

The last two plots of Fig. 3 shows the minor changes over time in the in-, out- and total-degree distributions. The shape of the distribution seems to be time independent and is likely an intrinsic property of the system. This observation

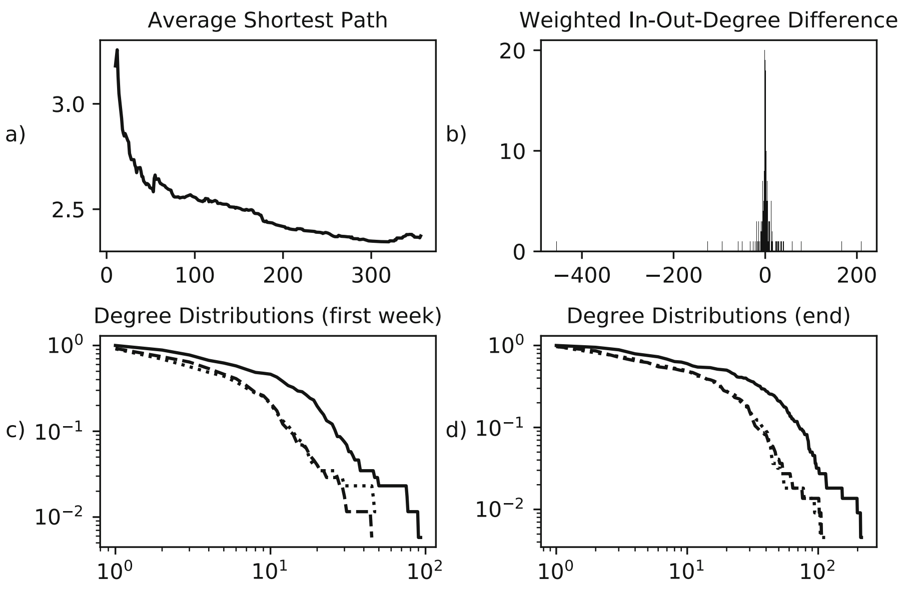

Fig. 3. (a) The average shortest path for the whole observation period; (b) the histogram of the weighted in-out-degree difference distribution after around two months; (c) and (d) the degree distributions after one week and at the end, where the in-degree is scattered, the out-degree is dotted and the total-degree plotted as solid line

can be proved by the two samples Kolmogorov-Smirnov test. The degree distributions from at least two months are drawn from the same distribution with a significance level of 0.2.

An example of a local property is included in the Fig. 1. The vertices are colored in a gray scale according to the value of local efficiency. High values of the local efficiency are concentrated on only a few vertices and the majority of vertices has a low value. An interesting check would be whether these well-connected machines are the critical or most important ones in context of the production as well. Yet, this is not possible on basis of the completion confirmation data only.

A complete discussion of all possible network characteristics is beyond the scope of this publication. Nevertheless, the given results should show the different possibilities. Moreover, the analysis of the time aspect allows to distinguish between dynamic and static properties as well as the identification of interesting time points.

5 Discussion and Outlook

In summary, the presented approach is capable of an elementary and effortless analysis of logistic systems from the point of view of time-dependent complex networks. This was illustrated with an real-world example of a material flow network. The analysis of dynamic network characteristics can deliver insights into the growth of complex network, which is far beyond the possibilities of a single view like the in-depth analysis of the final network. Additionally, the created tool allows a fast testing of different time scales in a combination with different choices of properties. Finally, the integration of the graph transformation into the created tool enable the data input from already existing systems.

In future work, the material flow network will be studied in a sliding window, which either includes a fixed time interval or a flexible time interval based on the stability of the development of the observed network. This extension would allow connections to decay and grow in time like it is usually observed in real-world scenarios. Furthermore, this addition would support the inclusion of real-time data to extend the system to a real-time tracking tool. Together with new characteristics dealing with time dependency of the network, this would enable a detection of critical time points or turning points of systems.

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