

**MASTER**

**Analysis and improvement of Elemica's supplier selection tool**

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ANALYSIS AND IMPROVEMENT OF ELEMICA'S  
SUPPLIER SELECTION TOOL

BY

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SITUATIONAL ANALYSIS, MAKE-OR-BUY DECISION



## ABSTRACT

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This master thesis is about the improvement of Elemica's scenario builder- a tool that calculates the cost-optimal transport volume allocation to the customers' suppliers under certain constraints.

At the beginning of the project, an understanding about the scenario builder's mechanism should be created by inserting different input parameters into the tool and analysing the corresponding output. Afterwards, a Situational analysis is performed in order to get a deeper knowledge about the market for e-sourcing solutions. Hereby, particular interest has been paid to customers' demands and the solutions which are provided by Elemica's competitors. Based on these findings a plan of action is created for Elemica on how to improve the scenario builder so that it adds more value for the customer and can compete with other solutions on the market.

These changes are implemented in a new model and validated by using GAMS as software.



## MANAGEMENT SUMMARY

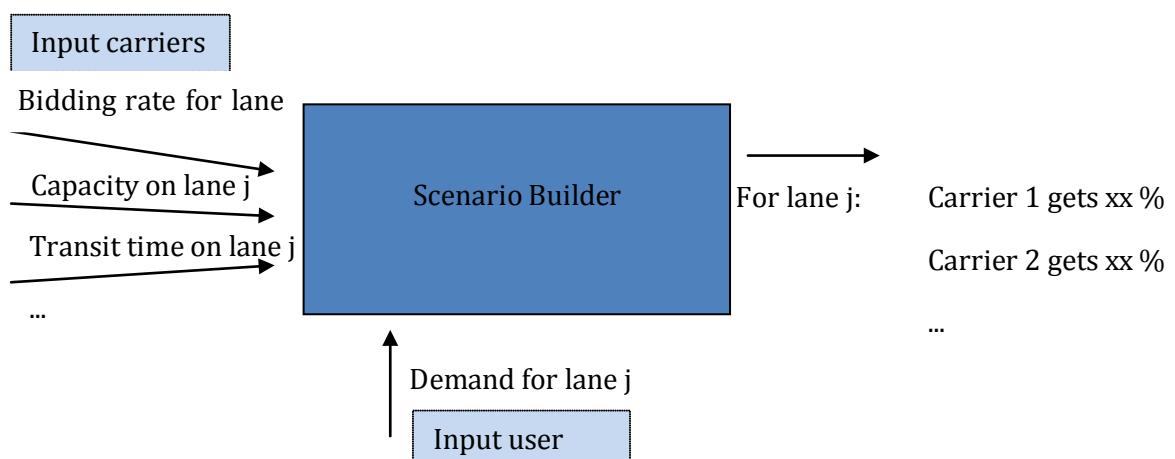
Sourcing, which describes different procurement practises such as selecting and engaging suppliers, is “a relatively new area compared to the more established practises like finance & accounting and HR” (Huber, Gupta, & Hegde, 2009). E-sourcing has gained importance through the last years due to its great savings potential. Especially the selection of a suitable supplier is an important factor for the overall sourcing performance (Sucky, 2005). Therefore, different practises such as sourcing optimization can be applied to find a (cost-)optimal transport volume allocation to the suppliers. In Elemica’s case, their optimization tool is not yet accepted by their customers. One of the reasons for this is that the tool has not been maintained during the last years. Therefore, it is questionable if it still represents the state-of-the-art in the field of advanced sourcing. Furthermore, the documentation on the tool is outdated so that there are some ambiguities about the tool’s mechanism. This master thesis aims to analyse and enhance the scenario builder in order to add value for the customer and to make it more competitive.

The main research question which should be answered with this thesis is the following:

How can the optimization tool which is provided by Elemica be modified/ renewed so that it adds additional value for the customer and can compete with other solutions that are available on the market?

In order to improve the tool, a necessary first step was to analyse its mechanism by inserting different input parameters and analysing the corresponding output. The following conclusions were made:

- The problem which is solved by the scenario builder is a vendor selection problem where the user wants to have a certain amount of transport goods been shipped on several lanes (each consisting of an origin and destination location). Different carriers hand in bidding rates for each lane. The scenario builder aims to assign all transport goods to the carriers so that the overall costs are minimized.
- Besides the bidding rates, carriers also have to state their capacities and expected transit time on each lane. Furthermore, there are several input parameters which are not mandatory but can be uploaded if the user requests them (s. table 29, appendix D).
- Moreover, different constraints are available to the user to limit the space of feasible solutions. A full list can be found in appendix D.





During the analysis of the scenario builder some flaws in the tool could be identified:

- Three of the constraints are actually not limiting the optimization problem but are instead converting the bidding rate, e.g. by adding a penalty factor. In order to avoid confusion a distinction between actual constraints and these conversion functions is made.
- Several constraints could not be motivated and others do not lead to the expected outcome. Table 4 (s. 4.1.3) lists all constraints that were changed in the new model formulation.
- According to Elemica's employees, the transit times which are inserted by the carriers are often too optimistic and deviate from the actual transit times.

In addition to the scenario builder analysis, a Situational analysis according to Steenburgh and Avery (2010) is performed which helps to get a deeper knowledge about the market for e-sourcing and to benchmark Elemica's optimization tool. The main findings of this analysis are listed below:

- Many companies, especially those with big transportation events, are considering the implementation of advanced sourcing services. Hereby, the most important incentive is to find cost-reducing alternatives.
- The market for e-sourcing is not yet saturated so that there are great opportunities to explore new markets and attract new customers.
- Elemica's main competitors have frequently maintained their sourcing optimization tools so that they are currently performing better in comparison to Elemica's scenario builder. Some features provided by the competition are not covered by Elemica's tool. Plus, due to the development of advanced optimization techniques, the runtime behaviour of the competitors' services outperforms the one of Elemica's tool.

Therefore, it is crucial for Elemica to enhance their optimization tool in order to stay competitive. After having summarized all findings in a SWOT analysis, a plan of action is developed for Elemica resulting in the following three action steps:

### **1) Enhancing User-friendliness**

During the analysis it became evident that the tool is sometimes not self-explaining. Therefore, the first step is to make the user experience more pleasant by guiding him stepwise through the scenario builder, giving clear instructions which parameters to fill in and explaining briefly how each constraint affects the outcome.

### **2) Developing a "clean" model formulation**

Since the mathematical model which has been formulated by an employee of Elemica includes several mistakes, the second action step foresees the development of a "clean" model which means that the underlying vendor selection problem has to be correctly described in mathematical terms. Moreover, the model's correctness is validated by implementing the model in GAMS- a high-level modelling system for mathematical programming models.

### **3) Adding more functionality**

After having developed and implemented a correct and simplified model, Elemica should add additional features and functions so that the user can make more specific transport requests to

his carriers. This paper presents an approach where chance constraints are added for the transit time which is assumed to be a stochastic parameter. This way an upper bound can be set to the possibility that the transit time exceeds a certain limit. Since Elemica has access to historic transit times, this data could be analysed in SPSS so that information about the average transit time of a carrier on a certain lane is available. Including this data gives a more accurate picture of a carrier's performance over time and therefore, adds valuable insights for users who are concerned about the good's timely arrival. Another advantage of this approach is that the chance constraint can be easily implemented into the model which can still be solved by using a branch-and-cut algorithm. Therefore, Elemica can continue using their Cbc solver or switch to another open-source solver (s. 6.2). A disadvantage of the approach with chance constraints is that a sufficient amount of data is needed in order to give a good approximation about the lane data's distribution.

In case Elemica wants to add more features as for example discount scheduling or a multi-objective approach with more stochastic parameters, advanced optimization techniques such as generic algorithms are needed. Therefore, the company needs to either invest in its own development capacities or outsource the development to one of the identified potential collaborators (s. 3.1.5). This decision depends on their priorities for development cost, speed and quality (s. 6.2).

## ACKNOWLEDGEMENTS

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This master thesis is the result of a project which took 1.5 years in total starting with the assignment of a mentor and resulting in this current paper. Various people have been involved in this project, everyone in his own way. I'd like to deeply thank those who supported me throughout the whole time:

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## 1 INTRODUCTION

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This thesis which is conducted at Elemica International B.V. aims to improve the scenario builder- a tool provided by Elemica which helps to identify cost-optimal transport volume allocations to the user's suppliers.

During this introduction part fundamental information about the company's profile and the problem situation at Elemica is given. Furthermore, the methodology which is used in order to structure the thesis is explained and an outline of the thesis is presented.

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### 1.1 COMPANY INFORMATION

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Elemica is a leading Supply Chain Operating Network (SCON) provider for the process industries whose vision is to give its customers total control over their global supply chains. By capturing transaction data across all trading partners and transforming this data into actionable information, customers can benefit from Elemica's services which help them to handle their supply chains in a more efficient way, e.g. by reducing information delays within the supply chain. Some of the main benefits of Elemica's SCON are that customers can automate their processes and integrate messaging, applications and analytics across a network of trading partners.

Elemica's network connects more than 5.000 companies from different industries and processes about 200 Billion \$ in annual transactions. The company is located in seven different countries all over the world with the headquarter being located in Philadelphia, US. Their customer base consists of companies such as BASF, Continental, Dow Chemicals, Michelin and Lanxess.

The company offers four different Software as a Service (SaaS) modules which are called SmartLink applications. While Logistics, Customer and Supply Management deal with classic supply chain processes, the Sourcing management module helps Elemica's customers to handle their sourcing processes more efficiently. Elemica offers solutions for the sourcing of different materials, products and services as e.g. raw materials, cleaning services, construction management etc. This thesis solely focuses on the sourcing of transportation events to third part logistic providers (3PL). Figure 21 (s. appendix A) gives an overview of all services that are offered by Elemica and how they are structured according to the four modules.

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### 1.2 PROBLEM SITUATION AND MOTIVATION

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According to Resource-based view (RBV) processes can be split into core and non-core processes where logistics is considered a non-core process in most organizations. If a company considers outsourcing parts of its organization, non-core processes should be rather outsourced than core processes according to the theory (s. 2.1.). Although most costs arise due to other factors (as e.g. material costs), transportation accounts for a spend amount that should not be neglected. Figure 1 shows the typical spend profile of a mid-sized manufacturing company

(Ghanti & Jha, 2013).

Category	Subcategory	Spend \$MM	
Direct Materials	Components	220	Core
	Rubber	50	
Government	Taxes	40	
Marketing	Creative Agency	20	
Logistics	Commercial Print	10	Non-Core
	Truckload	10	
	Ocean	10	
IT Products/Services	Small Parcel	10	
	Telecom	15	
	IT Hardware	5	
Machinery	Document Output	5	
	Dies / Cutting	7	
MRO	Material Handling	5	
	General Industrial	3	
Travel	Electrical	2	
	Safety	2	
	Air	3	
	Hotel	3	
<b>Total</b>		<b>420</b>	

- Constitutes 70–85% of annual spend
- Tightly controlled and purchased centrally
- Non-core could be direct (machinery, MRO) or indirect (marketing, logistics, IT)
- Companies typically do not focus on non-core purchases (constitutes 15–30% of annual spend)
- Purchasing is generally decentralized, limiting a uniform category approach
- Similar products are sourced from common supply bases in ad-hoc manner, reducing efficiency, and cost-savings opportunities.

FIGURE 1: TYPICAL SPEND PROFILE OF A MANUFACTURING ORGANIZATION (GHANTI & JHA, 2013)

The consultancy company Tata assigns the non-core processes which also include logistics a saving opportunity of 1-20%. One way to reduce costs is to source processes to another organization. Although outsourcing includes risks, it can lead to high cost-cuttings positively affecting a company's (financial) performance in case certain conditions are fulfilled (s. 2.1).

Companies that decide to outsource their transportation and logistics processes can make use of e-sourcing services such as Elemica's sourcing module. Using an automated electronic sourcing approach enables companies to accelerate their sourcing process and to make communication with the 3PLs more efficient. Moreover, it provides analytics, monitoring functions and other features (s. 2.2).

One of these features is Elemica's scenario builder- a tool that identifies cost-optimal transport volume allocations to 3PLs. By making use of this tool Elemica's customers can easily identify saving opportunities and compare their incumbent transport solution with other scenarios (what-if analysis). At the moment most of Elemica's customers are not making use of this function despite its great potential to identify savings. This master thesis aims to analyse why the scenario builder is not accepted yet and how it can be enhanced so that it adds more value to the customer. During the next subsection the main research questions are enumerated.

### 1.3 PROBLEM DEFINITION

As mentioned in the previous section Elemica's customers that have access to the sourcing platform do not make sufficient use of the scenario manager. A potential reason for this is that the tool has not been maintained during the last three years. Therefore, it is questionable if the tool still represents the state-of-the-art in the field of advanced sourcing techniques.

The following research questions are identified that run like a common thread through the thesis:



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### 1.3.1 RESEARCH QUESTIONS

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The main focus of the thesis is to analyse how the scenario manager can be enhanced so that it finds more acceptance on the user side and puts Elemica ahead of its competitors regarding advanced sourcing. Therefore, the following research question is formulated:

How can the optimization tool which is provided by Elemica be modified/ renewed so that it adds additional value for the customer and can compete with other solutions which are available on the market?

Additionally, several sub research questions should help to give support in order to find an answer for this main question. At the beginning the status quo of the tool should be investigated which means that its functionality and capacity have to be analysed.

- 1a) What is the objective of the optimization tool?
- 1b) Which parameters serve as input and output in order to solve the optimization problem?
- 1c) How can the optimization problem be described in mathematical terms?

Since the documentation on the scenario manager is scarce, one outcome of this thesis is a description on how the tool functions and the formulation of a mathematical model that represents the scenario builder.

According to Elemica one possible reason why most customers decide not to use the tool is that the objective function only considers which route is best in terms of costs. In real-life other parameters also have an influence on the transportation decision. Especially time and quality (e.g. reliability of the carrier) are important criteria.

Therefore, it should be analysed which other parameters need to be included in the optimization problem so that additional value for the user can be created. Also, each existing constraint should be motivated. This leads to the following research questions:

- 2a) Including which additional objectives would add value to Elemica's optimization tool from the perspective of the customers?
- 2b) What is the motivation for the existing constraints? Are they logical?

The next step includes a competitor analysis which should give insights about other solutions which are available on the market and how they perform compared to Elemica's optimization tool. This leads to the following set of sub questions:

- 3a) Which solutions are provided by competitors to optimize transportation events?
- 3b) How do they perform compared to Elemica's *scenario management* function?

Finally, Elemica wants to conclude the findings with a make-or-buy-decision about the development of the tool. Therefore, the following question can be asked:

- 4a) Is it more beneficial in terms of costs to develop the modified tool in-house or to outsource the development to an external company?

Therefore, this master thesis aims to give a description about how the tool can be improved based on the input from the Situational analysis and finishes with a financial analysis which answers the questions if it is more cost efficient to develop the tool internal or external

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### 1.3.2 SCOPE

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The outcome of this master thesis is a plan of action for Elemica including recommendations on how to improve the scenario builder based on the market analysis, plus a make-or-buy decision whether the tool should be (re-)developed in-house or by an external company.

The implementation of the enhanced scenario builder is not within the scope of this thesis.

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## 1.4 METHODOLOGY

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As methodology the regulative cycle by van Aken, Berends and van der Bij (2007) is used. It consists of six different phases which can be viewed in figure 2.

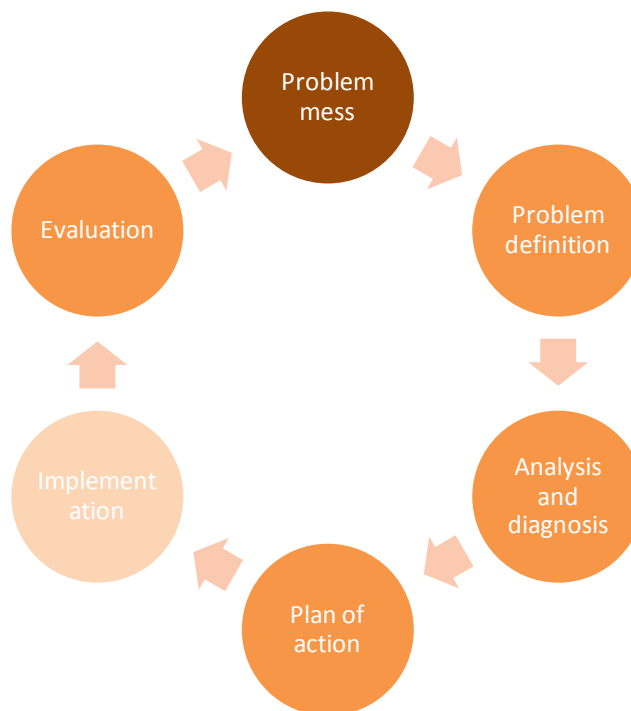


FIGURE 2: REGULATIVE CYCLE (VAN AKEN, BERENDS, & VAN DER BIJ, 2007)

As already stated the actual implementation is not included in the scope of this thesis. Therefore, only the first three phases plus the evaluation phase in the end are considered.

#### *Problem Definition:*

At the beginning the problem in the organization needs to be identified and formulated. Afterwards, a research design has to be developed. By gathering information at the company (e.g. interviews with employees, testing the optimization tool) the problem should be identified and articulated. Searching scientific literature helps to find a suitable methodological approach. This is the goal of the research proposal.

#### *Analysis and Diagnosis:*

The second step is about analyzing and creating an understanding for the nature of the problem. In order to deliver a proper analysis and diagnosis of the problem, it is necessary to understand the company, the product, the company's customers and the market in general. A Situational analysis is conducted which helps to get an understanding where the scenario builder can be positioned within the market.

*Plan of action:*

During this step a solution for the problem will be designed and a plan will be set up on how to implement the solution (s. 4.1.2.).

*Evaluation:*

This final step aims to give a future direction for the company. The success of the project should be measured by analysing its relevance for the company and the field of advanced sourcing.

In the original regulative cycle of van Aken et al. (2007) an implementation phase takes place between the analysis & diagnosis and the evaluation phase (s. figure 2). Its goal is to implement the recommendations from the plan of action within the company to enhance its performance. Van Aken et al. (2007) claim that a graduation project does not provide enough time to accomplish this phase. This is why the implementation phase is not within the scope of this project.

## 1.5 THESIS OUTLINE

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This master thesis is structured as follows: during the next chapter relevant literature about outsourcing is presented and linked to the thesis. Section three presents a Situational analysis that aims to give a detailed view on the market for e-sourcing and Elemica's position within the market. During a SWOT analysis all findings are summarized and a plan of action is set up. During chapter four the scenario builder is analysed and a mathematical model which describes the underlying mechanism is presented. Afterwards in section five, the model is validated by implementing it in GAMS. Finally, section six gives a conclusion and recommendations for Elemica. Moreover, a make-or-buy decision is performed whether Elemica should (re-)develop the optimization tool in-house or outsource it to an external company.

## 2 LITERATURE REVIEW

---

This section aims to give a theoretical foundation on the subject of (out-)sourcing. The sourcing decision is a key element of this master thesis since it affects it in two ways:

1. The scenario builder's purpose is to help Elemica's customers with making an enhanced sourcing decision by depicting a (cost-)optimal transport volume allocation.
2. In the end of the thesis a make-or-buy decision is made that helps to choose if the improvement of the scenario builder should be outsourced to an external company or if the tool should be (re-)developed in-house.

At first during this section a state-of-the-art of the literature on outsourcing is given including the main incentives for outsourcing, potential risks that are associated with it and theoretical frameworks that help to explain the parameters influencing the outsourcing decision and its outcome.

Afterwards, the background and history of e-sourcing and especially sourcing optimization is described and finally, the optimization problem that Elemica's scenario builder is solving is presented and current developments in the advanced sourcing field are named.

### 2.1 THE OUTSOURCING DECISION

---

The outsourcing decision or also referred to as make-or-buy decision concerns many companies of different sizes and from different sectors. In total "more than 90 percent of companies say that outsourcing is an important part of their overall business strategy" (Corbett, 2004). Outsourcing has a long tradition: during the mid-twentieth century outsourcing gained importance for companies in the manufacturing sector for industry goods (Hyder, et al., 2002). Nowadays also other departments such as HR, procurement or R&D are getting outsourced.

Companies that decide to outsource either parts of their production or services to another company might do this due to different reasons: cost savings, reduced development time, higher level of quality, enhanced innovativeness or a higher flexibility due to a lower commitment of internal resources are named as most common incentives (Kroes & Ghosh, 2010).

On the other hand outsourcing also includes certain risks. Especially, the risk of opportunistic behaviour by the supplying party is pointed out in the literature (Williamson, 1985), (Klein, Crawford, & Alchian, 1978). Opportunism becomes more likely when the supplying party is in the more powerful position, e.g. when an asset is very specific or only few companies offer the asset in the market. A company that behaves opportunistic usually offers its service at a higher cost.

Many factors influencing the outsourcing performance have been studied during the last decades and the literature gives various theoretical frameworks in order to identify these influences. One important finding is that the outsourcing decision is quite complex due to the existence of several trade-offs (Dabhilkar, 2011), (Holcomb & Hitt, 2007). One of these trade-offs is for example the positive correlation between the development time of an asset and the development cost. Also, the more specific and customized an asset is, the more likely it is that the supplying company offers it at a higher cost.

Two predominant theoretical underpinnings help identifying the main factors that are influencing the outsourcing decision and its outcome. These findings are relevant for the thesis since both theories will help to decide whether Elemica should outsource the development of a new scenario builder. The first main theory- Transaction Cost Economics (TCE)- was first

introduced by Wernerfelt (1984) and dominated the literature on outsourcing for years. TCE aims to identify and analyse the factors influencing the transaction costs which are “the costs of planning, adapting, coordinating and safeguarding exchange” (Cousins, Lamming, Lawson, & Squire, 2008). Table 23 (s. appendix B) lists all influencing parameters. One of the main findings of TCE is that certain governance mechanisms can help to keep transaction costs at a lower level and therefore, enhance the overall outsourcing performance.

The other main theory is the Resource-based View (RBV) which finds increasing support in the literature since the early 90es (Peteraf, 1993), (Barney, 1991), (Combs & Ketchen, 1999), (Leiblein & Miller, 2003), (Poppo & Zenger, 1998). The core idea of RBV is that companies are characterised by their distinct capabilities. In order to turn these into a value creating strategy companies need an efficient resource portfolio management. This does not only include the management of their internal resources but also finding suitable partner companies that help complementing the company’s strategy. Different factors such as a strategic relatedness with the supplier or a positive previous relationship can enhance the collaboration (Holcomb & Hitt, 2007) and lead to a competitive advantage for the outsourcing company.

During the last years several attempts have been made to create a framework that combines both theories and merge them with other foundations such as agency theory, organization theory, neo-classic economics and competitive strategy (Williamson, 1999), (Holcomb & Hitt, 2007), (Dabhilkar, 2011), (Poppo & Zenger, 1998), (Hoetker, 2005), (Jacobides & Winter, 2005) in order to include more factors and predict the outsourcing performance more accurately.

Besides these new frameworks, special interest has been paid to multi-objective decision making and the importance of strategic outsourcing. While in reality most companies still solely make their outsourcing decision based on costs, other factors such as timeliness or the quality of the supplier are also important criteria and should be included (Sucky, 2005). Strategic outsourcing means that also long-term costs and other factors are taken into account, as for example the costs for switching between different suppliers.

Various studies emphasize the importance of supplier selection and its impact on the outsourcing performance (Dabhilkar, 2011), (Sucky, 2005). During the last two decades software services have evolved that help to make better supplier selection decisions and different companies such as Elemica offer e-sourcing solutions that help their clients to source their goods.

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## 2.2 E-SOURCING

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Sourcing optimization is usually one part of the sourcing application (also called e-sourcing) which is defined as a “set of related solutions that support upstream procurement activities” (Wilson, Bergfors, & Adams, 2013). E-sourcing includes activities such as supplier selection, identifying saving opportunities, quantifying/ reducing supply risk, contract management, controlling and monitoring the performance of the suppliers as well as the procurement team (Wilson, Bergfors, & Adams, 2013).

While in the earlier periods bids have been exchanged in a paper-based process with many (re-)negotiation steps, sourcing has become a computerized process where suppliers hand in their bids in electronic form online. Both processes offer different advantages: while the advantage of the earlier one is that participants can be very expressive and specific about their transport requests (Sandholm, 2007), switching to an automated sourcing process accelerates the sourcing cycle, is more efficient and therefore more scalable compared to the conventional method. In contrast to paper-based sourcing, e-sourcing enables the user to contact multiple suppliers through an online tool (s. figure 3). During the 1990es a shift from plant-based to

global corporate wide sourcing took place and the need for an automated process became evident (Sandholm, Levine, Concordia, & Martyn, 2006). Also the internet boom during the 90es paved the way for online based sourcing (Sampaio, 2009).

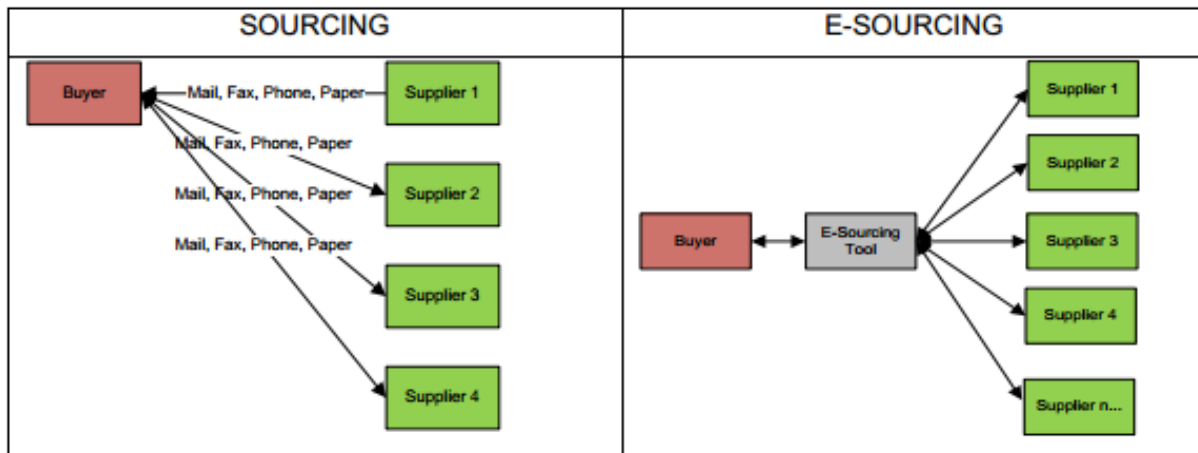


FIGURE 3: PAPER-BASED VS. ONLINE BASED SOURCING (SAMPAIO, 2009)

One way of making the automated process more expressive is to use combinatorial auctions<sup>1</sup>. This type of auction helps to identify if there are complementary bids which are economically more efficient when being bought together. Concerning transportation sourcing, a carrier might for example offer the customer a discount if he agrees to select him in both directions. Combinatorial auctions can be formulated as forward and reverse auctions<sup>2</sup>. While the mathematical model for the first type usually aims to maximize the revenue of the transport, the latter one yields to minimize the costs (Holland & O'Sullivan, 2005).

Another advantage besides the speed of e-sourcing solutions is that today's sourcing tools are able to cope with great complexity in the data. Buyers can make requests where they specify requirements for capacity, special handling, transit time etc. Moreover, some solvers are able to include suppliers' (conditional) discounts or more detailed cost drivers such as setup, transshipment and material costs (Sandholm, Levine, Concordia, & Martyn, 2006). This "new generation" of sourcing optimization tools tries to combine the advantages of an expressive language for both the bidder and seller and a quick, efficient process that leads to a (cost-)optimal solution (Sandholm, 2006).

Sourcing optimization applications, such as Elemica's scenario builder, solve an optimization problem which is referred to as the vendor selection problem or also supplier selection problem in the literature. The next section gives more information on this class of optimization problems and recent developments in the literature.

### 2.3 VENDOR SELECTION PROBLEM

The goal of the vendor selection problem is to find a transport quantity allocation that is usually optimal in terms of costs. Weber and Current (1993) define two decisions that have to be made: 1) which suppliers to select and 2) how much of the transport quantity should be assigned to the

<sup>1</sup> Combinatorial auctions were first introduced by Rassenti, Smith and Bulfin (1982) in order to assign airport landing slots. The advantage of combinatorial auctions is that combinations of discrete items could be obtained and bids could be bundled which makes the bidding process more efficient.

<sup>2</sup> Reverse auctions start with the highest bidding price that decreases until the bid gets confirmed by the buyer. Sandholm et al. criticize that reverse auctioning is not economically efficient and that these auctions "generally yield poor allocation decisions" (Sandholm, Levine, Concordia, & Martyn, 2006).



awarded suppliers. Therefore, the objective function of the vendor selection problem usually includes two decision variables which are of binary and integer type respectively. The vendor selection problem is NP-complete and (in the worst case) inapproximable in polynomial time (Sandholm, Levine, Concordia, & Martyn, 2006).

Most vendor selection models that appear in the literature propose a multi-objective approach. There are various reasons why a solely cost-motivated model is not practical when selecting a supplier. As already mentioned, other parameters such as the quality of the transport (e.g. goods arrive safely and undamaged at customer side), timeliness and environmental friendliness play an important role for the supplier selection as well. A cost-based selection method might foresee only one supplier in the optimal solution. In reality a high risk is associated with awarding a single supplier because strikes might occur, a supplier can go out of business or he might not be able to deliver in time. Especially, in order to guarantee the timely arrival of goods, distributing them among different suppliers makes sense. In case there is a high variability regarding the suppliers' prices a cost-optimal solution might also suggest switching suppliers frequently. In reality this might be harmful for the relationship with suppliers. In order to avoid a solution that only includes cost-optimal suppliers, constraints can be added to the optimization problem that ensure awarding certain suppliers or excluding others; e.g. a supplier can only be chosen if he can transport within a given transit time or if his capacity does not exceed a certain value.

Already in 1966 Dickson investigated different criteria that influence the supplier selection decision and rated their importance (s. table 24, appendix B). Dickson comes to the conclusion that "quality, delivery, performance history, warranties and claim policies, production facilities and capacity, price and technical capabilities" are the most influential parameters. Another study by Weber and Current (1993) on vendor selection literature until 1991 analysed which of the criteria listed by Dickson appears most often in the presented models. According to their research, "net price, delivery and quality" are most often mentioned. They argue that the increasing popularity of JIT production systems during the 1980s is related to the growing amount of proposed models including timeliness as an objective. Additionally, Weber and Current analyse which optimization technique the models make use of. They conclude that linear weighting models<sup>3</sup> are the predominant technique, followed by mixed integer and goal programming models whereas a more recent study by Ding et al. (2004) states that most models base on mathematical programming models. Ding et al. also criticize that random variables such as "demand volatility and lead-time variability" are too often neglected in the literature.

Including stochastic parameters within the vendor selection problem has become increasingly popular over the last decade. Especially, when a parameter shows a high variability, this can have a big impact on the transportation event and its costs. Table 25 (s. appendix B) summarizes the most recent literature on multi-objective (stochastic) vendor selection problems and names the parameters that are included plus the type of model. Most stochastic models work with so-called chance-constraints which add upper/ lower bounds for the probability that e.g. the transit time is lower than a certain amount of weeks or the demand equals a certain amount of units.

The scientists Ekhtiari and Poursafary (2013) argue that conventional algorithms are not sufficient in order to deal with the high complexity that arises due to the stochastic parameters. Therefore, metaheuristic algorithms are used, such as genetic algorithms, Artificial Bee Colony (ABC) or Particle Swarm Optimization (PSO).

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<sup>3</sup> Each criterion gets a weight assigned. The objective is to minimize the sum of the weight of the criteria multiplied with the criteria value.

This literature research gives a theoretical foundation for the ongoing thesis. During the next section a Situational analysis is conducted to investigate the state-of-the-art in the e-sourcing market and how Elemica's service performs in comparison to others.



### 3 SITUATIONAL ANALYSIS

A Situational analysis according to Steenburgh and Avery (2010) is performed in order to know where Elemica's scenario builder can be positioned in the market and how it performs compared to similar software solutions. Furthermore, the overall level of competitiveness within the industry is estimated with the help of Porters' Five Forces. During the SWOT analysis new trends, opportunities and threats are identified that help as input to improve the optimization tool.

The Situational analysis is organized in three steps which can be viewed in the figure below:

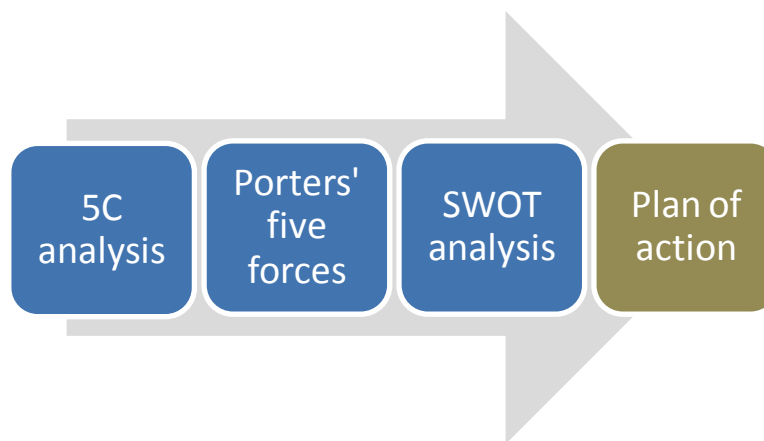


FIGURE 4: STEPS OF THE SITUATIONAL ANALYSIS

#### 3.1 5C ANALYSIS

First, a 5C analysis is conducted which helps to analyse Elemica's market environment and the performance of the scenario builder in contrast to competitor's sourcing optimization solutions. The first step is to describe the company's strategy, its history as well as the position of the provided software in the market. Afterwards, the technological and economic environment is studied and trends, opportunities as well as potential threats within the market are identified. Furthermore, the main competitors are named and compared with Elemica's performance. Finally, the needs of Elemica's customers concerning sourcing optimization should be further analysed and potential collaborators are identified.

##### 3.1.1 COMPANY

By conducting interviews with Elemica's employees insights could be obtained about Elemica's history, where the company sees itself in the market and which strategy the network provider follows. Here, we focus on the sourcing function and more specifically on logistic sourcing. Since Elemica has recently merged with another company called Rubber network a brief overview of the development of Elemica's tool and the merging with Rubber network's services is given (s. figure 5).

Besides logistic sourcing, Elemica also offers sourcing of other services, such as construction services, facility management, raw materials etc. Logistic sourcing which is characterized by big data sets including multiple lanes, carriers, locations etc. differs from the other types of sourcing due to its higher complexity. The logistic sourcing team of Elemica is spread over different

locations worldwide; in their Amsterdam office two people are working full-time on logistic sourcing.

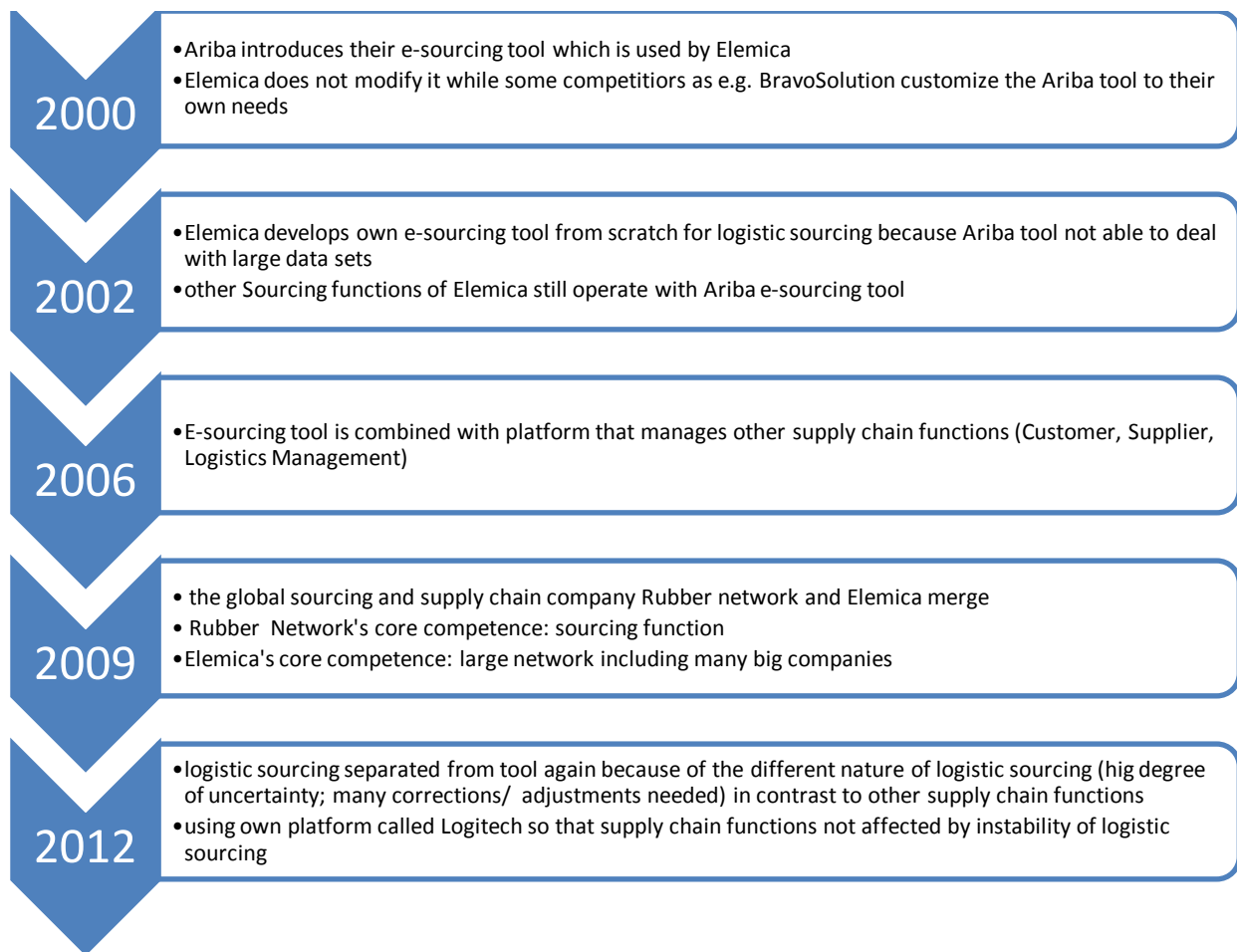


FIGURE 5: HISTORY OF ELEMICA'S LOGISTIC SOURCING FUNCTION

Elemica is focusing on the rubber and tire industry as well as the chemical industry. When they merged with Rubber Network in 2009 also their client bases were combined. While Rubber network was the leading sourcing provider in the rubber and tire industry, Elemica focused on chemical companies. Merging the two companies was beneficial for both of them since their services were complementary and together they could provide a whole suite to their customers including supply chain functions as well as e-sourcing applications.

Elemica is a region and industry specific provider focusing on the tire, rubber and chemical industry within the USA and Europe. One reason why Elemica is focusing on companies from these regions and industries is that they have similar needs regarding logistic sourcing, e.g. often similar information about transport characteristics is requested (capacity, special handling etc.).

Not all of Elemica's clients are using the whole suite; some of them only make use of several functions. Companies that are using the e-sourcing applications pay Elemica per project they want to source where projects can be bundled at a lower price so that the customers benefit from the economies of scale. Projects are priced according to the effort that is required. Senior Vice President for Europe and North America Sergio Juarez states that "Simple sourcing projects like reverse auctions or RFI's can be priced as standard products because they are [...] relatively easy to define and scope. The moment you go to more complex projects like tenders in transportation and logistics, [...] you will have to price based on the level of subject matter expertise time required and the size of the total deal to be sourced".

Different distribution channels are used in order to acquire new customers. These include marketing campaigns in sourcing conferences and presentations at purchasing forums where Elemica functions as a sponsor, offering pilot projects at a lower cost to new customers, mass e-mail campaigns to customers that make use of supply chain services and organization of round tables on current innovations. Elemica as a brand is well recognized in the industries where it is operating.

Elemica's development team that is maintaining the platform consists of five developers, one person working on quality assurance and one co-operator. The scenario builder has not been updated during the last years.

As a conclusion it can be stated, that Elemica's core competence is its supply chain functions (Logistics, Customer and Supply Management) which are also generating most of the company's profit. Concerning e-sourcing, their main competitive advantage is sourcing execution and their knowledge about the fields they are focusing on (Rubber, Tire and Chemicals).

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### 3.1.2 CONTEXT

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A context study should help to identify economic, demographic as well as technologic trends in order to get a better picture of the market for sourcing optimization and how it has evolved over the past years. Different studies conducted by the analyst companies Gartner, Aberdeen Group, InfoSys etc. serve as input.

The demand for sourcing solutions in general and for sourcing optimization in particular has been continuously growing over the last years and the market's potential is still not fully exploited. The reason for this is that with increasing amounts of international shipments and a higher number of intermodal transports, sourcing decisions become more complex and contacting each supplier individually gets a highly time-consuming process. E-sourcing which is an automated process can help to lower this complexity and make the process faster and more efficient. The analyst company Gartner (Wilson, Bergfors, & Adams, 2013) estimates the size of the whole procurement technology market as 2.7 Billion Dollars in 2012, where the "strategic sourcing suite accounts for approximately half the total market". According to another study which is conducted by the analyst company Aberdeen Group 50% of the firms that are interviewed in the study state that they plan to implement sourcing optimization solutions (Limberakis, 2012).

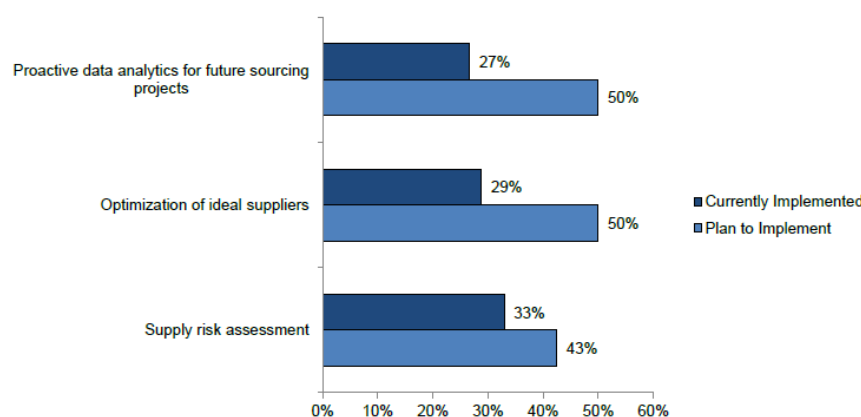


FIGURE 6: LAGGING ATTRIBUTES IN STRATEGIC SOURCING PROGRAMS (LIMBERAKIS, 2012)

One of the reasons is the application's potential to identify solutions that lead to reduced costs. In the Aberdeen study 72% of the interviewed companies state that their main incentive for applying strategic sourcing methods, which includes sourcing optimization, are "increased

level[s] of cost savings” (Limberakis, 2012). Also the economic/ financial crisis plays an important role: many companies were faced with decreasing profits after 2007 and had to identify new opportunities to reduce costs (Wilson, Bergfors, & Adams, 2013). Making use of sourcing optimization is a relative easy way to find cost-reducing solutions.

It is important to mention that logistic sourcing in general has gone through a lot of changes. While in earlier times transport units have been assigned in a long process where involved parties mainly relied on one-to-one phone calls (s. 2.2.), nowadays sourcing is conducted via electronic B2B market places which are usually web-based interfaces that help to fasten the process and make it more efficient by bundling several sourcing events and handling all involved carriers at the same time. Another change is that in the past companies usually chose only one vendor that was responsible for the whole transport, while today’s sourcing tools help to assign volumes to various vendors (Rossignoli, Mola, & Zardini, 2007).

While demand for sourcing (optimization) solutions is high and increasing, also the number of companies entering the market for sourcing solutions is growing. This forces companies to develop strategies to stay competitive. Therefore, many providers decide to offer customized services to their users in order to satisfy their (often) unique requirements regarding outsourcing solutions (Huber, Gupta, & Hegde, 2009).

Another economic trend is the high number of acquisitions that took place during the last years, e.g. SAP acquired the sourcing provider Ariba, IBM acquired Emptoris and SciQuest bought CombineNet in order to add a sourcing function to their suite, Also Elemica merged in 2009 with the sourcing company RubberNetwork (s. 3.1.1.).

The next step is to identify demographic trends regarding the companies providing sourcing applications. According to a survey conducted by the analyst company Gartner an “explosion of region and industry specific vendors” took place over the last years (Wilson, Bergfors, & Adams, 2013). These vendors rather focus on a specific region or industry in order to use their knowledge to provide customized services for their clients. A disadvantage for these companies is that they are often restricted to the market they are focusing on. As already mentioned a lot of new emergent vendors - mainly small firms- entered the market during the past decade but also global players such as SAP, IBM and other started providing more advanced sourcing functions by acquiring companies that are specialized in this field. According to Gartner ERP system providers are not competing efficiently because they can often not “successfully support upstream procurement activities” (Wilson, Bergfors, & Adams, 2013). By merging with a company specialized in advanced sourcing, big ERP providers could solve this problem and add value to their provided services. According to Gartner the typical vendor is a small size company with an average of 92 employees.

Not to mention most revenue is currently obtained in the US and Europe, while also the importance of new markets in Central/ South America and the Near East grows (Wilson, Bergfors, & Adams, 2013).

Finally, technologic trends within the market are named. First of all, an increasing demand for additional functionality has shaped the market for sourcing tools during the last years. While traditional strategies such as reverse auctions and RFX still build the core of companies’ sourcing tools, advanced techniques such as “optimization and integration with spend analysis and supplier management” offer more opportunities to the user (Limberakis, 2012). Although, these advanced sourcing tools are not that widely used yet<sup>4</sup>, the Aberdeen group concludes in their study that the companies that belong to the “best-in-class” have implemented these techniques

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<sup>4</sup> According to the study by the Aberdeen Group only 29% of the interviewed companies have implemented sourcing optimization techniques in their business processes.

(Limberakis, 2012). Especially, companies using sourcing optimization techniques perform better than the average. Considering these findings, it is not surprising that the number of companies considering the implementation of advanced sourcing techniques is high (s. figure 6).

Another trend concerns strategic sourcing whose objective is to “obtain a consolidated view of a commodity and to determine the total cost of that commodity before making a procurement decision based on price alone” (Limberakis, 2012). Overall, 68% of all respondents that take part in the Aberdeen study state that strategic sourcing plays a prominent yet critical role in their organizations. This is in line with recommendations from the scientific literature (Sucky, 2005) that stresses the importance of a multi-objective view when sourcing to an external party (s.2.3). Besides an attempt to include more multi-objective parameters, strategic sourcing also means having a long-term view on sourcing, for example building strong collaborations with vendors. In order to support the strategic approach, it is important that “sourcing activities and strategies need to be aligned with the ones of the greater organization” (Limberakis, 2012) which means that different departments such as operations, finance and IT collaborate and a standardized sourcing processes is implemented.

Figure 7 summarizes all identified trends within the market for e-sourcing.

Economic	Demographic	Technologic
<ul style="list-style-type: none"> <li>• High and growing demand for sourcing (optimization) solutions</li> <li>• Increasing number of new vendors; market becomes more competitive</li> <li>• High number of acquisitions</li> </ul>	<ul style="list-style-type: none"> <li>• Region and industry specific vendors</li> <li>• Mainly small companies ; but also global players (usually acquire smaller companies that provide e-sourcing)</li> <li>• Main markets: US and Europe</li> <li>• New markets: South America, Near East</li> </ul>	<ul style="list-style-type: none"> <li>• Shift to web-based electronic marketplaces</li> <li>• Additional advanced functions (analysis, optimization)</li> <li>• Strategic sourcing (e.g. multi-objective view)</li> </ul>

FIGURE 7: SUMMARY OF ECONOMIC, DEMOGRAPHIC AND TECHNOLOGIC TRENDS IN THE INDUSTRY

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### 3.1.3 COMPETITORS

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This section aims to name Elemica’s main competitors in the field of sourcing optimization and to compare their performance with Elemica’s. One important source is a bi-yearly report which is created by the analyst company Gartner in order to benchmark companies providing procurement services (Wilson, Bergfors, & Adams, 2013). The results of their analysis are summarized in the so-called magic quadrant where companies are assigned to four categories (s. figure 8).

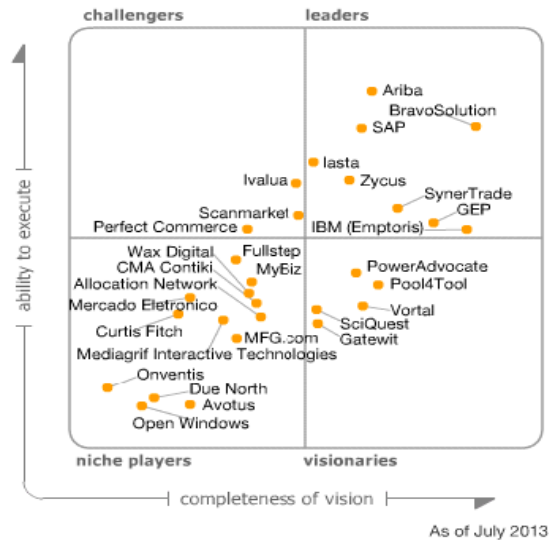


FIGURE 8: MAGIC QUADRANT FOR SOURCING APPLICATIONS SUITES (WILSON, BERGFORS, & ADAMS, 2013)

Besides the consideration of the report, also employees at Elemica have been asked and a Telco meeting with Gartner has taken place in order to identify the main competitors regarding advanced sourcing. Finally, three companies could be identified who are CombineNet (since 2013 part of SciQuest), Trade Extensions and BravoSolution. The magic quadrant only shows the performance of SciQuest (without CombineNet) and BravoSolution. The reason why Elemica, Trade Extensions and CombineNet are not listed within the report is that they did not fulfil the criteria. (The report focuses on the procurement suite as a whole and not only sourcing optimization. Trade Extensions and CombineNet are not providing a complete procurement suite.). However, Gartner lists CombineNet as a company “worthy of consideration” for e-sourcing and Elemica “worthy of consideration” for b2b integration and transaction enablement. Table 1 gives an overview of the companies’ backgrounds and summarizes their strengths and weaknesses.

TABLE 1: COMPETITOR SUMMARY

	CombineNet/ SciQuest	Trade Extensions	BravoSolution
<b>Founded in</b>	CombineNet was founded in 2000; Acquired by SciQuest in 2013	Trade Extensions was founded in 2000; merged with Freight Traders (UK-based logistics sourcing solution provider) in 2009	2001
<b>Locations</b>	USA (4 offices), Canada, UK, Germany	Sweden (3 offices), USA (2 offices), UK, Canada, France	Italy, UK, France, Germany, Spain, Netherlands, USA, Mexico, Brazil, United Arabian Emirates, Pakistan, Oman, China and Australia
<b>(Financial) performance</b>	revenue of SciQuest in fiscal year 2013: \$90.23 million (2014)	No numbers found for revenue	2012: \$81 million (WirelessNews, 2013)



<b>Industry focus</b>	Retail, consumer packaged goods, food and beverage manufacturing, quick-service restaurants	Retail (20% of sales) and manufacturing (50% of sales) (Smith, Spend Matters UK/ Europe, 2014)	five business sectors (industry, food, construction, transportation and government)
<b>Scope of the tool</b>	SciQuest provides whole suite (before: CombineNet offering advanced sourcing services)	sourcing platform + e-sourcing and optimization solutions	BravoSolution provides whole suite
<b>Strengths</b>	<ul style="list-style-type: none"> <li>- Continuous updates of sourcing optimization tool</li> <li>- Strong development team; high level of expertise regarding optimization techniques (developed very fast tree search algorithms to solve vendor selection problem)</li> <li>- Corporation with universities (CEO and founder Sandholm himself was professor at Carnegie Mellon University)</li> <li>- SciQuest dominates US procurement market (high brand recognition especially in higher education and state/local government markets) (Wilson, Bergfors, &amp; Adams, 2013)</li> </ul>	<ul style="list-style-type: none"> <li>- High knowledge on optimization algorithms</li> <li>- Pioneer in combinatorial auctions (did the first combinatorial auction worldwide in 2001)</li> <li>- Corporation with universities (CEO and chairman Andersson is expert and was working as professor at university of Uppsala for computer science)</li> <li>- well established in local Nordic markets (Scandinavia) (Smith, Spend Matters UK/ Europe, 2014)</li> </ul>	<ul style="list-style-type: none"> <li>- Strong e-sourcing module; rated as one of the top five e-sourcing providers by Gartner and in top three for sector sourcing and optimization</li> <li>- Large business service organization</li> <li>- Strong functionality and event management expertise in transportation sourcing (Wilson, Bergfors, &amp; Adams, 2013)</li> </ul>
<b>Weaknesses</b>	<ul style="list-style-type: none"> <li>- Due to many acquisitions: some functions are overlapping (e.g. e-sourcing and contract management)</li> <li>- Users concerned about changes due to acquisitions (Wilson, Bergfors, &amp; Adams, 2013)</li> <li>- although both CombineNet and SciQuest big on the US market, little influence in Europe (Smith, Spend Matters UK/ Europe, 2013)</li> </ul>	<ul style="list-style-type: none"> <li>- not well established in the States yet (although this is one of the biggest markets) (Smith, Spend Matters UK/ Europe, 2014)</li> </ul>	<ul style="list-style-type: none"> <li>- Weak functionality for post execution contract process (no references for commodity risk management)</li> <li>- No supplier directory</li> <li>- Very dependent on financial performance of parent company Italcementi Group who holds 80% of shares (Wilson, Bergfors, &amp; Adams, 2013)</li> </ul>

CombineNet as well as Trade Extensions profit from deep knowledge on sourcing optimization techniques and both companies collaborate with universities. BravoSolution does not develop all algorithms in-house but works together with companies that are specialized in the ICT sector as e.g. Ariba for their e-sourcing function.

In 2013 CombineNet updates their E-sourcing platform and improves it with new features such as “expressive bidding, creating customized analytics and optimizing award decisions” which make the tool more scalable so that it can deal with bigger data sets. Thanks to their unique concept of expressive bidding, customers can profit from “the advantages of highly expressive human negotiations with the advantages of reverse auctions” (Sandholm, 2007).

Also the analyst company Gartner considers CombineNet as the best-in-class when it comes to sourcing optimization. While BravoSolution is rated as one of the leading companies regarding

the whole procurement suite (s. figure 8), they cannot completely compete with CombineNet's high knowledge on sourcing optimization techniques. E.g. the tree-search algorithms that solve the vendor selection problem at CombineNet are the fastest in the world (Sandholm, 2007), more robust compared to other algorithms and able to solve very big datasets with up to 2.6 million bids and 300.000 side constraints (Sandholm, 2006).

Although Trade Extensions also has deep knowledge on sourcing optimization, their revenue is mainly obtained through licenses and not sourcing projects. Plus, their current focus is to broaden their sourcing optimization to more categories instead of enabling it to deal with a higher complexity. Therefore, CombineNet can be declared as Benchmark Company in sourcing optimization. Still due to the merging with SciQuest in autumn 2013, it is questionable how these organizational changes will affect the company's performance in the future.

The analyst company Spend Matters states that Trade Extensions as "the last remaining specialist player in this field" (Smith, Spend Matters UK/ Europe, 2013) could profit from CombineNet's uncertain position. According to another expert voice from Gartner, Elemica is able to rise up to CombineNet but in order to do this; technologic changes within the sourcing optimization tool are needed. E.g. CombineNet's solver still offers more functionality (discount schedules, advanced capacity constraints) to the user than Elemica's tool does.

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#### 3.1.4 CUSTOMERS

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This section aims to identify the most common companies' sourcing methods, the influences for the customer's decision to use e-sourcing (optimization) software and what usually drives their decision to select suppliers.

Instead of conducting a customer analysis and interviewing Elemica's customers who have access to the sourcing application, reports from analyst companies, scientific literature and interviews with Elemica's employees have been used as input. The reason for this is mainly that Elemica's customers are currently not using the scenario management function so that they cannot share their experience.

A market survey which was conducted by CombineNet among 100 top commercial companies (not CombineNet customers) about their preferred sourcing methods indicates that the majority of firms uses Excel spreadsheets. The second biggest group- companies that have an e-sourcing and procurement suite implemented in their business- makes partially use of Microsoft Excel. According to the study 74% of e-Sourcing users use spreadsheets to create RFPs and to collect bids while 85% use Excel to analyse their bids (CombineNet Market Survey, 2011).



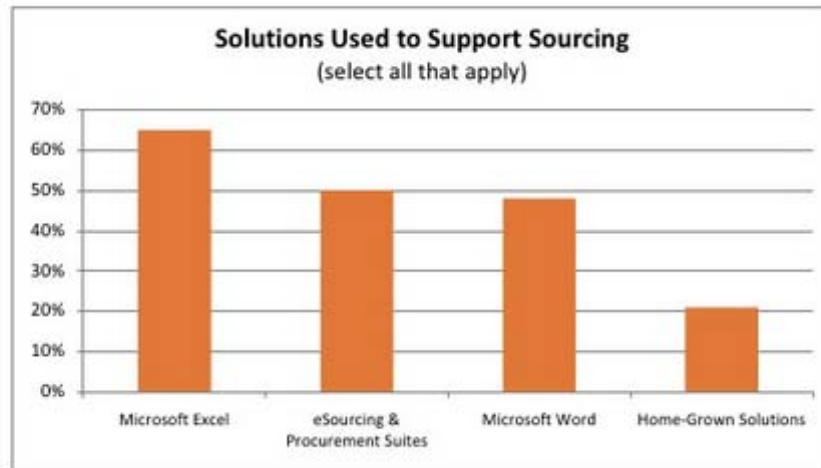


FIGURE 9: PREFERRED METHODS FOR SOURCING (COMBINENET MARKET SURVEY, 2011)

CombineNet argues that general sourcing tools are not designed for more complex sourcing events. They conclude that companies need to switch to automated e-sourcing techniques when dealing with more complex events or bigger data sets. Another study conducted by the Analyst Company Aberdeen Group clusters companies in three groups: Best-in-class, Industry average and Laggards. It is investigated which automated sourcing techniques are implemented by which group to which extend. Figure 10 shows that Best-in-class companies are more likely to use an automated process for sourcing optimization, event analysis and other sourcing functions (Limberakis, 2012). The result identifies a gap between Best-in-class and Laggards regarding all automated sourcing functions. The Industry average and Best-in-Class companies use similar functions. However Best-in-Class companies deviate from the average regarding their use of sourcing optimization: while 50% of Best-in-class companies have implemented sourcing optimization processes only 7% of the laggards did.

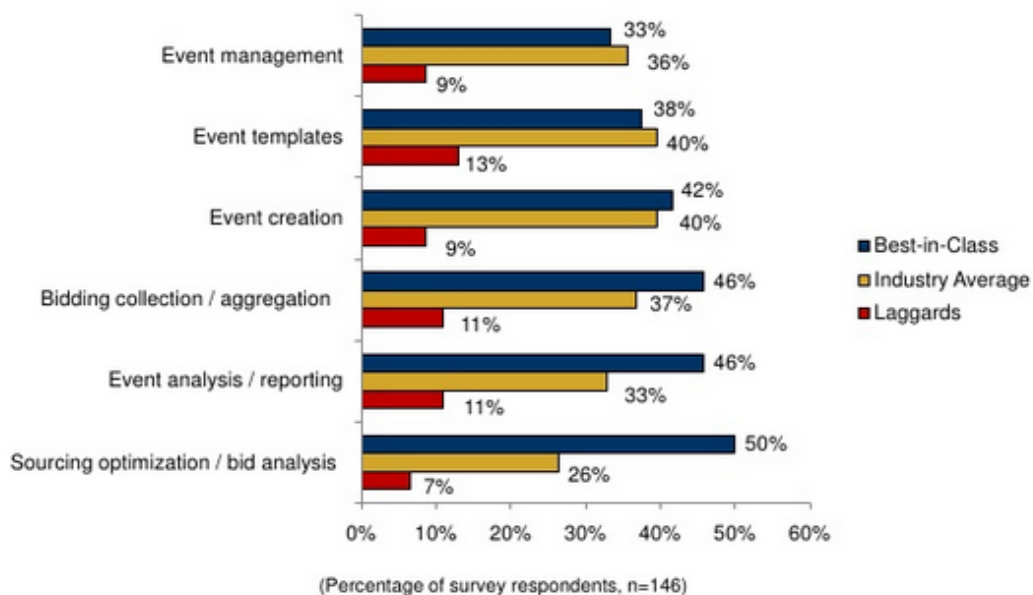


FIGURE 10: IMPLEMENTED AUTOMATED SOURCING FUNCTIONS (LIMBERAKIS, 2012)

During the same study companies were asked which criteria determine their decision to select a SaaS supplier. The results show that companies primarily make their decision based on the

degree of functionality and features (Limberakis, 2012). Regarding sourcing optimization, this could be interpreted as a trend towards tools that are able to cope with higher complexity and more different constraints so that companies can express their transport requests more precisely.

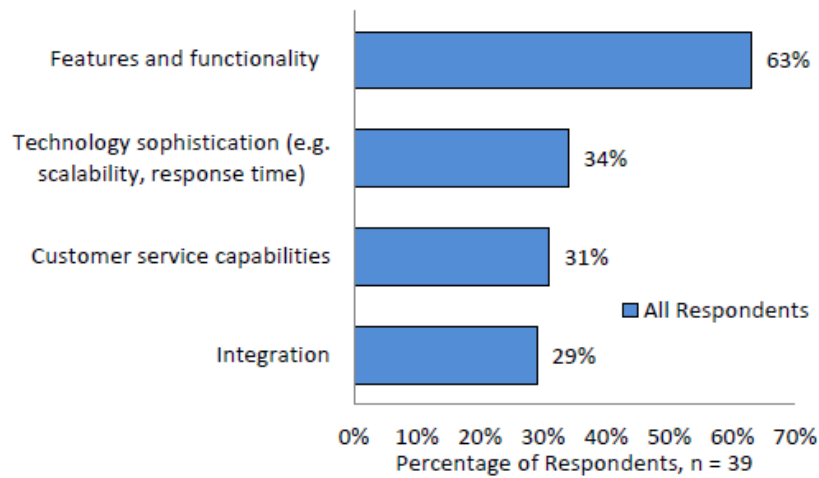


FIGURE 11: SELECTION CRITERIA FOR A SAAS PROVIDER (LIMBERAKIS, 2012)

Furthermore, the interviewed companies were asked to name the main pressures to use strategic sourcing which also includes the application of sourcing optimization. In total 69% of all respondents named “the corporate mandate to reduce costs/ increase savings” as the main reason to choose strategic outsourcing. The study also revealed that the ability to find cost-decreasing solutions is seen as the main benefit of strategic sourcing.

Another question that should be answered is which parameters customers include when they select a supplier for their own sourcing events. According to studies by Dickson (1966), Weber and Current (1993) and a more recent one by Sucky (2005), input parameters such as quality and timeliness play the most important role besides the cost (s. 2.3.). These objectives can also be found in the study conducted by the Aberdeen Group (s. figure 12) where a “need to improve sourcing performance” and “need to mitigate supplier risks due to supply disruptions” are named as third and fourth most important pressure to apply strategic sourcing.

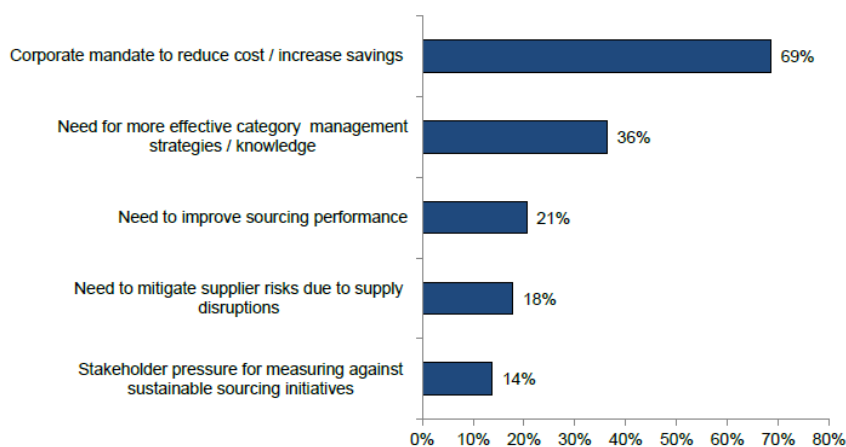


FIGURE 12: TOP PRESSURES FACING A STRATEGIC SOURCING PROGRAM (LIMBERAKIS, 2012)

It can be stated that customers are primarily driven by incentives to lower costs but that especially the quality of the collaboration with the supplier is a highly important factor for the sourcing decision.

Finally, the results from the mentioned reports lead to the conclusion that companies who implement advanced sourcing into their processes tend to perform better than companies that are not making use of these tools. Another interesting finding is that customers prioritize “features and functionality” of SaaS the highest.

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### 3.1.5 COLLABORATORS

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The last part of the Situational analysis includes the identification and investigation of collaborators which are in this case potential suppliers of a new software solution for Elemica. Based on the competitor analysis and expert voices from analyst companies three main potential collaborators are chosen. During the following part the three companies are presented and advantages/ disadvantages of a potential collaboration are enumerated.

#### *Ariba*

Ariba was founded in 1996 in Sunnyvale, California. Acquired by SAP in 2012 it is now part of the global player as the “cloud procurement product line”. With 3.000 employees Ariba is bigger than the average provider of procurement software. The company’s core competence is its sourcing application which was developed in the 1990es by Free Market- a software company bought by Ariba. Analyst Company Gartner rates Ariba as one of the top five companies regarding sourcing and as one of the leading firms in the procurement software market (Wilson, Bergfors, & Adams, 2013). Furthermore, Ariba has developed the other modules of Elemica’s procurement suite (Logistics, Supplier and Customer Management) so that this cooperative experience (s. 2.1) can have a positive impact on the collaboration. According to Gartner Ariba also worked closely with Elemica’s competitor CombineNet but since the acquisition by SciQuest their collaboration is weakened. As Ariba’s weaknesses the “limited support for public sector sourcing” and that “Activities related to SAP’s acquisition of Ariba [are] likely to be a distraction” are named in the Gartner report (Wilson, Bergfors, & Adams, 2013).

#### *CombineNet*

As already mentioned during the competitor section, CombineNet can be viewed as one of the main or even the biggest player in sourcing optimization. Especially their knowledge on algorithms and constraint optimization gives them a competitive advantage. Moreover, their strategic direction towards more complex bidding events and multi-objective optimization are in line with trends that could be identified in the market. Also analyst company Gartner confirms that CombineNet is ahead of its competitors when it comes to advanced sourcing. This makes CombineNet an attractive collaborator for Elemica. Although CombineNet’s and Elemica’s tools are similar, the sourcing solution of the competitor provides some additional feature such as conditional offers and the option to express complementarity between bids which are not covered by Elemica. On the other hand, it is questionable if a collaboration is possible since both software providers are focusing on the US market and helping Elemica to improve their sourcing tool might harm CombineNet/ SciQuest. Also the acquisition by SciQuest might lead to some uncertainty regarding CombineNet’s future development.

### Trade Extensions

The Swedish company Trade Extensions has already been introduced and analysed during the competitor part. Similar to CombineNet the company benefits from their development capabilities and a good knowledge on sourcing optimization algorithms and modelling. Although their sourcing optimization tool might be less evolved compared to CombineNet's, Trade Extensions also tries to dominate the advanced sourcing market with its "beyond sourcing" approach (Smith, Spend Matters UK/ Europe, 2012). A unique feature is the mapping capability of the tool where supply chain routes and the associated risks are being visualized in a "what if" analysis.

In order to judge which company is the most suitable for a "buy" decision, factors from RBV are taken into consideration (s. figure 13).

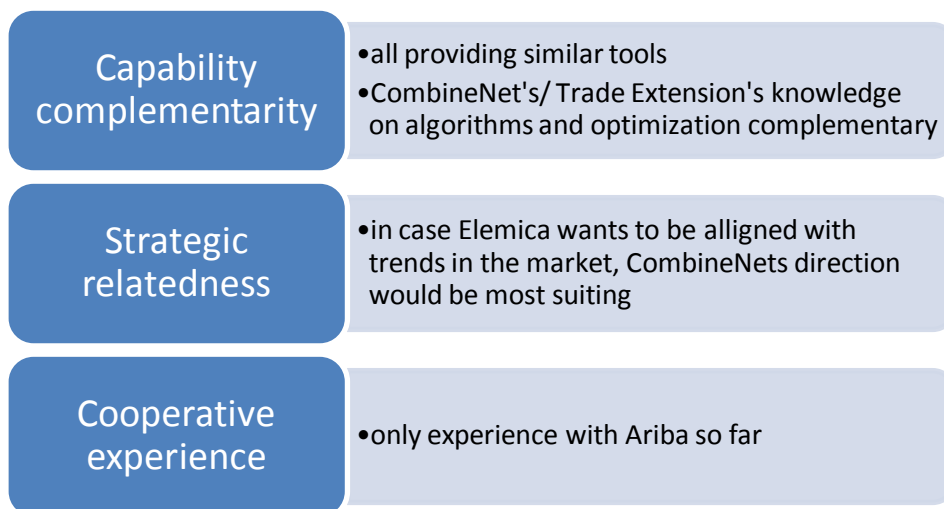


FIGURE 13: RBV FACTORS FOR CHOOSING A POTENTIAL COLLABORATOR

All three providers might be suitable for a further corporation. In the end, it is important to know how high the associated costs are. Therefore, requests need to be formulated and sent to the companies. Also, the risk which is associated with a potential collaboration has to be considered.

The main findings of the Situational analysis are

- that there is a high and growing demand for advanced sourcing techniques which also includes sourcing optimization. Furthermore, the market's potential is not fully reached yet so that there are various opportunities for Elemica to attract new customers.
- that customers' main incentive to use advanced sourcing solutions is its cost-decreasing potential. When choosing a procurement solution provider, their decision is primarily based on functionality and features.
- and that Elemica needs to improve its Scenario builder in order to stay competitive since the tools offered by competitors CombineNet (SciQuest) and Trade Extension currently perform better.

## 3.2 PORTERS' FIVE FORCES

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The second part of the Situational analysis includes Porters' Five Forces. Michael Porter first introduced this framework in 2008 in order to analyse the degree of competitiveness within an industry (Porter, 2008). Although the 5C analysis already gives insights about Elemica's main competitors, the Porters' Five Forces draw a wider picture by analysing the density of the market, the entry barriers for new companies and the availability of substitutes outside the market.

### *Threat of New Entrants*

As stated during the context analysis (s. 3.1.2), the market for e-sourcing has been steadily growing since its revolution 15 years ago. Not to mention the market changes very quickly: new technologies are introduced such as faster algorithms that accelerate the search for an optimal supplier, smaller companies with high expertise are acquired by global players (s. 3.1.2) and customers demand more and better features (s. 3.1.4). This gives new entrants the opportunity to identify niches that are not yet satisfied. Since the e-sourcing market is relatively new, it has not matured yet and there are still several possibilities to exploit.

Still, new entrants need to make sure that they follow a good strategy to stand out from their competitors and to find a niche in the market. Companies within the e-sourcing industry are mainly competing on functionality so that it is crucial to add innovative features to the software solution which provide additional value to the customer. Also, a success-based pricing strategy, e.g. one that agrees on being paid a fraction of the savings achieved by the sourcing project, can help to attract more customers.

Although not very high investments in physical assets are required, new entrants need to ensure that they have a skilled development team or invest in patents for existing algorithms/ optimization techniques. Furthermore, the trend from stand-alone solutions to combined suites that offer different functions (Sampaio, 2009) forces companies to provide a whole procurement suite to the customer in order to stay competitive. Offering the latter requires larger investments and therefore, entrance barriers are higher. Another option is to collaborate with a company that has complementary capabilities to provide a whole procurement suite together.

### *Threat of Substitutes*

Here, only substitutes outside the market for e-sourcing software are considered. As stated during the customer analysis (s. 3.1.3), the majority of sourcing activities is still supported by Microsoft Excel. However, using spreadsheets can only be applied for sourcing events on a small scale. When data sets become bigger and more constraints have to be considered, Excel does not provide sufficient support. Therefore, it can be argued that there are no perfect substitutes for advanced sourcing outside the market.

### *Bargaining Power of Buyers*

How powerful consumers are depends on many factors such as the availability of substitutes, the switching costs, the price sensitivity of the users, the asset specificity of the product etc. In general the bargaining power of the buyers can be rated as rather low. The reason for this is that most customers are big global operating companies that are less price sensitive than small or medium sized firms. Plus, their sourcing events are often very complex and include big datasets so that using spreadsheets does not provide sufficient support.

Although exact numbers for switching costs are difficult to estimate, a study conducted by AT Kearney suggests that in order to implement e-sourcing successfully into daily business, high investments in training activities and reengineering of sourcing processes are needed

(A.T.Kearney, 2011). High switching costs generally lead to lower bargaining power of the buyers.

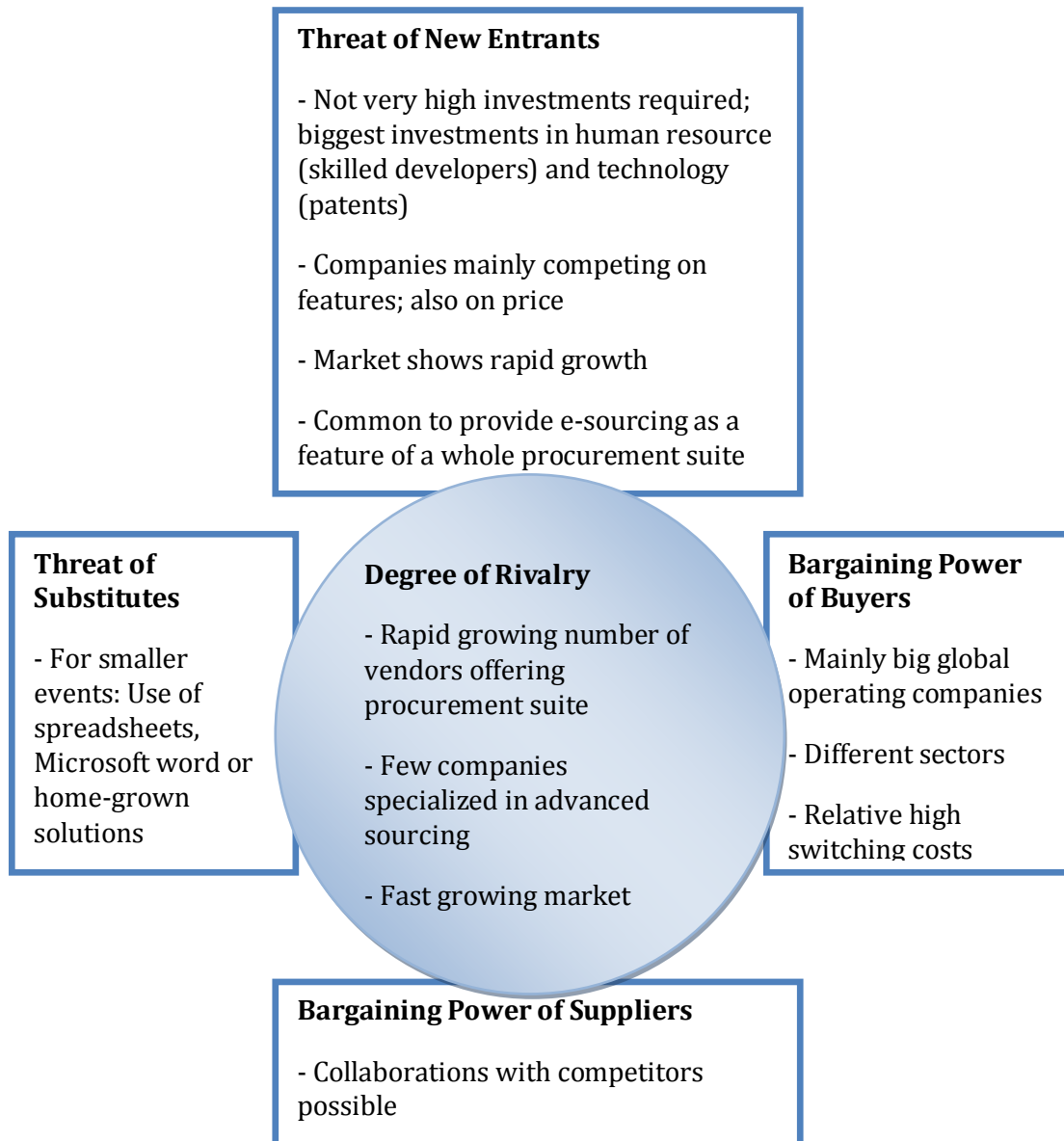


FIGURE 14: SUMMARY OF PORTERS FIVE FORCES

#### *Bargaining Power of Supplier*

A provider of e-sourcing software can develop the platform and its content in-house, (partially) outsource functions to an external company or merge with another provider for procurement software. This mainly depends on a company's own development capabilities. A make-or-buy decision can help to analyse which option is cheaper and more beneficial. Therefore, it is difficult to give a general answer to the question of how high the bargaining power of suppliers in the field of e-sourcing is.

#### *Degree of Rivalry*

At first glance the market for procurement SaaS seems quite dense: e.g. the "Magic Quadrant" report which is launched by the analyst firm Gartner includes 29 different vendors from the procurement industry. But when looking closer at the market, it can be concluded that different

vendors satisfy different needs so that the market is not very concentrated. Although there are also global players in the field (e.g. SAP, IMB), most companies are rather niche players focusing on a specific (local) industry.

The same applies to advanced sourcing. Besides CombineNet and Trade Extensions, only few other companies (BravoSolution, Emptoris, Iasta) “have capabilities in their broader suits” (Smith, Spend Matters UK/ Europe, 2013) to support advanced analytics, sourcing optimization etc. Thus, the degree of rivalry can be rated as rather low especially for solutions enabling advanced sourcing.

Finally, it can be summarized that the market for e-sourcing shows a healthy growth and therefore, companies can generate higher revenues without competing aggressively against each other. Figure 14 lists the key points of the Porters’ Five Forces.

During the next section the results from the 5C analysis and Porters’ Five forces are brought together in a SWOT analysis. Also, observations on the scenario builder’s mechanisms are evaluated.

### 3.3 SWOT

During this section all results from the previous analysis and the observations of the scenario manager are summarized in a SWOT analysis. This tool helps to identify the strengths and weaknesses of Elemica’s e-sourcing and advanced sourcing service. Moreover, opportunities in the market for e-sourcing and more specifically sourcing optimization are identified. Additionally, potential threats that can harm Elemica’s performance in the e-sourcing market are enumerated.

In order to develop a plan of action it is crucial to get an accurate picture on what is happening in the sourcing market and how Elemica is currently performing in contrast to its competitors.

TABLE 2: SWOT ANALYSIS

<b>Strengths</b>	<b>Weaknesses</b>
<p><i>e-Sourcing</i></p> <ul style="list-style-type: none"> <li>• Since merging with RubberNetwork providing whole procurement suite (in line with trend providing whole suites instead of stand-alone solutions)</li> <li>• High knowledge regarding tire, rubber and chemical industry</li> <li>• Good brand recognition within these industries</li> <li>• Sourcing execution process</li> <li>• Marketing: using multiple channels to increase awareness</li> </ul> <p><i>Scenario Builder</i></p> <ul style="list-style-type: none"> <li>• USP: Information about past transportation events (date of delivery, transit time etc.)</li> </ul>	<p><i>e-Sourcing</i></p> <ul style="list-style-type: none"> <li>• Limited brand recognition in other sectors (not tire, rubber and chemical industry)</li> </ul> <p><i>Scenario Builder</i></p> <ul style="list-style-type: none"> <li>• Scenario builder not very user friendly <ul style="list-style-type: none"> <li>○ Few instructions e.g. on how to use scenario builder, activate constraints, fill in parameters</li> <li>○ Constraints not always intuitional</li> <li>○ Input fields not always intuitional</li> <li>○ Cannot return to previous page with browser (error message)</li> </ul> </li> <li>• No standard for pricing structure of bid rates; no explanation which costs included in bid rate &gt; lack of transparency</li> <li>• Filling in data is time-consuming for customer</li> <li>• Scenario builder has not been maintained during last years</li> <li>• Documentation on optimization model</li> </ul>



	<p>includes flaws and not complete; no “clean” formulation; person who developed model not working for Elemica anymore</p> <ul style="list-style-type: none"> <li>• No advanced sourcing features such as “discount scheduling” or the option express compatibility between items provided (lagging behind competitor CombineNet)</li> <li>• Solver’s run-time for big datasets (competitor CombineNets tree-search algorithm much faster)</li> </ul>
<p><b>Opportunities</b></p> <p><i>e-Sourcing</i></p> <ul style="list-style-type: none"> <li>• Sourcing events become more complex and can often not be handled with Excel/ Word anymore &gt; automated process needed &gt; Growing demand for e-sourcing solutions; potential to acquire new customers</li> <li>• Focus on new market (new industry: e-sourcing used in many different sectors; new country: less saturated markets e.g. in South/ Latin America)</li> <li>• Competitor’s vulnerabilities: CombineNet might be weakened due to acquisition (restructuring, relocating etc.)</li> </ul> <p><i>Scenario Builder</i></p> <ul style="list-style-type: none"> <li>• High demand for advanced sourcing (analysis, sourcing optimization); many companies planning to implement advanced sourcing &gt; potential new customers</li> <li>• Number of providers specialized in advanced sourcing is fairly limited &gt; not very competitive field</li> <li>• Competitors specialized in advanced sourcing “not out of reach” (according to Gartner)</li> <li>• Collaborating with other e-sourcing provider (sharing capabilities; joined knowledge)</li> <li>• High switching costs: once trained to use Elemica’s sourcing function; less likely to switch to competitor</li> <li>• Developing advanced algorithms that solve optimization problem in less time</li> <li>• Adding multi-objectivity to optimization tool; so far only</li> </ul>	<p><b>Threats</b></p> <p><i>e-Sourcing</i></p> <ul style="list-style-type: none"> <li>• Low acceptance on Customer side (sticking to conventional sourcing methods such as MS Excel/ Word) also due to high switching costs (reengineering process; training employees)</li> <li>• Technologic challenge: Difficult challenge to provide highly customized solutions but still having an automated process</li> <li>• New market entrants (number of entrants very high during last years) &gt; forces Elemica to stay competitive</li> <li>• Cheaper e-sourcing providers (e.g. tools developed in emerging countries at a lower cost)</li> </ul> <p><i>Scenario Builder</i></p> <ul style="list-style-type: none"> <li>• Good development capabilities of competitors (especially Trade Extension and SciQuest/ CombineNet) &gt; possibility of improving/ developing new algorithms before Elemica does; optimization techniques; high development speed</li> <li>• Collaborating with other e-sourcing provider (s. 2.1.; risks of outsourcing; especially opportunism; high development costs)</li> </ul>



considered through constraints (by Elemica and competition); not included in objective function > competitive advantage	
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One of the main disadvantages of the scenario builder is that some constraints and input fields are not self-explaining and require further explanation. Unfortunately, documentation on the tool is scarce. The analysis part of this master thesis gives insights about how each constraint affects the solver's outcome and also points out different flaws in the tool. One action that should be taken by Elemica in order to make the user's experience of the scenario builder more pleasant is to give clear explanations what each function does and what kind of input data is required. Instructions on how to activate the constraints and to set the scope would help the user to navigate through the scenario builder.

The optimization problem has been formulated by an employee of Elemica. It includes several flaws in the formulation: e.g. the slack carrier is not included, some of the constraints do not appear in the actual scenario builder and the notations include mistakes. An open-source MIP solver called Cbc (Coin-or branch and cut) is used to solve the optimization problem. Since the scenario builder has not been maintained or modified during the last years and competitors could enhance their tools in the meantime, Elemica's optimization tool does not represent the state-of-the-art in the market for advanced sourcing. The "Best-in-class" company CombineNet offers a so-called "expressive bidding" solution where customers can precisely express their transport requests. Although Elemica's solution also offers additional flexible input fields where the user can specify his request, CombineNet's tool provides additional features such as "discount scheduling" and "bundled item offers" that are not covered by Elemica's optimization tool.

Furthermore, CombineNet's tool performs better when it comes to scenario optimization since their user interface is easier to use and more self-explaining. (s. appendix C). Moreover, the run-time behavior of CombineNet's solver outperforms Elemica's service when it comes to bigger data sets. The competitor's solver performs better due to the advanced tree-search algorithms it uses. The algorithms which are developed in-house and patented by CombineNet belong to the fastest in the world according to Sandholm (2006).

### 3.4 PLAN OF ACTION

In order to stay competitive Elemica needs to improve their scenario builder by a) making it more user-friendly, b) "cleaning" the model and c) adding more functionality. A higher level of user-friendliness can be achieved by providing a better documentation and guiding the user step-wise through the scenario builder.

"Cleaning" the model means that the optimization problem should be described correctly in mathematical terms. The mathematical model which has been developed by Elemica includes mistakes. Therefore, an improved formulation will be created during the next section of this thesis.

Finally, the aim is to add features to the scenario builder that put Elemica's service ahead of its competitors instead of simply imitating the competitor's solutions. One feature which is not implemented yet is the use of multi-objective optimization problems which means that not only the costs are optimized but simultaneously other parameters are taken into consideration. According to the literature timeliness and quality of the supplier are the most important objectives (Sucky, 2005). So far the timely aspect of the transport is only implemented as a

conversion function where an additional cost is added if the transit time deviates from the incumbent transit time. Estimating how much an additional day of delay costs is a difficult task and many parameters have to be considered. So far the user inserted a cost that is a rough estimation and therefore, it does not lead to exact results. Also, it is questionable if the carriers give exact transit times for the lanes when they're requested to upload their bids.

Elemica captures data about past actual transit times for ocean freight which is unique for a sourcing solution provider. Using this data about transit time can help to get a good approximation about average transit time and the variance for a specific carrier on a lane. This will lead to more exact results. Therefore, past lane data needs to be analysed for systematic patterns and a model is needed that includes transit time as a second objective besides transportation costs.

This section helped to create a plan of action how Elemica's scenario builder can be improved so that it can successfully compete with rivalling services. Particular interest is paid to the question how additional value can be added to the service so that the customer benefits. During the next section the scenario builder's mechanism is explained and all flaws that have become evident during the analysis are enumerated. Furthermore, a new mathematical model according to the plan of action is created.

## 4 SCENARIO BUILDER

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During the fourth section the scenario builder's mechanism is described and afterwards, a mathematical model is formulated. Since the scenario builder and also its documentation have not been maintained during the last three years, the most recent documentation is outdated. Therefore, this section aims to give a detailed description of the tool's mechanism. Not to mention, the mathematical model which has been developed by one of Elemica's employees in 2010 includes mistakes in the formulation so that a corrected model is a necessary first step in order to optimize the tool.

By inserting different input parameters and analysing the corresponding output, the scenario builder's mechanism could be derived. During the analysis, it became evident that there are flaws in the scenario builder, e.g. some constraints do not lead to the expected outcome. Therefore, the new model deviates from the underlying model of the scenario builder.

At the beginning of this section it is explained how the bidding process takes place, which input data is requested from carriers and how the scenario builder works. Afterwards, the enhanced mathematical model is presented, explained and validated.

### 4.1 OPERATION BREAKDOWN

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The scenario builder is one sub function of the Transportation and Logistics Sourcing Platform. Its purpose is to identify cost-optimal transport volume allocations and to compare a user's incumbent solution to other alternative allocations. Besides the scenario manager there are several other sub functions which are listed in the table below.

TABLE 3: FUNCTIONS OF THE TRANSPORTATION SOURCING AND LOGISTICS PLATFORM

<b>Sub function</b>	<b>Description</b>
<b>Lane Management</b>	Creating lanes and modifying them
<b>Event Management</b>	Viewing events, creating new events, customizing events (defining required information from carriers), modifying events
<b>Bids</b>	Checking bids received from carriers
<b>Locations</b>	Adding locations and modifying them
<b>Rate Management</b>	Overview of all transportation rates; statistics about carriers, rates etc.

If the user wants to create a new transportation event, he needs to ensure that the lanes (as well as the origin and destination location) already exist in the system. Otherwise he needs to add new lanes (or locations) to the portal.

During the next subsection the input data which is requested by the carrier is named and the bidding process is explained. The scenario builder can be used after receiving the bidding rates from the carriers.

#### 4.1.1 INPUT DATA FROM CARRIERS

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First, a company who is looking for a suiting carrier creates an event where they can determine the information they request from the other party (s. appendix D, table 29). This makes the platform flexible since the user is not restricted to a general form but can instead specify which data is important for his decision. This flexibility is important since input data for transport events varies between different regions worldwide. This is why every customer uses by default

the same input parameters but has the option to activate more additional input fields in order to formulate a customized request to his carriers.

Furthermore, the user specifies the dates when the bidding rounds should take place and which carriers to invite to each round. The user can still change the data concerning bidding rounds, invited carriers etc. via the according functions (s. 4.1.).

Once a bidding round is opened carriers can either place their bids online or via Excel file uploads. The following information has to be filled in by each carrier for each lane for the transport mode ocean:

- Bidding rate (price/ transported unit)
- Sailings per year
- Commitment per Sailing<sup>5</sup>
- Transit time
- Direct or Transshipment (if the latter one is the case he has to insert the transshipments port(s) as well)

Besides this mandatory information the carriers can also hand in more information about the transport depending on what the user requests (s. appendix D, table 29). Based on this information the company can decide which carrier fits the event the best. If they do not choose a carrier during the first round, a second round gets initiated etc. This goes on until a carrier is chosen or the final round is over. (The company specifies the amount of bidding rounds.) Figure 15 shows the bidding process where the pointed line describes the possibility to create an event and choose lanes that already exist in the system.

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<sup>5</sup> Depending on the values for “Sailings per year” and “Commitment per Sailing” the carrier’s capacity for this lane can be calculated.

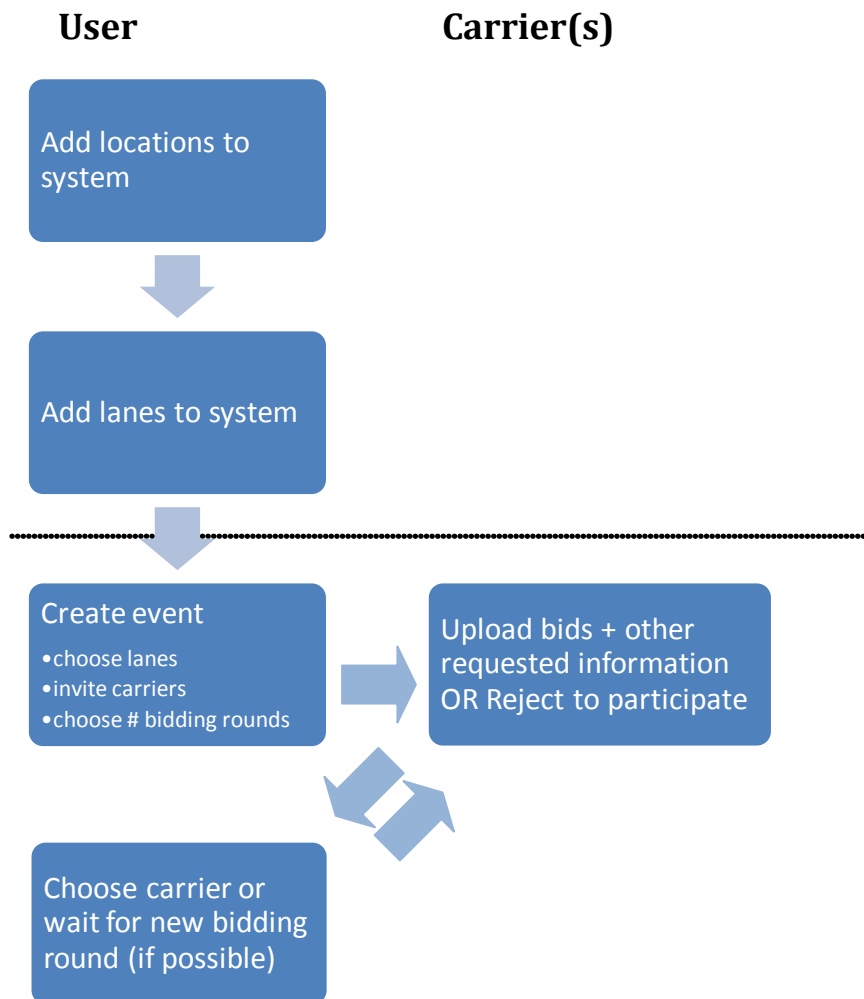


FIGURE 15: BIDDING PROCESS

#### 4.1.2 SCENARIO BUILDER MECHANISM

The scenario management function is a web-based user interface. Its purpose is to optimize a transportation scenario where the user wants to assign transport volumes to his carriers so that the overall transportation costs are minimized. The benefits of the scenario builder are that the user can analyse how his incumbent solution performs in contrast to other possible solutions. Additionally, the tool helps to identify if there is a better solution (in terms of cost) for his scenario.

The user starts by creating a new scenario which requires three steps:

- Naming scenario
- Choosing an event that was created before
- Choosing a (bidding) round for which the volume allocation should be optimized (*Note: The amount of carriers usually decreases from round to round. Some carriers that are still participating in one round might lose their interest and leave the scenario or the user himself might cancel the invitation for the next round.*)

Furthermore, the user is free to select from a list of constraints that can be added to the optimization problem:

### Activating Constraints

After the scenario is built, different constraints which are listed in table 31 (s. appendix D) can be activated. First, the user chooses the constraint he wants to activate, e.g. “Set minimum award” and afterwards, he can define a scope which means that he chooses bids which are affected by the constraint. Table 30 (s. appendix D) shows all options for defining the scope.

FIGURE 16: SCREENSHOT OF THE SCENARIO MANAGER; ADDING CONSTRAINTS TO THE OPTIMIZATION PROBLEM

For example, the user could select the constraint “Set maximum award to xx percent” (s. Figure 17). In case he does not specify the scope, all bids are considered in the optimization problem and the solver would only award xx percent of the transport quantity to the carriers. The rest would be assigned to a dummy carrier whose bidding rate equals the one of the most expensive (real) carrier.

However, it makes more sense to set a scope for this constraint because there is no reasonable explanation why he does not want his whole transport volume to be shipped. Therefore, he can choose from a scope menu which bids should be affected by the constraint (s. table 30, appendix D). He could, for example, choose a carrier (s. figure 18) whose award should be maximum xx percent or he could determine that all bids with a transit time of more than three weeks should only be awarded with maximum xx percent (because these bids present a risk in terms of timeliness to the customer).

FIGURE 17: SCREENSHOT OF THE SCENARIO MANAGER: SETTING SCOPE FOR CONSTRAINT

Sometimes the lanes do not include all data that can be selected within the scope menu. E.g. information about business units or the equipment type is often not available (because the user did not request it). In this case no bids are affected and the optimizer ignores the constraint. It is also possible that the combination of activated constraint and selected scope is not logical, as e.g. favor a specific lane. Unfortunately, the tool does not consider this and the user has to make sure

that his selection is logical and data is available. Otherwise the solver states that the model is infeasible but does not give further insights about what causes the infeasibility.

During the analysis of the scenario manager which has been developed by creating three dummy carriers to insert different input parameters and by observing the output, it becomes evident that three constraints are rather “conversion functions” since they are not restricting the optimization problem.

#### *Conversion Functions*

In addition to the constraints the user can activate conversion functions which appear in the menu for activating constraints but actually do not restrict the problem. In order to avoid confusion they are called conversion functions throughout the thesis. The following functions are available in the menu:

- **Adjust for each day difference between the bid and legacy transit times by xx dollar**

If there are legacy transit times available which are the transit times of the incumbent solution the user can activate this constraint in order to penalize/ award the new carrier for deviating from the incumbent transit times. This additional cost is added to the total cost. *(Note: the adjustment can also be negative meaning that the total cost decreases in case the new solution has better transit times than the incumbent solution.)*

- **Penalize by xx percent or xx dollar**

A penalty cost for specific user can be added. This means that their bid rates get converted into the actual bid rate plus a penalty cost. The optimization tool compares these new bid rates when identifying the least expensive carrier for each lane.

- **Penalize xx percent for each 1% increase in the market rate**

An increase in the market rate means that the annual demand  $q_j$  goes up. For each 1% increase certain carriers can be penalized. This works the same way as the penalize conversion function (s. above). Also for this conversion function legacy values have to be available.

These functions converse the actual bidding rates of the affected carriers and add/ subtract a certain cost. Afterwards, the model is solved given the conversed bidding rates.

During the validation of the scenario manager, data about the incumbent solution was not available, so that the optimization problem which is described during the next section does not consider these functions. During the next sub section all flaws that could be identified during the analysis of the scenario builder are listed.

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### 4.1.3 PLAN OF ACTION FOR THE SCENARIO BUILDER

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As stated before, the new mathematical model deviates from the underlying model of the scenario builder. Since some constraints could not be motivated or the obtained results did not seem logical they were changed or eliminated in the mathematical model. The following table lists all observations that were considered as illogical and how they were changed in the new model:

TABLE 4: CRITIC ON SCENARIO BUILDER AND HOW IT IS IMPLEMENTED/ CHANGED IN THE NEW MATHEMATICAL MODEL

Scenario Builder	Critic	New Mathematical Model
<p><i>Bidding rate slack carrier</i></p> <p>The dummy carrier (“slack carrier”) is always chosen when the transport quantity cannot be transported by other carriers (due to constraints or capacity restrictions). His bidding rate equals the one of the most expensive carrier.</p> <p>The mathematical model does not mention the slack carrier.</p>	<p>In reality backorders would arise in this situation where the cost of backorders deviates from the bidding rate of the most expensive carrier.</p>	<p>The slack carrier is still chosen when transport volume cannot be shipped by the other carriers. The mathematical model includes the slack carrier in the objective function.</p>
<p><i>Favor constraint not leading to expected results</i></p> <p>Without further specifying the scope, the favor constraint does not have an impact on the solution. If a certain carrier is favored, he will get all transport units assigned that he can transport according to his capacity.</p>	<p>The inserted % value does not affect the favor constraint. In a scenario with two carriers all transport units are assigned to carrier 1 when carrier 2 is favored with less than 17 percent and the total volume is assigned to carrier 2 when he is favored by at least 17 percent. For the case with three carriers different results are observed. Therefore, no pattern could be derived.</p>	<p>The constraint is not included in the scenario builder. If a carrier should be awarded with all transport volume; the min. award constraint can be set to the according transport volume for this carrier. This leads to the same result.</p>
<p><i>Min. number of carrier constraints cannot be motivated</i></p> <p>The min. number of carrier constraint aims to check if there are enough selected carriers in the solution. If this is not the case one bid is awarded to a non-cost-optimal carrier (who is not part of the solution yet) so that the cost increases the least.</p>	<p>After activating the constraint the solution only changes slightly (one transport unit awarded to other carrier). In reality awarding additional carriers results in higher overhead costs. Therefore, the overall costs would go up.</p>	<p>The constraint is not included in the new model because it could not be motivated.</p> <p>In case the user wants to make the supply chain more competitive by awarding more different carriers, he can use the min. award constraint.</p>
<p><i>Max. award constraint not leading to expected results</i></p> <p>The “Set maximum award (if awarded)” constraint awards the carrier with the double amount of the inserted value.</p>	<p>Not clear why the double amount is awarded.</p> <p>Also a difference between the purpose of this constraint and the “Set maximum total award” could not be found.</p>	<p>In the mathematical formulation this constraint is not included.</p> <p>If the user wants to limit the max. award for a subset of bids, he can set a scope and use the max. award constraint.</p>



<p><i>Min. # of bids (per lane) constraint cannot be motivated</i></p> <p>The “Set minimum number of bids” and “Set minimum number of bids per lane” are supposed to ensure that a minimum number of carriers is transporting on a certain lane. This makes sense if for example the customer needs to ensure the timely arrival of the goods.</p>	<p>Although this constraint makes sense in theory, the scenario builder usually only assigns one item to the more expensive carrier (in case two carriers should share the transport goods for the lane.) It can be doubted that the lower risk that is associated with this solution can compensate the higher overhead costs that occur when the user collaborates with more suppliers.</p>	<p>The constraint is not included in the new mathematical model. By activating the minimum award constraint for a certain lane and carrier a lower bound can be set for this bid and the same effect can be achieved.</p>
<p><i>Transit time</i></p> <p>In case data about the user’s incumbent solution is available, he can choose to add a penalty cost to the bidding rates of carriers where the expected transit time deviates from the expected transit time of the incumbent solution.</p>	<p>Estimating how much a day of delay costs, is a difficult task where many factors have to be considered. Therefore, this approach is only a vague estimation of the expected costs.</p>	<p>Instead of making use of the conversion function, a constraint is added so that only bids can be awarded where the expected transit time does not exceed an upper bound.</p>

During the next sub section the enhanced mathematical model is presented and explained.

## 4.2 MATHEMATICAL MODEL

The scenario builder tries to solve a so-called vendor selection problem (or also supplier selection problem, s. 2.3.). In order to simplify this problem some assumptions are made

- For simplicity reasons only direct shipments are allowed.
- All carriers hand in bid rates for each lane. In reality the carriers can also refuse to hand in bids which means that they reject to participate in the bidding process.
- If two or more carriers have the same bid rate, the carrier is preferred who places his bid first in the system.
- Backorders are not considered. In case carriers cannot transport more volume (due to their capacity restrictions) a dummy carrier called “slack carrier” can take over the volume. This assumption is made because there is no information about backorder costs available.
- The slack carrier is only selected if no transport volume can be assigned to the other carriers (due to capacity and/ or maximum award constraints) although his bidding rate is equal to the one of the most expensive real carrier.

The table below lists all relevant parameters:

TABLE 5: VARIABLES FOR VENDOR SELECTION PROBLEM

Parameter	Explanation
$q_j$	Annual volume for lane $j$ ; $j \in J$
$c_{ij}$	Capacity for bid $(i, j)$ ; $(i, j) \in I \times J$
$p_{ij}$	Bidding rate for bid $(i, j)$ ; $(i, j) \in I \times J$
$a$	Max number of selected carriers
$v_{max}$	Max. awarded transport volume to bids in scope
$v_{min}$	Min. awarded transport volume to bids in scope
$r_{ij}$	Binary variable indicating if bid $(i, j)$ is in the scope
$s_{ij}$	Binary variable indicating if bid $(i, j)$ is in the scope
$t_{ij}$	Transit time of carrier $i$ on lane $j$
$t_{j,max}$	Max. allowed transit time on lane $j$

Each bid is defined as a tuple consisting of a carrier and a lane:  $(i, j) \in I \times J$  where the two subsets represent the Carrier  $i \in I = (1, \dots, n)$  with  $n =$  number of carriers and lane  $j \in J = (1, \dots, m)$  with  $m =$  number of lanes.

A slack carrier that is not part of the carrier set is assigned to all the remaining transport volume. His transport volume on lane  $j$  is therefore  $x_{Sj} = 1 - \sum_{i=0}^n x_{ij}$  and his bidding rate equals the one of the most expensive carrier:  $p_{Sj} = \max\{p_{1j}, p_{2j}, \dots, p_{nj}\}$  for  $\forall j \in J$ . Moreover, his capacity  $C_{Sj} = q_j$  for  $\forall j \in J$  so that the demand can always be satisfied.

The decision variables are defined as:

- $x_{ij} =$  fractional allocation quantity assigned to bid  $(i, j)$
- $y_i = \begin{cases} 1, & \text{if carrier } i \text{ is selected} \\ 0, & \text{otherwise} \end{cases}$
- $w_{ij} = \begin{cases} 1, & \text{if carrier } i \text{ is awarded on lane } j \\ 0, & \text{otherwise} \end{cases}$

The optimization problem is defined as

$$\text{Min} \sum_{i=0}^n \sum_{j=0}^m p_{ij} x_{ij} q_j + \sum_{j=0}^m p_{Sj} x_{Sj} q_j + \sum_{i=0}^n y_i + \sum_{i=0}^n \sum_{j=0}^m w_{ij}$$

s.t.

$$\sum_{i=0}^n x_{ij} + x_{Sj} = 1, \quad \forall j \in J \quad (1)$$

$$x_{ij} q_j \leq c_{ij}, \quad \forall (i, j) \in I \times J \quad (2)$$

$$0 \leq x_{ij} \leq 1, \quad \forall (i, j) \in I \times J \quad (3)$$

$$y_i \in \{0, 1\}, \quad \forall i \in I \quad (4)$$

$$w_{ij} \in \{0, 1\}, \quad \forall (i, j) \in I \times J \quad (5)$$

Optional Constraints:

$$\sum_{i=0}^n y_i \leq a \quad (6)$$

$$\sum_{j=0}^m x_{ij} / m \leq y_i, \quad \forall i \in I \quad (7)$$

$$\sum_{i=0}^I \sum_{j=0}^J r_{ij} x_{ij} q_j \leq v_{max} \quad (8)$$

$$\sum_{i=0}^I \sum_{j=0}^J s_{ij} x_{ij} q_j \geq v_{min} \quad (9)$$

$$w_{ij} t_{ij} \leq t_{j,max} \quad \forall (i, j) \in IxJ \quad (10)$$

$$x_{ij} \leq w_{ij} \quad \forall (i, j) \in IxJ \quad (11)$$

The objective function is to minimize the cost for the entire transportation event where the cost is calculated by taking the assigned quantity per bid  $x_{ij}q_j$  and multiplying it with the bidding rate which is the price per transported unit for bid  $(i, j)$ . If the quantity equals zero, this means that nothing is assigned to the bid. The second term equals the cost that occurs by assigning transport volume to the slack carrier. Also the number of selected carriers and the number of awarded bids should be minimized which is expressed by the last two terms of the objective function. This way it is ensured that constraint (6) and (11) are only awarding a carrier (a bid) if necessary (s. below).

The user can activate several constraints when he builds a scenario. By default no constraints are activated so that the scenario builder goes through each lane, compares the bid rates the carrier have inserted per lane and chooses the carrier that is the least expensive. Each lane has an annual volume  $q_j$  that should be transported on this lane. The least expensive carrier gets as much of  $q_j$  assigned as his capacity on that lane  $C_{ij}$  allows him which equals  $\min\{C_{ij}, q_j\}$ . If the annual volume cannot completely be transported by the least expensive carrier, the second best carrier in terms of costs gets identified, then the third best carrier etc. This goes on until the annual volume for each lane is completely assigned. If there are not sufficient carriers or they do not have sufficient capacity, a dummy carrier called “slack carrier” is assigned with the remaining volume. It is assumed that the “slack carrier” has a transport capacity that equals the demand so that backorders are not considered by the tool. The worst case would be if the slack carrier had to ship all the transport volume.

The first constraint determines that the sum of all assigned fractional transport volumes equals one on each lane so that the demand is always met. (*Note: Actually the demand is not really satisfied. In case the slack carrier is chosen, it would resemble a situation with backorders.*) The second constraint ensures that the assigned quantity for each bid is not exceeding the carrier’s capacity on this lane. For the transport mode “Ocean” each carrier inserts values for “Sailings per year” and “Commitment per Sailing” for each lane. Both numbers multiplied with another give his annual capacity for each lane which has to be at least as high as his assigned quantity for this lane. Constraint (3) states that the decision variable about the fractional quantity on each lane which should be assigned to each bid is between zero and one, whereas the decision variables whether a supplier should be selected (on lane j) are binary ones (4)-(5).

Additionally, the user can restrict the optimization problem by activating several constraints: restriction (6) enables the user to choose an upper bound for the number of carriers that should appear in the solution. The “slack carrier” is not counted this means that e.g. in case that the maximum number of carriers is set to one but this carrier cannot satisfy the demand by himself the slack carrier can stand in so that constraint (1) is still met. A high number of different carriers is always associated with high overhead costs so that it might be preferable to limit the number of collaborations. Constraint (7) indicates if a supplier is selected or not. If the fractional transport quantity is greater than zero, the binary variable would be one. Since the objective function tries to minimize the number of suppliers, the solver will always try to set the decision variable to zero if not possible otherwise.

Constraints (8) - (9) give a lower and upper bound for the assigned quantity for the bids that are activated in the scope. By activating these constraints the user can decide how much transport volume should at least/ at the most be awarded to these bids. In case a deal with one carrier has already been agreed upon, the user can set a lower bound to make sure that this carrier gets awarded with the according quantity. Whereas an upper bound would make sense, if transport units should be assigned to more different carriers so that the supply chain stays competitive.

The last two constraints (10)-(11) ensure that the carrier's transit time on lane  $j$  is less than the upper bound  $t_{j,max}$  on lane  $j$ . If the maximum allowed transit time for carrier  $i$  on lane  $j$  cannot be respected, no transport volume is assigned to that bid. The binary decision variable  $w_{ij}$  is set to 1 if transport volume is assigned to the according bid (11).

The number of constraints for the above described optimization problem deviates from the number of constraints that the scenario builder provides. The reason for this is that some constraints in the scenario builder are rather conversion functions and some are redundant or do not lead to logic solutions (s. 4.1.3.).

### 4.3 MATHEMATICAL MODEL WITH CHANCE CONSTRAINTS

The model presented in section 4.2 assumes that transit times which are handed in by the carriers for each lane are deterministic. In reality it is not predictable how long the transport will actually take and therefore, including transit times as stochastic parameters is a more reasonable assumption. As described during the SWOT analysis, Elemica keeps track on the actual past transit times for the transport mode ocean. In order to identify patterns within the lane data, an analysis in SPSS has been conducted.

At first, a Shapiro-Wilk test and the histogram plots have been analysed in order to check if the lane data follows a normal distribution. Based on the histogram plots it can be concluded that – in case sufficient data entries are available for one carrier on one lane- the transit time can be best approximated by a gamma distribution. Although the Shapiro-Wilk test is significant in cases where only few data is available which means that a carrier has only done few transports on one lane, it shows non-significant results when more data is available. The cases where more data entries are available give a more accurate picture on the distribution of transit times. This is why it is decided not to use a normal distribution.

Figure 18 shows the cumulative distribution function (cdf) of the gamma distribution with parameters  $\alpha = 0.9, \beta = 2$  and the distribution of the lane data for carrier 1 on lane 1. The graphs for the other lanes can be found in appendix E. Although not all lane data distributions fit the gamma distribution with  $\alpha = 0.9, \beta = 2$  well, it could be observed that the more data entries are available, the better this approximation fits. The gamma distribution usually applies to events where the waiting time between events is relevant (WikiStat- AP Statistics Curriculum 2007 Gamma, 2012).

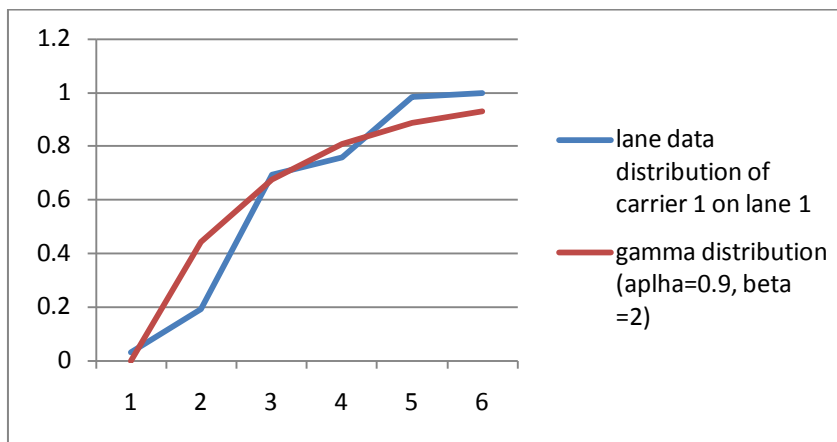


FIGURE 18: LANE DATA DISTRIBUTION FITTED WITH GAMMA DISTRIBUTION FOR CARRIER 1 ON LANE 1

One way of implementing this information in the model is to include chance constraints. This way the former hard constraint

$$w_{ij}t_{ij} \leq t_{j,max} \quad \forall (i,j) \in IxJ \quad (10)$$

can be softened. This is done by exchanging it with a chance constraint which ensures that the probability, that the transit time of carrier  $i$  on lane  $j$  is below a maximum transit time, is above  $1 - p_j$ . Hereby, the probability  $p_j$  (which is the probability that the max. transit time on lane  $j$  cannot be respected) is chosen by the user:

$$P\{w_{ij}t_{ij} \leq t_{j,max}\} \geq 1 - p_j, \quad \forall (i,j) \in IxJ$$

Due to the results of the lane data analysis, it is assumed that  $t_{ij}$  are independent and identically distributed Gamma variates for  $\forall (i, j) \in IxJ$ :  $t_{ij} \sim G(\alpha, \beta)$ , where  $\alpha > 0, \beta > 0$  with mean  $E(t_{ij}) = \min(\hat{t}_{ij}) + \frac{\beta}{\alpha}$ , where  $\min(\hat{t}_{ij})$  equals the smallest value of all past transit time values for carrier  $i$  on lane  $j$ , and variance  $Var(t_{ij}) = \frac{\beta}{\alpha^2}$ .

A model from Khan, Anwar and Ahmad (2012) is modified so that it can be defined as

$$S_{ij} = w_{ij}t_{ij}, \quad \forall (i, j) \in IxJ$$

$$\text{So that } E(S_{ij}) = (\min(\hat{t}_{ij}) + \frac{\beta}{\alpha}) w_{ij} \text{ and } Var(S_{ij}) = \frac{\beta}{\alpha^2} w_{ij}$$

Assuming that we have a sufficient large amount of data entries on each lane, it can be concluded from Liapounoff's central limit theorem that  $S_{ij} \sim N(E(S_{ij}), Var(S_{ij}))$  Therefore, the constraint

can be rewritten as  $P \left\{ Z_{ij} \leq \frac{t_{j,max} - E(S_{ij})}{\sqrt{Var(S_{ij})}} \right\} \geq 1 - p_j, \quad \forall (i, j) \in IxJ$ , where  $Z_{ij} = \frac{S_{ij} - E(S_{ij})}{\sqrt{Var(S_{ij})}}$  is a standard normal variate, so that  $\Phi(Z_{ij}) \geq \Phi(Z_{(1-p_j)})$ , where  $\Phi$  is the distribution function of the standard normal variate and  $Z_{(1-p)}$  is s.t.  $P \{ Z_{ij} \leq Z_{(1-p_j)} = 1 - p_j \}$ . Because  $\Phi$  is non-decreasing, it can be concluded that  $\frac{t_{j,max} - E(S_{ij})}{\sqrt{Var(S_{ij})}} \geq Z_{(1-p_j)} \Leftrightarrow \frac{t_{j,max} - ((\min(\hat{t}_{ij}) + \frac{\beta}{\alpha})w_{ij})}{\sqrt{\frac{\beta}{\alpha^2}w_{ij}}} \geq Z_{(1-p_j)}$

$$\text{Hence, } \beta w_{ij} + \min(\hat{t}_{ij}) w_{ij} + Z_{(1-p_j)} \sqrt{\beta w_{ij}} \leq \alpha t_{j,max}, \quad \forall (i, j) \in IxJ$$

By replacing this constraint with the former hard constraint (10) a new model is set up where all other constraints and the objective function stay the same. The whole model with a list of all variables can be found in Appendix D.

The advantage of this model compared to the deterministic one is that the transit time depends on the distribution of the past transit times. Currently carriers hand in their expected transit times on each lane when uploading their bidding rates to the system. Elemica's employees criticize that some carriers are too optimistic with their transit times so that the actual values often deviate from the ones that carriers upload. Furthermore, having access to historic transit time data is not common for a SCOM provider so that this can add a competitive advantage to Elemica's tool. A disadvantage of this approach is that historic transit times need to be available for every carrier on each lane. Also, estimating the scale and shape parameters of the gamma distribution requires additional effort.

During the next sub section, an outlook is given where other approaches are discussed.

#### 4.4 OUTLOOK

The model which is presented in the previous section includes transit time as a stochastic parameter. By adding a chance constraint to the model the user can choose a probability level that should be fulfilled. Of course, it is also possible to assume that other parameters such as the amount of damaged items or the amount of items that arrive in time are stochastic. Table 28 in appendix B lists models that include different deterministic as well as stochastic parameters.

Models using chance-constraints are one way of incorporating different stochastic parameters. Talluri, Narasimhan, & Nair (2006) use chance constraints to set a lower bound for 1) the quality which is "represented as the percentage of shipped units that are rejected" and 2) delivery

where “delivery is measured as the percentage of ordered units that are delayed”. Similar to the model that is used in the previous section, they use historic data which is assumed to follow a normal distribution. Shiwei, Chaudhry, Lei, & Baohua (2009) add chance constraints to their model to ensure that a certain amount of items is delivered on time and that sufficient good/undamaged items arrive at the customer’s side. In another research conducted by Zang, Liu, & Li (2012) the objective function tries to maximize the probability that different kinds of costs (e.g. transportation, purchasing, fixed cost for signing contract with supplier) are not exceeded. Additionally, chance constraints for the supplier’s quality and his lead time are included. Most models presented in the literature try to include lead time and the quality of the transport (e.g. amount of damaged/ rejected goods) as factors. If Elemica can get access to historic data about the amount of rejected items, it would be possible to include a second chance constraint into the model. For users that are concerned about the quality of their carriers, this approach would be beneficial. In case the random variable does not follow a gamma but a normal distribution, the chance constraint can be expressed as a second order cone program (Wikipedia- Second-order Cone Programming, 2014).

Besides including different stochastic parameters by using chance constraints, another approach foresees to use a total cost of ownership approach which works with a more detailed structure of the costs. Different models ( (Taleizadeh, Niaki, & Barzinpour, 2011), (Kasilingamand & Lee, 1996), (Leung, Wu, & Lai, 2006)) include not only the transportation costs, but also expenses for inventory, backorders, setup, labour etc. The advantage of this approach is a higher transparency. Also, if information about backorder costs is available, the unrealistic assumption of a slack carrier -that can take over the transport volume in case the real carriers cannot ship-becomes obsolete. The disadvantage of this approach is that carriers need to put additional effort into collecting and delivering data. Plus, they might not want to reveal too much information about their cost structure.

Assuming that parameters are stochastic seems reasonable, especially when a high variety in the past data can be observed. Unfortunately, assuming that parameters are stochastic makes the problem more complex and advanced optimization techniques, as e.g. generic algorithms are needed to solve the problem. Therefore, it has to be checked if Elemica has the capacities to develop advanced algorithms that are able to deal with a higher complexity.

During the next section the deterministic as well as the stochastic model which have been developed during this chapter should be validated and the impact of single parameters should be investigated.

## 5 CASE STUDY

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In order to validate the mathematical model it has been implemented in GAMS and several test runs with varying parameters have been conducted. GAMS (General Algebraic Modeling System) is a high level optimization modelling language which uses a CPLEX solver<sup>6</sup>.

The model which has been implemented deviates in two points from the mathematical model:

### 1) Awarding the slack carrier

The bidding rate of the slack carrier has been increased to the actual bidding rate plus ten units so that the slack carrier is only chosen when transport volume cannot be shipped by any of the other carriers. The corrected costs (with the slack carrier's bidding rate set to the one of the most expensive carrier) are captured in the parameter "actualcost".

### 2) Ensuring that transit time doesn't exceed the upper bound

In order to save run time as well as space and therefore, make the model more efficient, a conditional statement is used which checks if the transit time  $t_{ij}$  is greater than the maximum transit time on that lane. Only if the transit time is smaller, transport volume can be awarded to the according bid. This way decision variable  $w_{ij}$  becomes obsolete and the solving time gets reduced.

The full code can be viewed in Appendix E. At first, a model with transit time as a deterministic parameter is implemented in GAMS. Afterwards, a model with a chance constraint as described in 4.3 is set up (s. 5.2.).

### 5.1 DETERMINISTIC MODEL

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All input parameters are saved in an excel file. XLS2GMS is used as an interface tool that takes data from the excel spreadsheet and saves it in the according parameters in GAMS. The data for the lanes including the demand on each of the 14 lanes (s. table 6) is taken from Elemica's sourcing platform. The results of Elemica's scenario builder are compared with the ones of the GAMS version so that the correctness of the model can be evaluated.

TABLE 6: DEMAND Q(J) ON LANE J

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
q(j)	1	1	1	4	1	1	15	1	423	1	1	1	1	1

The following scenarios are run for the deterministic model where each scenario validates one of the constraints that can be added to the scenario builder:

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<sup>6</sup> The CPLEX software usually uses a simplex algorithm in order to solve large optimization problems. In case of MIP problems a branch-or-cut algorithm is used. (GAMS- Solver Descriptions)



TABLE 7: TESTED SCENARIOS FOR DETERMINISTIC MODEL

Scenario	Description
1	No constraints activated; carriers not limited by capacity
2	Carriers limited by capacities (s. table 9); no other constraints
3	Max. amount of awarded carriers is 1; Carriers limited by capacities (s. table 9)
4	Min. award of 4 units for carrier 2 on lane 4; Carriers limited by capacities (s. table 9) Min. total award of 110 units for carrier 2; Carriers limited by capacities (s. table 9)
5	Max. total award of 200 units for carrier 2; Carriers limited by capacities (s. table 9)
6	Upper bound for transit time on lane 1 and 2; Carriers limited by capacities (s. table 9)

### 1. No constraints

During the first test run the following bidding rates are fed to the GAMS model. In this scenario both carriers are not restricted by their capacity. Since the transport mode ocean is considered, it is actually not an unrealistic assumption that carriers are unlimited when it comes to their capacity. According to an employee from Elemica, most container ships nowadays are able to load huge volumes so that it occurs very rarely that a carrier cannot ship the entire transport volume.

TABLE 8: BIDDING RATES OF CARRIER I ON LANE J

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	50	60	60	50	60	60	60	55	60	60	60	50	60	60
2	60	50	50	60	50	50	50	50	50	50	50	60	50	50

The solver awards the least expensive carrier with the full transport volume on the according lane. The resulting costs are 22.650 dollars. Carrier 1 is awarded with 6 transport units and carrier 2 with 447. The slack carrier does not have to stand in since both carriers are not restricted by their capacities.

### 2. Carriers limited by capacities

During a second model run the capacities for both carriers are changed (s. table 9) while the bidding rates stay the same. This way the second constraint of the mathematical model is validated.

TABLE 9: CARRIERS CAPACITIES IN TEST RUN 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	1	1	4	0	1	15	1	100	1	1	1	1	1
2	1	1	1	4	0	1	15	1	200	1	1	1	1	1

The assigned transport quantities (in %) can be found in table 10. As expected the less expensive carrier gets awarded with the transport quantity his capacity allows him. This means that also the slack carrier has to stand in for lane 5 and 9. The overall cost increases to 24.900 dollars. The transport volume for lane 9 is split between the carriers where carrier 1 is awarded with 23,6 % of the volume on this lane. This equals 100 transport units which is his capacity on lane 9.

TABLE 10: ASSIGNED TRANSPORT VOLUMES (IN %) FOR CARRIER I ON LANE J

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	0	1	0	0	0	0	0.236	0	0	1	0	0
2	1	1	1	0	0	1	1	1	0.473	1	1	0	1	1
3	0	0	0	0	1	0	0	0	0.291	0	0	0	0	0

### 3. Max. amount of awarded carriers

For this test run, capacities and bidding rates are left as they were during test run 2. This time the constraint for the amount of selected carriers (excl. the slack carrier) is limited to one carrier. Since awarding carrier 2 leads to lower costs compared to awarding carrier 1, only carrier 2 appears in the solution. The transport quantity which cannot be shipped by him due to his capacity restrictions is awarded to the slack carrier. The results can be found in table 11. The total overall costs are 24.950 dollars.

TABLE 11: ASSIGNED TRANSPORT VOLUMES (IN %) FOR CARRIER I ON LANE J WHEN # OF CARRIERS LIMITED TO 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	1	0	1	1	1	0.473	1	1	1	1	1
3	0	0	0	0	1	0	0	0	0.527	0	0	0	0	0

### 4. Min. award constraint

The minimum award constraint can be activated if e.g. a deal with a supplier has already been agreed upon but the solver would usually not consider awarding this carrier. Regarding the results of the second scenario a minimum award could be implemented for carrier 2 on lane 4. Since his bidding rate is higher than the one of carrier 1, he'd usually not be chosen. Table 12 shows the results for the scenario where a minimum award of 4 units for carrier 2 on lane 4 is foreseen.

TABLE 12: ASSIGNED TRANSPORT VOLUMES (IN %) FOR CARRIER I ON LANE J WITH MIN. AWARD OF 4 UNITS FOR CARRIER 2 ON LANE 4

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	0	0	0	0	0	0	0.236	0	0	1	0	0
2	1	1	1	1	0	1	1	1	0.473	1	1	0	1	1
3	0	0	0	0	1	0	0	0	0.291	0	0	0	0	0

Instead of setting a lower bound for a specific bid, also a lower bound for the total award of carrier 1 can be determined by setting variable  $s_{ij}$  to 1 for  $i = 1$  and  $\forall j \in J$ . This leads to the following assigned transport volumes. In total 110 transport units (=min. award) are assigned to carrier 1 while his capacity restrictions are still holding.

TABLE 13: TRANSPORT VOLUMES (IN %) FOR CARRIER I ON LANE J WITH MIN. TOTAL AWARD OF 110 UNITS FOR CARRIER 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	0	1	0	0	0.267	1	0.236	0	0	1	0	0
2	1	1	1	0	0	1	0.733	0	0.473	1	1	0	1	1
3	0	0	0	0	1	0	0	0	0.291	0	0	0	0	0

### 5. Max. award constraint

The maximum award constraint can be activated in case multiple suppliers should be awarded. This can help to keep the supply chain competitive. Table 14 lists the results if the total max. award for carrier 2 is set to 100 units. Under normal conditions (without activating the max. award constraint; all other parameters are set as in scenario 2) his assigned quantity would be 224. This increases the costs to 26 125 dollars.

TABLE 14: TRANSPORT VOLUMES (IN %) FOR CARRIER I ON LANE J WITH MAX. TOTAL AWARD OF 200 UNITS FOR CARRIER 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	1	1	1	0	1	1	1	0.236	1	1	1	1	1
2	0	0	0	0	0	0	0	0	0.236	0	0	0	0	0
3	1	0	0	0	1	0	0	0	0.527	0	0	0	0	0

### 6. Max. transit time

Besides the bidding rates and capacities, carriers also upload their transit times on each lane. The following transit times are handed in:

TABLE 15: TRANSIT TIMES OF CARRIER 1 AND 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	1	1	1	1	1	1	1	1	1	1	1	1

The user can set a limit for the transit time on each lane. Constraints ensure that no bid is awarded where the corresponding transit time is higher than the upper bound. A test run with the following maximum transit times is conducted. Under normal conditions (without upper bounds for the transit times) carrier 2 gets awarded on lane 1 and 2.

TABLE 16: UPPER BOUNDS FOR TRANSIT TIME ON LANE J

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
tmax(j)	1	1	99	99	99	99	99	99	99	99	99	99	99	99

This scenario helps to validate if the last two constraints (9) and (10) are correct. The assigned quantities can be viewed in table 17. According to the results, all transport volume on lane 1 and 2 is shipped by the slack carrier since the other carriers' transit times are exceeding the maximum allowed transit time.

TABLE 17: ASSIGNED TRANSPORT VOLUMES (IN %) FOR CARRIER I ON LANE J WITH TMAX = 1 FOR LANE 1 AND 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	0	1	0	0	0	0	0.236	0	0	1	0	0
2	0	0	1	0	0	1	1	1	0.473	1	1	0	1	1
3	1	1	0	0	1	0	0	0	0.291	0	0	0	0	0

The correctness of each constraint has been validated through multiple test runs. The obtained results are compared with the ones of the scenario builder where only those constraints are activated that lead to logical results (s. 4.1.3.). The obtained costs are the same and so are the assigned volumes. The following table lists the advantages of the new solution and also enumerates which features are not available in the new model.

TABLE 18: COMPARISON OF THE PERFORMANCE OF THE NEW MODEL AND THE SCENARIO BUILDER

Improved	Not implemented
<p><i>Reduced # of constraints</i> All constraints that do not lead to logical results or those that could not be motivated are excluded from the new model. By adding variables that indicate if a bid is within the scope, two constraints are sufficient to set lower/ upper bounds for the transport volume. Therefore, the favour, min/ max (total) award constraints and the number of bids (per lane) are summarized by these two constraints in the new model. This makes the new model simpler while the same level of functionality can be maintained.</p>	<p><i>Units</i> The scenario builder allows implementing constraints with different units, e.g. it is possible to add a max. transport volume in transport units, dollars or per cent. The new model only calculates in transport units. This could be easily solved by adding additional constraints for dollars and fractional transport volumes.</p>
<p><i>Correctness of the results</i> While some constraints in the scenario builder lead to unreasonable results, the new model leads to the expected outcome as can be seen during the case study.</p>	<p><i>Extended scope</i> In the scenario builder the menu for setting the scope also includes information about the transport such as the container size, the commodity etc. Including all this information does not change the new model itself but checking which bids are in the scope would become more extensive.</p>
<p><i>Adding the slack carrier in the formulation</i> While the slack carrier is obviously considered by the scenario builder, it did not appear in the mathematical formulation of the old model. The new model includes it in both the mathematical formulation and the implemented model.</p>	<p><i>Runtime</i> The runtime behaviour of the new model is not keeping up with the one of the scenario builder. The reason for this is that it takes quite long to extract the variables from the excel sheet. The actual solving time is as good as the one of the scenario builder since both solvers are using a branch-or-cut algorithm. Accelerating the overall solving time can be achieved by listing all the input values in the GAMS code. An excel sheet is used because the input parameters can be better viewed this way.</p>

Due to the correctness of the new model and its simplicity, it can be seen as an improvement of Elemica's advanced sourcing tool. Adding other features, as different units and an extended scope, would be the next step to enhance the tool.

Another way of adding value to the model is to consider parameters as uncertain. Therefore, a chance constraint for the transit time of the shippers is added to the model. The case study in the following section validates this modified model.

## 5.2 MODEL WITH CHANCE CONSTRAINTS

As mentioned during section four, the past lane data can be best approximated by a gamma distribution if sufficient data entries are available. By analyzing the lane data for ocean freight, the shape and scale parameters for the gamma distribution could be estimated. After clearing a dataset for missing values, 5,700 data entries are remaining (including carrier name, origin/destination location, starting date and end date of the transport). Afterwards, outliers (data entries with a z-score of 2.5 or higher) are eliminated.

Although it used to be common in the past, that only one carrier has been responsible for the transport on a single lane over the past, there are also lanes where two or more carriers have been transporting. 6 lanes where the same two carriers have been shipping are selected and the data for alpha and beta are estimated for the evaluation in GAMS (s. appendix E). The lane data with most entries (lane 6) can be well approximated with  $\alpha = 0.9$  and  $\beta=2$ . The graphs in appendix E show the lane data distribution for every carrier on each lane, compared with the gamma distribution ( $\alpha = 0.9$  and  $\beta=2$ ). While for lanes with many entries, the gamma distribution function is a good approximation, lanes with less data differ from this distribution function. Since lanes with many data entries give a more accurate picture on how lane data is distributed, the gamma distribution with the parameters mentioned above, seems to be a decent approximation.

In order to implement the chance constraint

$$\beta w_{ij} + \min(\hat{t}_{ij}) w_{ij} + Z_{(1-p)} \sqrt{\beta w_{ij}} \leq \alpha t_{j,max} \quad , \forall (i,j) \in I \times J$$

some mathematical libraries have to be imported in GAMS so that the inverse normal distribution function can be used.

At first, the shape and scale parameters are set to  $\alpha = 0.9$  and  $\beta = 2$ . The best transit times  $\min(\hat{t}_{ij})$  of each carrier can be found in the following table. The values are taken from the historic transit times:

TABLE 19: BEST TRANSIT TIME OF CARRIER I ON LANE J

	1	2	3	4	5	6
1	16	27	33	39	24	19
2	18	34	43	67	21	19

### 1. Scenario: chance constraint not activated

At the beginning, it is assumed that both carriers are not restricted by their capacities. Their bidding rates can be found in the following table:

TABLE 20: BIDDING RATE OF CARRIER I ON LANE J

	1	2	3	4	5	6
1	50	60	50	60	60	60
2	60	50	60	50	50	50

In case the chance constraint for the transit time is not activated (max. transit times are set to 1000 weeks) the following transport volume allocations could be observed:

TABLE 21: VOLUME ALLOCATION (IN %) IF CHANCE CONSTRAINT IS INACTIVE

	1	2	3	4	5	6
1	1	0	1	0	0	0
2	0	1	0	1	1	1

As expected the less expensive carrier is awarded. Since both carriers are not restricted by their capacities, it is not necessary to award the slack carrier. The resulting overall costs are 1200.

## 2. Scenario: chance constraint activated

During a second scenario the chance constraint is activated and the max. transit times  $t_{j,max}$  are set to the best transit times:  $\forall j \in J: t_{j,max} = \min \{ \min(\hat{t}_{1j}), \min(\hat{t}_{2j}) \}$ . The confidence interval equals  $p_j = 0.05$  for  $\forall j \in J$ . This means that in 95% of the cases, the carriers need to ship according to their best possible transit time (taken from the past data). As a result, all transport volumes are assigned to the slack carrier.

When looking closer at the chance constraint, it is evident that the scale parameter  $\alpha$  has a big impact on the outcome. In case  $\alpha$  is set to 0.9, as assumed so far, the constraint becomes more restrictive since carriers need to ship within 90 per cent of the max. transit time  $t_{j,max}$  for lane  $j$  given a possibility  $p_j$  for lane  $j$ . If  $\alpha$  becomes bigger, it is more likely that carriers can respect this constraint. The question is whether the gamma distribution is still a good approximation if  $\alpha$  increases. Figure 19 shows the gamma distribution with varying scale parameters and the lane data distribution of carrier 2 on lane 6. With 110 past shipments, this lane for carrier 2 has the most data entries.

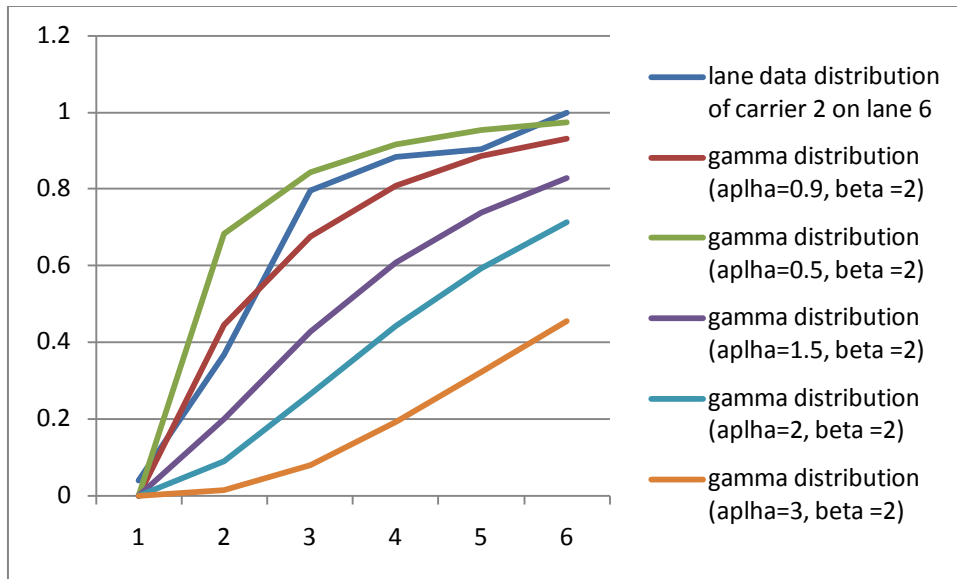


FIGURE 19: GAMMA DISTRIBUTION WITH VARYING ALPHA AND LANE DATA DISTRIBUTION OF CARRIER 2 ON LANE 6

Both gamma distributions with  $\alpha = 0.5$  and  $\alpha = 0.9$  are decent approximations for the lane data distribution. While  $\alpha = 0.5$  makes the chance constraint very restrictive for the carriers, setting  $\alpha$  to 0.9 makes the chance constraint more feasible. Therefore, it is decided that  $\alpha = 0.9$ .

Since the inverse cdf  $Z_{(1-p)}$  will lead to values between 0 and 4 for  $p > 0.01$ , also  $\beta$  influences the feasibility of the chance constraint. Moreover, the higher values for  $\beta$  are inserted, the less likely it is that the chance constraint is feasible. Given that  $\alpha = 0.9$ , the gamma distribution with varying betas is plotted in figure 20.

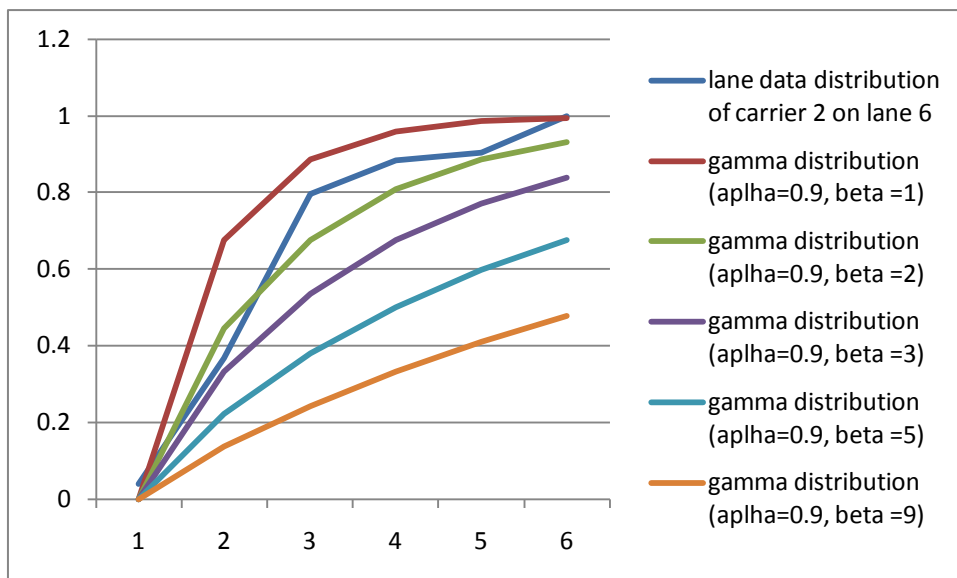


FIGURE 20: GAMMA DISTRIBUTION WITH VARYING BETA AND LANE DATA DISTRIBUTION OF CARRIER 2 ON LANE 6

From figure 20 it can be seen that  $\beta = 2$  or  $\beta = 3$  are good approximations for the lane data distribution.

In case  $p_j$  stays 0.05 and the max. transit times still equal the best possible transit time on each lane, all transport volume is still assigned to the slack carrier (independent from the decision if  $\beta = 2$  or  $\beta = 3$ ).

During a next test run the max. transit times are set to the best transit time plus 7 weeks:  $\forall j \in J: t_{j,max} = \min \{ \min(\hat{t}_{1j}), \min(\hat{t}_{2j}) \} + 7$ . The assigned transport volumes can be found in the following table for  $\beta = 2$ . If  $\beta = 3$  the chance constraint becomes less feasible and carrier 2 cannot respect the constraint on lane 5 and 6. This is why the carrier has to stand in for these two lanes (s. assigned volumes in brackets).

TABLE 22: ASSIGNED TRANSPORT VOLUMES IF  $t_{j,max} = \min \{ \min(\hat{t}_{1j}), \min(\hat{t}_{2j}) \} + 7$

	1	2	3	4	5	6
1	1	0	0	0	0	0
2	0	0	0	0	1 (0)	1 (0)
3	0	1	1	1	0 (1)	0 (1)

If the max. transit time is set to the best transit time plus 9 weeks, all transport volume can be shipped by carriers 1 and 2. The results can be viewed in the following table. For  $\beta = 3$  the result changes slightly: carrier 1 cannot respect the chance constraint on lane 5 so that the slack carrier needs to take over the transport volume on this lane.

TABLE 23: ASSIGNED TRANSPORT VOLUMES IF  $t_{j,max} = \min \{ \min(\hat{t}_{1j}), \min(\hat{t}_{2j}) \} + 9$

	1	2	3	4	5	6
1	1	1	1	1 (0)	0	0
2	0	0	0	0	1	1
3	0	0	0	0 (1)	0	0

Although carrier 1 has the higher bidding rate on lanes 3 and 5, transport volume is assigned to him on these lanes for the case with  $\beta = 2$ . The reason for this is that carrier 2 shows higher past transit times and cannot obey the chance constraint on the mentioned lanes.

Finally, the influence of  $p_j$  should be discussed. Different values for the probability that the transit times can be respected are fed to the model and the results are compared. The max. transit times are still set to  $t_{j,max} = \min \{ \min(\hat{t}_{1j}), \min(\hat{t}_{2j}) \} + 9$ . Moreover,  $\alpha = 0.9$  and  $\beta = 2$ .

TABLE 24: ASSIGNED TRANSPORT VOLUMES WITH  $p_j = 0.05 / 0.01 / 0.9999$

	1	2	3	4	5	6
1	1/1/1	1/1/0	1/0/1	1/0/1	0/0/0	0/0/0
2	0/0/0	0/0/1	0/1/0	0/0/0	1/1/1	1/1/1
3	0/0/0	0/0/0	0/0/0	0/1/0	0/0/0	0/0/0

The values in the table show the results if  $p_j$  is set to 0.05 which means that in 95% of the cases the carriers can ship within the max. given transit times. To make the chance constraint more restrictive, the probability value is set to 0.01 (s. red values). In this case, carrier 1 cannot respect the constraint anymore on lane 3 and 4. Furthermore, different values above 0.05 are tested. The results do not differ from the ones where  $p_j$  is set to 0.05 unless  $p_j$  gets very close to 1 (s. green values). The results are almost identical to the scenario where the chance constraint is inactive so that on each lane the less expensive carrier is awarded. Only on lane 4 the more expensive carrier is assigned with the transport volume. The reason for this is that carrier 2's best transit time on lane 4 is significantly higher than the best value of carrier 1. The upper



bound would have to be loosened to  $t_{j,max} = \min \{ \min(\hat{t}_{1j}), \min(\hat{t}_{2j}) \} + 34$  while all other parameters stay the same.

During this case study, the influence of the different parameters  $\alpha$ ,  $\beta$ ,  $t_{j,max}$  and  $p_j$  are tested. By setting these parameters the user can choose how restrictive the chance constraint should be. Hereby, the influence of  $p_j$  is rather low compared to the other parameters. During the next section, the results of the case study are summarized.

### 5.3 SUMMARY CASE STUDY

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During the case study both the deterministic and the model with chance constrained are tested and validated with GAMS. For the deterministic model each constraint is tested individually. The obtained results show the expected outcome. In case two constraints are conflicting, e.g. if the min. total award for a carrier is set to 100 but his total capacity equals 70, the solver states that the problem is infeasible. Therefore, the user needs to ensure that the constraints he activates are not conflicting.

After having validated the deterministic model, the chance constraint is switched with the former hard constraint for the maximum transit time. Furthermore, the historic transit times are used instead of the transit times that are handed in by the carriers. This way the input parameters are more reliable since the historic transit times represent the actual performance of the carriers over time. One disadvantage of this approach is that data is not available for each carrier on each lane. In most cases only a single carrier has been responsible for the shipping on a single lane.

Since the lane data can be best approximated by a gamma distribution, it is also mandatory to estimate the scale and shape parameters. In this case study the lane with most data entries is taken to estimate the parameters. Based on the lane data analysis, it could be observed that setting the parameters to  $\alpha = 0.9$  and  $\beta = 2$  seems to be a good approximation for lanes with many data entries. If only few data is available, the parameters might differ from the above mentioned ones. For simplicity reasons, it is assumed that all parameters are identical although estimating shape and scale parameter for each carrier on each lane leads to more accurate results. The gamma distribution can also be automatically fitted with the data by using for example the maximum likelihood method. This makes the parameter estimation more efficient.

During the last section of this thesis, a conclusion is obtained where all main findings are summarized. Afterwards, recommendations for Elemica are given on how they can implement the enhanced version of the scenario builder. Finally, a make-or-buy decision should help to decide if the development should be outsourced or not.

## 6 CONCLUSION

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During the development of the research proposal, it was addressed by different employees of Elemica that the scenario builder- a tool that calculates the cost-optimal transport volume allocation to the customers' suppliers- is not sufficiently used by Elemica's customers. Not to mention the tool has not been maintained during the last three years and the documentation about its mechanism is scarce. Therefore, this master thesis aims to figure out how the tool works and why it is not yet accepted by the customers.

Several research questions have been formulated in order to structure the thesis. The main research question is:

How can the optimization tool which is provided by Elemica be modified/ renewed so that it adds additional value for the customer and can compete with other solutions which are available on the market?

In order to answer this main research question, a necessary first step was to understand the scenario builder's mechanism. Based on an input-output analysis, the underlying mathematical model could be derived. Furthermore, it was found out that a branch-and-cut algorithm is used in order to solve the problem.

Elemica's scenario builder solves a vendor selection problem where the decision is about awarding transport volumes to multiple carriers on different lanes. Based on the bidding rates that each carrier uploads to the system the solver identifies the least expensive carrier on each lane and awards him with the maximum possible quantity. Different constraints are available to set an upper/ lower bound to the awarded transport quantity and to limit the number of carriers that should appear in the solution. If the carriers do not have enough capacity or are limited by constraints, a so-called "slack carrier" can help out by taking over the remaining transport volume. Moreover, it is possible to add a penalty cost to the bidding rate, e.g. in case his expected transit time deviates too much from the incumbent one.

During the scenario builder analysis, several flaws became evident, e.g. some constraints could not be motivated and others did not lead to the expected results. Table 4 (s. 4.1.3) lists all observed flaws and how they were corrected in the new model.

Additionally, a Situational analysis was conducted in order to get a deeper knowledge about the market for sourcing solutions and to benchmark Elemica's tool. The main findings of this analysis are that there is a high demand from the customers' side for advanced sourcing tools such as sourcing optimization due to its great potential to identify cost-decreasing transport solutions. Furthermore, the e-sourcing market is not yet saturated so that there are multiple options to enter new markets and attract new customers. When comparing Elemica's tool with the ones of the competition, it becomes evident that companies such as CombineNet (now SciQuest) and Trade Extensions are ahead of Elemica regarding advanced sourcing. Their tools offer additional features, as e.g. discount scheduling and the option to express compatibility between items. These functions are not covered by Elemica's tool.

In the literature on supplier selection special interest has been paid on models with multiple objectives. In particular timeliness, delivery and quality of the supplier are important factors. During the project, it was decided to add the transit time of the suppliers as a second objective to the tool because this is one of the main concerns of Elemica's customers and because this parameter is easy to quantify. So far the carriers could hand in their expected transit times when uploading their bidding rates. According to Elemica's employees, these transit times are often too optimistic estimations and differ from the actual transit times. Therefore, it was decided to

include transit time as a stochastic parameter. Since Elemica has access to historic transit times, it was possible to find out how the lane data is distributed (in case enough data is provided). A chance constraint was added to the model so that an upper bound could be set for the probability that the transit time exceeds a limit.

The advantage of this model is that including historic transit times gives a more accurate picture on the performance of the carriers. Especially, if timeliness is of great concern for the user, this model is beneficial. The disadvantages of the model with chance constraints are that many data entries are needed for each carrier on each lane so that the assumptions for the chance constraint still hold. Also, not every carrier has been shipping on each lane so that there is often no data available. Estimating the shape and scale parameter for the gamma distribution can automatically be done by using for example the maximum likelihood method which is provided by different statistic software, such as R. This helps to lower the additional effort which has to be spent on fitting the lane data.

The next section will summarize all recommendations that can be derived from the findings of this master thesis in order to answer the main research question.

## 6.1 RECOMMENDATIONS

---

In order to improve the scenario builder and to make it more competitive, Elemica should take several action steps:

### 1. Enhancing user-friendliness

As mentioned during the SWOT analysis and the plan of action, Elemica's scenario builder lacks user-friendliness. By guiding the user stepwise through the tool, giving clear brief instructions about which parameters need to be filled in and explaining the purpose of each constraint, the experience with the scenario builder could be improved. Also, only monitoring logical scope/constraint combinations can help to avoid frustration on the customer's side. One example how this is successfully done is CombineNet's tool (s. figure 22, appendix C).

### 2. Developing a "clean" model formulation

The mathematical model which has been developed by an employee of Elemica is outdated since the mentioned constraints differ from the ones that the scenario builder provides. Also, the slack carrier is not mentioned within the model and the formulas are not correct. Therefore, a new model is developed throughout the thesis (s. 4.2). All changes which have been implemented are listed in table 4 (s. 4.1.3).

Moreover, the model has been validated by implementing it in GAMS and by running several scenarios (s. 5). The obtained results lead to the expected values. The new model outperforms the underlying one of Elemica's scenario builder due to its correctness and simplicity.

Elemica can implement the new model just as it is. So far the model calculates the fractional awarded transport quantities (in %) but it is also possible to modify the model so that it gives the total awarded transport units, the equivalent in dollars or other currencies. Also, the scope can be extended so that only bids with certain origin/ destination locations, volume tiers etc. are considered.

So far Elemica is using an open-source mixed integer programming solver which is called Cbc. It uses a branch-and-cut algorithm which is also used by the CPLEX solver for MIP problems in GAMS (GAMS- Solver Descriptions). Furthermore, it is possible to call the Cbc solver within GAMS (Coin or branch-and-cut- Wiki, 2014). If Elemica decides to implement the suggested

model of this thesis, they could either use GAMS with a purchased or a demo license or continue using their Cbc solver. The advantage of both solvers is that they are open-source while the downside is that the solving time increases significantly for more complex events. The reason for this is that the branch-and-cut algorithm aims to solve multiple smaller sub problems and thus, can become very computative intensive.

### 3. Adding more functionality

While studying Elemica's competitors as part of the Situational analysis, it became evident that they provide some features that Elemica's tool does not cover. Especially CombineNet's tool is outstanding in the field of advanced sourcing. The options to take volume discounts into consideration and to express compatibility between items make their optimization tool more expressive. In general, the trend goes towards adding more functions and complexity to advanced sourcing tools so that users can formulate very detailed transport requests.

The model with chance constraints which is presented in this thesis is one approach to add more functionality to the tool. The advantages and disadvantages of including transit time as a stochastic parameter are discussed in the previous section. If Elemica wants to make use of this approach, it will be crucial to collect lots of historic transit time data because otherwise the assumptions for the model do not hold (s. 4.3).

Depending on which data is available, also chance constraints for other parameters such as the number of items which get rejected or items that do not arrive on time can be included. In case the stochastic variable is not gamma but normal distributed, the chance constraint can be expressed as a second order cone program (SOCP) (Wikipedia- Second-order Cone Programming, 2014).

Besides the use of chance-constraints, there are various other approaches in the literature to include multi-objectivity (s. table 28, appendix B). The reason why a model with chance constraints is used is that stochastic parameters can be easily included in the model and it can still be solved by using a branch-and-cut algorithm. Other models, especially if they include multiple uncertain variables, are so complex that conventional optimization techniques cannot solve them. Therefore, advanced algorithms/ heuristics are needed. Developing this kind of advanced optimization techniques requires time and development capacities. Therefore, the approach with chance-constraints is found more suitable for Elemica.

Other features which can be added to the model are discount scheduling, compatibility between items and a total cost of ownership approach. Due to the timely limit of the thesis, these approaches have not been further investigated.

During the next section a make-or-buy decision is made where it is decided if the development of a new optimization tool should be outsourced.

## 6.2 MAKE-OR-BUY DECISION

---

After detecting the flaws in Elemica's optimization tool and giving recommendations on how to enhance the tool's performance, the last part of this thesis finally determines whether or not Elemica should outsource the development of the sourcing tool.

The model which is presented in this master thesis is implemented in GAMS with a demo license. This limits the model to max. 300 variables and constraints, 2000 nonzero elements and 50 discrete variables. Additionally, a license can also be purchased in order to solve bigger problems in GAMS. Instead of buying a GAMS license, Elemica can also use the OpenSolver in Excel or the SolverStudio- a free add-on for Excel 2007, 2010 and 2013 which performs better

and faster when it comes to large optimization problems. Furthermore, SolverStudio supports different modelling environments also including GAMS so that the code can be easily imported and used in Excel.

In case Elemica wants to add more complex features to its tool, which would require advanced optimization techniques, it might be beneficial to buy a solution from an external company. Based on the factors from RBV SciQuest and Ariba are the most suitable companies to collaborate with (s. 3.1.5). Additionally, factors from TCE should be taken into consideration in order to decide whether it makes sense to develop a new model in-house or to outsource it:

TABLE 25: TCE FACTORS AND THEIR IMPLICATIONS FOR ELEMICA'S OUTSOURCING DECISION

<b>Factor</b>	<b>Implication for Elemica</b>
<b>Asset specificity</b>	When it comes to the use of advanced optimization techniques, the asset specificity can be considered as high since Elemica's competitors have developed customized algorithms throughout the last years. If Elemica wants to outsource the development of advanced algorithms/ heuristics to another company, they might have to expect opportunistic behaviour and therefore, high development costs.
<b>Small numbers bargaining</b>	As mentioned during Porters Five Forces, there are only few companies that have the capabilities for advanced sourcing (Smith, Spend Matters UK/ Europe, 2013). This increases the likelihood for opportunism which has a negative impact on the development cost.
<b>Technological Uncertainty</b>	Since the market for e-sourcing changes very quickly (s. xx), technological uncertainty can be considered as high. The effect of technological uncertainty on opportunism follows a u-shaped curve (Holcomb & Hitt, 2007). If uncertainty becomes very high, opportunistic behaviour is likely.

According to TCE, it is very likely that an external company behaves opportunistic in case the development of the model or the optimization techniques are outsourced.

In the end, the decision whether to outsource the development depends on Elemica's priorities. If keeping the development costs at a low level (especially in the long run), Elemica should consider building up its own development capacities. If development speed is of great concern for the SCON provider, collaborating with one of the mentioned companies is beneficial. Also the quality of the tool might benefit from outsourcing since some competitors (CombineNet, Trade Extensions) have constantly worked on their knowledge on mathematical formulations and the development of optimization techniques.

Finally, this master thesis should be evaluated in terms of its relevance for Elemica and the field of advanced sourcing in general.

### 6.3 EVALUATION

---

In order to evaluate if this thesis is contributing sufficiently to the company and the field of advanced sourcing three key points are further investigated: success, generalization and novelty.

#### **Success**

The success of the thesis can be measured by evaluating its usefulness for the company, e.g. the contribution to Elemica's strategy, and the efficacy which means the degree to which the plan of action achieves its expected results.

At the beginning of the project, it was expressed by an employee of Elemica that more functionality should be added to the scenario builder, e.g. by making use of a multi-objective approach. Furthermore, the company wanted to add a feature which is not yet used by the competition. By adding chance constraints and including transit time as a stochastic parameter, both requirements mentioned above are fulfilled.

The goal which has been set during the plan of action was to enhance the scenario builder and to add value for the customer. This has been achieved by developing a "clean" mathematical model and validating its correctness. Furthermore, using historic transit times of the carriers gives an accurate picture on the suppliers' performance and therefore, helps Elemica's customer to make better supplier selection decision. Thus, it can be argued that the goal that has been set by the plan of action is achieved.

#### **Generalization**

Generalization means that the solution which has been developed during the thesis is also applicable in different environments. This is definitely valid for the deterministic model which can be used by companies independent from their industry, size etc. The model with chance constraint is conceptualized for transit times which follow a gamma distribution. In case transit time is not gamma distributed, the model needs to be modified. Therefore, a data analysis needs to be performed in the first place in order to check if the model is applicable.

#### **Novelty**

The vendor selection model with chance constraints where transit time is considered to be stochastic is new in the field of sourcing optimization. Since Elemica's knowledge about past transit times is unique for a sourcing SaaS provider, it can be used to add value to the model and make it more competitive.

The model which has been developed by Khan, Anwar and Ahmad (2012) is about the recruitment of new employees to jobs. This model has been modified so that it applies for Elemica's problem where transport units needs to be assigned to suppliers. Instead of the job completion time, the transit time of the carrier is considered. Therefore, it can be argued that the modification of this model adds useful insights to the field of advanced sourcing.

## 7 LIST OF ABBREVIATIONS

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3PL	Third party logistic provider
ABC	Artificial Bee Colony Algorithm
Cbc	Coin-or branch and cut
GA	genetic algorithms
GAMS	General Algebraic Modeling System
LTL	less than truckload
PSO	Particle Swarm Intelligence
RBV	Resource-based View
RFI	Request for Information
SCON	Supply Chain Operating Network
SaaS	Software as a Service
TCE	Transaction Cost Economics
USP	Unique Selling Point



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APPENDIX A

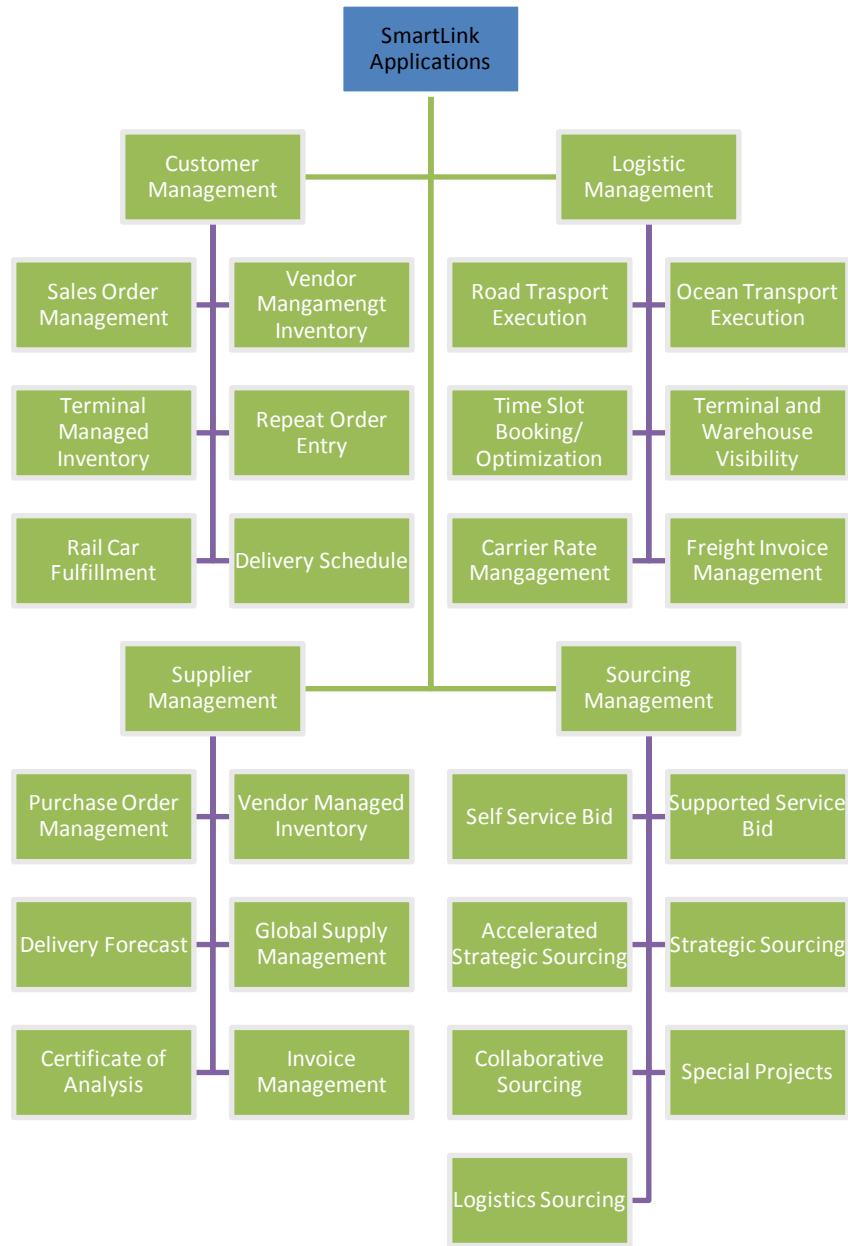


FIGURE 21: ELEMICAS SMARTLINK MODULES

## APPENDIX B

TABLE 26: INFLUENTIAL FACTORS OF TRANSACTION COST THEORY

Factor	Explanation
<b>Bounded rationality</b>	“Cognitive limitation of the human mind” (Dabhilkar, 2011); decision makers intend to make rational decisions but are restricted by their own cognitions, the information they have and/ or the time that is available (Simon, 1978) e.g. this factor makes it impossible to write “complete, contingent contracts” (Lyons, 1995)
<b>Opportunism</b>	Under specific conditions the supplying company might behave opportunistic and rather follow own (maybe conflicting) motives that might not be in accordance with (contract) agreements Opportunistic behaviour of the supplier is causing higher transaction costs (Klein, Crawford, & Alchian, 1978), (Williamson, 1985)
<b>Asset specificity</b>	The uniqueness of an asset; a high level of asset specificity increases the chance that the supplying company behaves opportunistic since an “interdependent relationship” might be created (Carney, 1998), (Jones, 1983)
<b>Uncertainty</b>	“The degree of unpredictability or volatility of future states as it relates to the behavioural or environmental factors” (Williamson, 1991), (Poppo & Zenger, 2002), (Aubert, Patry, & Rivard, 2004) In the context of TCE it is mainly referred to technological uncertainty, meaning the “unanticipated changes in circumstances surrounding technology” (Holcomb & Hitt, 2007) A high level of uncertainty requires a higher resource commitment and also often leads to frequent contract changes and renegotiations (Poppo & Zenger, 2002). It is therefore in favour of in-house development/ production
<b>Transaction frequency</b>	“The number of times a client organization initiates a transaction, typically categorized as either occasional or frequent” (Williamson, 1991); a high transaction frequency can help to mitigate the risk of opportunism (for transactions with specific trading partners)
<b>Economies of scale/ scope</b>	A supplying company can lower costs since they are providing the same or a similar products to two or more companies; this effect only occurs in case of low asset specificity (Lyons, 1995)

TABLE 27: SUPPLIER SELECTION CRITERIA SORTED BY IMPORTANCE (DICKSON, 1966)

<b>Rank</b>	<b>Factor</b>	<b>Mean rating</b>	<b>Evaluation</b>
1	Quality	3.508	Extreme importance
2	Delivery	3.417	
3	Performance History	2.998	
4	Warranties and claim policies	2.849	
5	Production facilities and capacity	2.775	Considerable Importance
6	Price	2.758	
7	Technical capability	2.545	
8	Financial position	2.514	
9	Procedural Compliance	2.488	
10	Communication System	2.426	
11	Reputation and Position in Industry	2.412	
12	Desire for business	2.256	
13	Management and Organization	2.216	
14	Operating Controls	2.211	
15	Repair service	2.187	Average Importance
16	Attitude	2.120	
17	Impression	2.054	
18	Packaging ability	2.009	
19	Label relations record	2.003	
20	Geographical location	1.872	
21	Amount of past business	1.597	
22	Training Aids	1.537	
23	Reciprocal arrangements	0.610	Slight Importance



TABLE 28: LITERATURE ON (STOCHASTIC) MULTI-OBJECTIVE VENDOR SELECTION

Author	Parameter	Stochastic Parameter	Solution Type
(Kasilingamand & Lee, 1996)	Costs for transportation and purchasing, fixed cost for establishing vendors, costs due to receiving poor quality parts	Demand	Mixed-Integer Programming (MIP)
(Yahya & Kingsman, 1999)	Delivery, Facility, Capability	Quality, Technical	Analytic Hierarchy Process (AHP)
(Alonso-Ayuso, Escudero, Garin, Ortuno, & Perez, 2003)	Benefit (Profit, Costs)	Product Price, Demand	Net
(Zhang, Li, & Liu, 2005)	Price, stability, Experience in the same industry, Location, International scope	Financial	AHP/ Data Envelope Analysis (DEA)
(Arunkumar, Karunamoorthy, Anand, & Ramesh Babu, 2006)	Number of defected items, Timeliness, Cost		Lexicographic method
(Lam & Tang, 2006)	Cost, Quality (in multi-echelon supply chain)		Multi-objective Linear Programming (MOLP)
(Leung, Wu, & Lai, 2006)	Costs (Production, labour, hiring and lay-off, operational and penalty costs )	Demand	Two-stage stochastic programming model
(Talluri, Narasimhan, & Nair, 2006)	Price, quality and delivery	Quality and Delivery	Chance-constrained data envelopment analysis
(Keskin, Ster, & Etinkaya, 2006)	Costs (fixed management costs; purchasing, dispatch and transportation costs, inventory replenishment and holding costs)	Demand	Mixed Integer Nonlinear Model
(Shiwei, Chaudhry, Lei, & Baohua, 2009)	Costs	Quality and Service	Chance-constrained model
(Lin, Lin, Yu, & Tzeng, 2010)	Delivery, Quality, Price, Service		Analytic Network Process (ANP)
(Hsu, Wang, & Tzeng, 2011)	Quality, Delivery, Risk, Cost, Service, Environmental Collaboration		DEMATEL-based on ANP (DANP)

(Taleizadeh, Niaki, & Barzinpour, 2011)	Costs (Purchasing, Holding, Ordering, Transportation costs)	Backorder, Set up,	Demand	Integer Programming	Non-linear
(Farahani & Fadaei, 2012)	Price, Quality, Capacity	Reputation,		Weighted function	linear
(Zang, Liu, & Li, 2012)	Costs		Costs, Quality and Lead Time	Chance-constrained model	

APPENDIX C

- My Account
- My Projects
- Log Out

Home
Monitor Event
Reference Documents
Surrogate Bidding
Scenarios
Reports
Supplier Help
Assessment
Setup

Scenario Builder
COMBINENET

Current Scenario: Round 1 - Test Jan 29

[Goto Scenario Settings](#)

**Scenario Scope** in bid Round: Round 1, lane owners: Optimize Now

**Comments**

Save Comments

**Scenario Rules**

Add a Rule

**Step 1. Select a rule and define the necessary parameters.**

Require at least 1 suppliers

Allow a maximum of 1 suppliers

---

Require between 1 and 1 suppliers

Award at least   dollars of total cost to Canada Approved on Any bids

Award at most   dollars of total cost to Canada Approved on Any bids

Favor Canada Approved by   percent on Any bids

Award as much business as possible to Canada Approved on Any bids

Favor incumbent by   percent

Award as much business as possible to incumbent

Consider a transition cost of   dollars (\$) for Canada Approved on Any bids

Favor bids by   % where Transit Time is less than average bid Transit Time by   or more days

Favor bids by   % where Transit Time is less than historic Transit Time by   or more days

Any winning carrier must win at least   loads per lane

**Step 2. Apply this rule**

Everywhere.

To the following:

All Items

---

to Item(s):  

All lane owners

to lane owners: P&G

All types

to types: CPU For Hire N/A

All GBUS

to GBUS: Baby Care CPG

All origin descriptors

to origin descriptors: 00010042 000100GH

All origin cities

to origin cities: AGAWAM AKRON ALEANY

All origin states

to origin states: AB AK

All origin regions

to origin regions: 231-237 300-303

All origin countries

to origin countries: CAN MEX USA

<input type="radio"/> Any winning <input type="text" value="carrier"/> cannot win more than <input type="text" value=""/> loads <input type="text" value=""/> per lane	<input checked="" type="radio"/> All ships to code <input type="radio"/> to ships to code: <input type="text" value="00010042"/> <input type="text" value="00011223"/>
<input type="radio"/> Favor the Package: <input type="text" value=""/> by <input type="text" value=""/> percent	<input checked="" type="radio"/> All destination cities <input type="radio"/> to destination cities: <input type="text" value="ABBOTSFORD"/> <input type="text" value="ABILENE"/> <input type="text" value="ABINGDON"/>
<input type="radio"/> Penalize the Package: <input type="text" value=""/> by <input type="text" value=""/> percent	<input checked="" type="radio"/> All destination states <input type="radio"/> to destination states: <input type="text" value="AB"/> <input type="text" value="AL"/> <input type="text" value="AR"/>
<input type="radio"/> Award the Package: <input type="text" value=""/>	<input checked="" type="radio"/> All destination countries <input type="radio"/> to destination countries: <input type="text" value="CAN"/> <input type="text" value="MEX"/> <input type="text" value="USA"/>
<input type="radio"/> Use 24 month pricing for: <input type="text" value="Canada Approved"/> on <input type="text" value=""/> bids	<input checked="" type="radio"/> All movement types <input type="radio"/> to movement types: <input type="text" value="Customer FP"/> <input type="text" value="Inbound from Deconsol to DC"/>
<b>Step 3. Review and Add the rule</b>	<input checked="" type="radio"/> All Destination Regions <input type="radio"/> to Destination Regions: <input type="text" value="Atlantic (CA)"/> <input type="text" value="BC &amp; Yukon (CA)"/> <input type="text" value="Mexico"/>

FIGURE 22: USER INTERFACE OF COMBINENET'S SCENARIO BUILDER (SANDHOLM, LEVINE, CONCORDIA, & MARTYN, 2006)



## APPENDIX D

TABLE 29: LANE DATA FOR TRANSPORT MODE OCEAN

Parameter	Description
<b>Lane Number (automatic)</b>	Unique Identifier for the Lane
<b>Container Size*</b>	Standard container size
<b>Commodity*</b>	Type of commodity transported on this lane
<b>SBU*</b>	Responsible strategic business unit
<b>Origin</b>	Information about the origin location
Region	
Country	
Location*	
Coast	
<b>Destination</b>	Information about the destination location
Region	
Country	
Location*	
Coast	
<b>Delivery type*</b>	The type of delivery required on this lane; e.g. door to door, port to port etc.
<b>THC included at origin/ destination (NO by default)</b>	Indicates if Terminal Handling Charges included at origin/ destination location
<b>Special Handling</b>	Comments on special handling requirements for this lane can be inserted. Requirements must be met in order to bid.
<b>Legacy Lane Number</b>	Unique Identifier for the legacy Lane
<b>Legacy rate (0 by default)</b>	Current transportation rate transported on this lane.
<b>Legacy transit time (0 by default)</b>	Current transit time for this lane.
<b>Legacy Carrier</b>	Current carrier for this lane.
<b>Annual estimated volume* (0 by default)</b>	The annual estimated number of containers or loads on this lane.
<b>Market rate (0 by default)</b>	Usual price charged for goods in market.
<b>Owner region</b>	
<b>Flexible fields</b>	
<b>Origin Free Time</b>	Free time for detention/ demurrage at origin location.
Detention*	
Demurrage*	
<b>Destination Free Time</b>	Free time for detention/ demurrage at destination location.
Detention*	
Demurrage*	

\* Required input data.

TABLE 30: POSSIBLE SCOPE FIELDS

Scope fields	Selection Options
<b>Origin</b>	Only defined region (e.g. Europe)
	Only defined location
	Only defined country
<b>Destination</b>	Only defined region (e.g. Europe)
	Only defined location
	Only defined country
<b>Volume</b>	Volume (=,<,<=,> or >= than xx units)
	Volume tiers (Low (1-49), Medium (50-300) or High (more than 300))
<b>Lane</b>	Lane number (only specific lane)
	Commodity
	Business Unit
	Equipment type (e.g. only specific container size)
	Type of rate
<b>Percent Range</b>	Transit time (<,<=,> or >= than xx% of legacy transit time)
	Total commitment (<,<=,> or >= than xx% of annual estimated volume)
	Rate (<,<=,> or >= than xx% of market rate)
<b>Bid</b>	BidFlexField

TABLE 31: CONSTRAINTS WHICH CAN BE ADDED TO THE OPTIMIZATION PROBLEM

Constraint	Unit	Type
<b>Adjust for each day difference between the bid and legacy transit times</b>	dollar	Conversion
<b>Favor</b>	Per cent or dollar	Constraint
<b>Minimum number of carriers</b>	Carrier(s)	Constraint
<b>Maximum number of carriers</b>	Carrier(s)	Constraint
<b>Penalize</b>	Per cent or dollar	Conversion
<b>Penalize N% for each 1% increase in market rate</b>	Per cent	Conversion
<b>Set maximum award (if awarded)</b>	Per cent or units	Constraint
<b>Set maximum number of bids</b>	Bids	Constraint
<b>Set maximum number of bids per lane</b>	Bids	Constraint
<b>Set maximum total award</b>	Per cent, units or dollars	Constraint
<b>Set maximum volume awarded per bid (if awarded)</b>	Per cent or units	Constraint
<b>Set minimum award (if awarded)</b>	Per cent or units	Constraint
<b>Set minimum number of bids</b>	Bids	Constraint
<b>Set minimum number of bids per lane</b>	Bids	Constraint
<b>Set minimum total award</b>	Per cent, units or dollars	Constraint
<b>Set minimum volume awarded per bid (if awarded)</b>	Per cent or units	Constraint

Mathematical model for the vendor selection problem with transit time as a stochastic parameter:

The table below lists all relevant parameters:

TABLE 32: VARIABLES FOR VENDOR SELECTION PROBLEM WITH TRANSIT TIME AS STOCHASTIC PARAMETER

Parameter	Explanation
$q_j$	Annual volume for lane $j$ ; $j \in J$
$c_{ij}$	Capacity for bid $(i, j)$ ; $(i, j) \in I \times J$
$p_{ij}$	Bidding rate for bid $(i, j)$ ; $(i, j) \in I \times J$
$\alpha$	Max number of selected carriers
$v_{max}$	Max. awarded transport volume to bids in scope
$v_{min}$	Min. awarded transport volume to bids in scope
$r_{ij}$	Binary variable indicating if bid $(i, j)$ is in the scope
$s_{ij}$	Binary variable indicating if bid $(i, j)$ is in the scope
$t_{ij} \sim G(\alpha, \beta)$	Stochastic transit time of carrier $i$ on lane $j$ , with $\alpha > 0, \beta > 0$ and $E(t_{ij}) = \min(\hat{t}_{ij}) + \frac{\beta}{\alpha}$ , $Var(t_{ij}) = \frac{\beta}{\alpha^2}$ , where $\min(\hat{t}_{ij})$ equals the smallest value of all past transit time values for carrier $i$ on lane $j$
$t_{j,max}$	Max. allowed transit time on lane $j$
$p_j$	Probability that the max. transit time on lane $j$ cannot be respected
$Z_{(1-p_j)}$	Inverse cumulative standard normal distribution function

Decision variables:

- $x_{ij}$  = fractional allocation quantity assigned to bid  $(i, j)$
- $y_i = \begin{cases} 1, & \text{if carrier } i \text{ is selected} \\ 0, & \text{otherwise} \end{cases}$
- $w_{ij} = \begin{cases} 1, & \text{if carrier } i \text{ is awarded on lane } j \\ 0, & \text{otherwise} \end{cases}$

The optimization problem is defined as

$$\text{Min} \sum_{i=0}^n \sum_{j=0}^m p_{ij} x_{ij} q_j + \sum_{j=0}^m p_{sj} x_{sj} q_j + \sum_{i=0}^n y_i + \sum_{i=0}^n \sum_{j=0}^m w_{ij}$$

s.t.

$$\sum_{i=0}^n x_{ij} + x_{sj} = 1, \quad \forall j \in J \quad (1)$$

$$x_{ij} q_j \leq c_{ij}, \quad \forall (i, j) \in I \times J \quad (2)$$

$$0 \leq x_{ij} \leq 1, \quad \forall (i, j) \in I \times J \quad (3)$$

$$y_i \in \{0, 1\}, \quad \forall i \in I \quad (4)$$

$$w_{ij} \in \{0, 1\}, \quad \forall (i, j) \in I \times J \quad (5)$$

Optional Constraints:

$$\sum_{i=0}^n y_i \leq a \quad (6)$$

$$\sum_{j=0}^m x_{ij}/m \leq y_i, \quad \forall i \in I \quad (7)$$

$$\sum_{i=0}^I \sum_{j=0}^J r_{ij} x_{ij} q_j \leq v_{max} \quad (8)$$

$$\sum_{i=0}^I \sum_{j=0}^J s_{ij} x_{ij} q_j \geq v_{min} \quad (9)$$

$$\beta w_{ij} + \min(\hat{t}_{ij}) w_{ij} + Z_{(1-p_j)} \sqrt{\beta w_{ij}} \leq \alpha t_{j,max} \quad \forall (i,j) \in I \times J \quad (10)$$

$$x_{ij} \leq w_{ij} \quad \forall (i,j) \in I \times J \quad (11)$$

---



---

 APPENDIX E
 

---

**GAMS Code for deterministic Model:**

```

$title Scenario Builder: Cost-optimal assignment of transport quantities to carriers

$ontext
set of carriers + slack carrier
$offtext
set i/ 1*3/;

$ontext
subset (real carriers)
$offtext
set i1(i)/ 1*2/;

$ontext
subset (slack carrier)
$offtext
set i2(i)/ 3/;

$ontext
set of lanes
$offtext
set j/ 1*14/;

display i,i1,i2,j;

scalar
$ontext
max. number of selected carriers
$offtext
a max. number carriers /2/

$ontext
min. and max. awarded transport quantity
$offtext
d max. award /999/
e min. award /0/

display a,d,e;

parameters
$ontext
annual volume per lane
$offtext
q(j) annual volume on lane j/
$call =xls2gms r=summary!a3:b16
i="C:\Users\nadine.gruchot\Documents\gammdir\projdir\summary data gams.xlsx"
o=demand.inc
$include demand.inc
/
$ontext

```

bidding rate of slack carrier on lane j (equals bidding rate of most expensive carrier)

\$offtext

ps(j) *slack carrier bidding rate/*

\$call =xls2gms

r=summary!e3:f16

i="C:\Users\nadine.gruchot\Documents\gamsdir\projdir\summary

data gams.xlsx"

o=slackprice.inc

\$include slackprice.inc

/

\$ontext

upper bound transit time on lane j

\$offtext

maxt(j) *upper bound for transit time on lane j/*

\$call =xls2gms

r=summary!j3:k16

i="C:\Users\nadine.gruchot\Documents\gamsdir\projdir\summary data gams.xlsx" o=maxt.inc

\$include maxt.inc

/

\$ontext

Definition of the outcome calculations

\$offtext

actualcost                   dollars -   calculates the cost with modified slack carrier bidding rate

awardcarrier1               units -   calculates total transport volume awarded to carrier 1

awardcarrier2               units -   calculates total transport volume awarded to carrier 2

awardslackcarrier          units -   calculates total transport volume awarded to slack carrier

costcarrier1                 dollars -   calculates costs through carrier 1

costcarrier2                 dollars -   calculates costs through carrier 2

;

\$ontext

capacity of carrier i on lane j

\$offtext

table c(i,j) *capacity of carrier i on lane j*

\$call =xls2gms

r=summary!a19:o22

I="C:\Users\nadine.gruchot\Documents\gamsdir\projdir\summary

data gams.xlsx"

o=capacity.inc

\$include capacity.inc

;

\$ontext

capacity of carrier i on lane j

\$offtext

table p(i,j) *bidding rate of carrier i on lane j*

\$call =xls2gms

r=summary!a25:o27

I="C:\Users\nadine.gruchot\Documents\gamsdir\projdir\summary data gams.xlsx" o=price.inc

\$include price.inc

;

\$ontext

transit time of carrier i on lane j

\$offtext

table t(i,j) *transit time of carrier i on lane j*

\$call =xls2gms

r=summary!a31:o33

I="C:\Users\nadine.gruchot\Documents\gamsdir\projdir\summary data gams.xlsx" o=t.inc

\$include t.inc

;

\$ontext

scope activated for bid ij for maximum award constraint

\$offtext

```

table z1(i,j)  scope activated for bid ij
$call          =xls2gms                      r=summary!a36:o38
I="C:\Users\nadine.gruchot\Documents\gammdir\projdir\summary
data          gams.xlsx"
o=scope1.inc
$include scope1.inc
;
$ontext
scope activated for bid ij for minimum award constraint
$offtext
table z2(i,j)  scope activated for bid ij
$call          =xls2gms                      r=summary!a41:o43
I="C:\Users\nadine.gruchot\Documents\gammdir\projdir\summary
data          gams.xlsx"
o=scope2.inc
$include scope2.inc
;
$ontext
declaration of decision variables and objective function value
$offtext
variable      x(i,j)      awarded fractional Quantity to bid ij;
binary variable y(i)      whether carrier i is selected;
variable      z           objective function value;

$ontext
Declaration of objective function and constraints
$offtext
equations
    obj_fun          Objective function

    demand(j)       guarantees that demand is satisfied
    capacity(i,j)   guarantees that capacity for each bid is restricted

    inscope1(i,j)   guarantees that fractional transport volume is greater than zero
    inscope2(i,j)   guarantees that fractional transport volume is smaller than one

    maxcarrier      guarantees that max. number of carriers is not exceeded
    selectedcarrier(i) guarantees that xij is set to one if carrier is awarded

    maxaward        sets an upper bound to the awarded quantity for bids in the scope
    minaward        sets a lower bound to the awarded quantity for bids in the scope

    transittime(i,j) ensures that only bids are awarded where tij is smaller than tmax
;

$ontext
model formulation
$offtext
obj_fun..          Sum( (i1,j),x(i1,j)*q(j)*p(i1,j))+ Sum( (j), ps(j)*q(j)*(1-Sum( (i1),
x(i1,j)))))+Sum( (i), y(i)) =e= z;

demand(j)..       Sum( (i), x(i,j)) =e= 1;
capacity(i,j)..   x(i,j)*q(j) =l= c(i,j);

inscope1(i,j)..   x(i,j) =g= 0;
inscope2(i,j)..   x(i,j) =l= 1;

```



```

maxcarrier..      Sum( (i1), y(i1)) =l= a;
selectedcarrier(i).. Sum( (j), x(i,j))/14 =l= y(i);

maxaward..      Sum( (i1,j), z1(i1,j)*x(i1,j)*q(j)) =l= d;
minaward..      Sum( (i1,j), z2(i1,j)*x(i1,j)*q(j)) =g= e;

transittime(i,j).. x(i,j)*(t(i,j) gt maxt(j))=e=0;

option optcr = 0;

model Transport /ALL/;
solve Transport USING mip MINIMIZING z;

actualcost      = Sum( (i1,j),x.l(i1,j)*q(j)*p(i1,j))+ Sum( (j), ps(j)*q(j)*(1-Sum( (i1), x.l(i1,j)))) -
10*Sum( (j), q(j)*(1-Sum( (i1), x.l(i1,j))));
awardcarrier1   = Sum( (j), x.l("1",j)*q(j));
awardcarrier2   = Sum( (j), x.l("2",j)*q(j));
awardslackcarrier= Sum( (j), q(j)*(1-Sum( (i1), x.l(i1,j))));
costcarrier1    = Sum( (j), x.l("1",j)*p("1",j)*q(j));
costcarrier2    = Sum( (j), x.l("2",j)*p("2",j)*q(j));

display actualcost, awardcarrier1, awardcarrier2, awardslackcarrier, costcarrier1, costcarrier2;

display y.l;
display x.l;
display z.l;

```

### Lane data fitting

The following graphs show the distribution of the lane data for each carrier on the selected lanes. For carrier 2 on lane 1 and 4 not enough data entries are available. Especially the last two lanes had a lot of data entries for both carriers so that they give a good picture on how lane data is distributed over time. It can be seen that the gamma distribution with parameters  $\alpha = 0.9$  and  $\beta = 2$  is a good approximation for especially these two lanes.

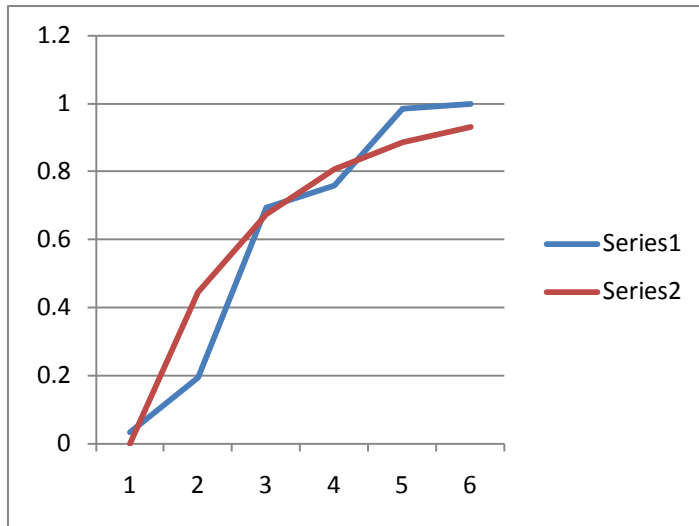


FIGURE 23: LANE DATA DISTRIBUTION OF CARRIER 1 ON LANE 1 COMPARED WITH GAMMA DISTRIBUTION (ALPHA=0.9, BETA=2)

Carrier 2 on lane 1: not enough data entries

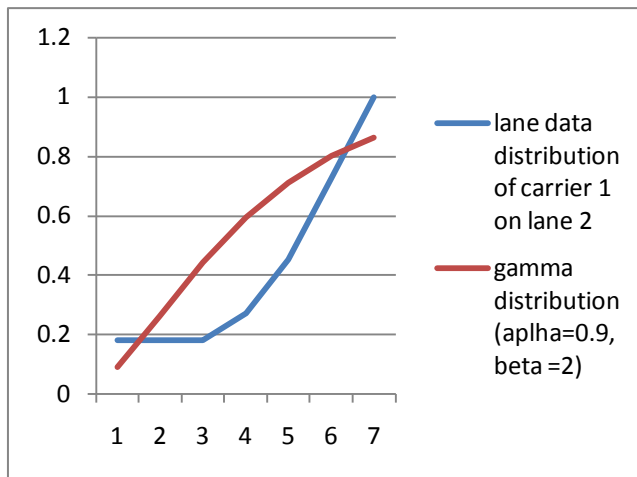


Figure 24: lane data distribution of carrier 1 on lane 2 compared with gamma distribution (alpha=0.9, beta=2)

FIGURE 25: LANE DATA DISTRIBUTION OF CARRIER 2 ON LANE 2 COMPARED WITH GAMMA DISTRIBUTION (ALPHA=0.9, BETA=2)

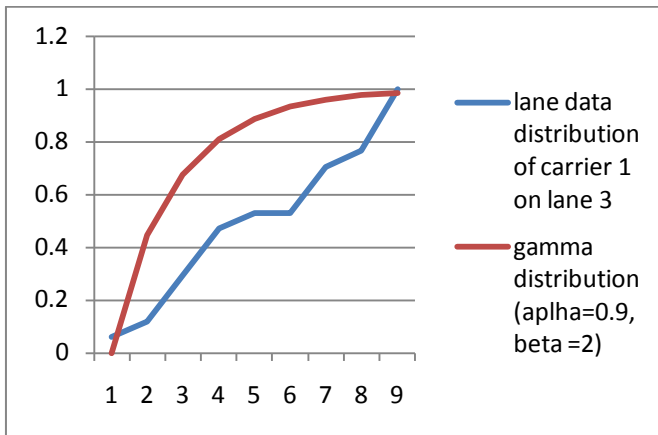


FIGURE 26: LANE DATA DISTRIBUTION OF CARRIER 1 ON LANE 3 COMPARED WITH GAMMA DISTRIBUTION (ALPHA=0.9, BETA=2)

Carrier 2 on lane 3: not enough data entries

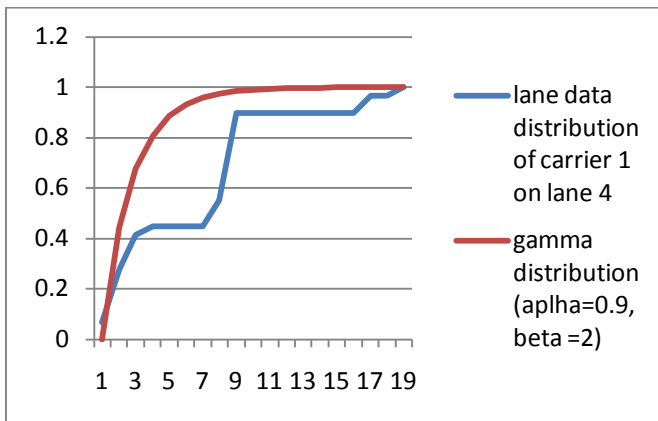


FIGURE 27: LANE DATA DISTRIBUTION OF CARRIER 1 ON LANE 4 COMPARED WITH GAMMA DISTRIBUTION (ALPHA=0.9, BETA=2)

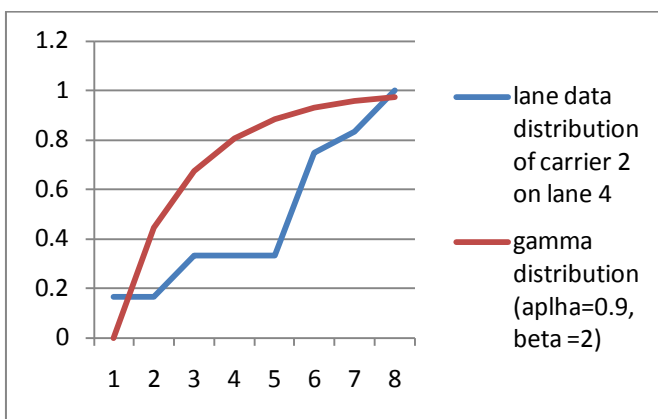


FIGURE 28: LANE DATA DISTRIBUTION OF CARRIER 2 ON LANE 4 COMPARED WITH GAMMA DISTRIBUTION (ALPHA=0.9, BETA=2)

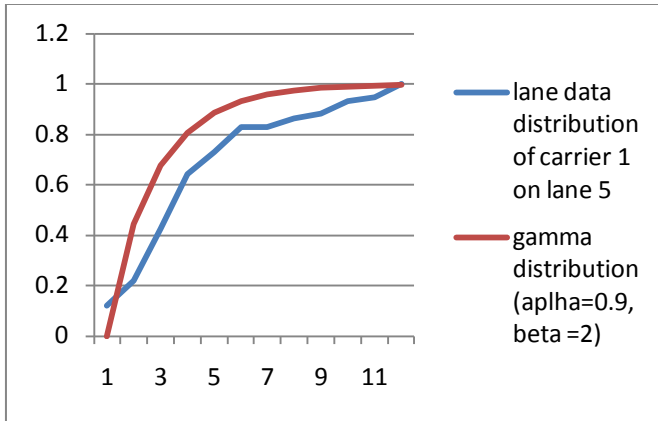


FIGURE 29: LANE DATA DISTRIBUTION OF CARRIER 1 ON LANE 5 COMPARED WITH GAMMA DISTRIBUTION (ALPHA=0.9, BETA=2)

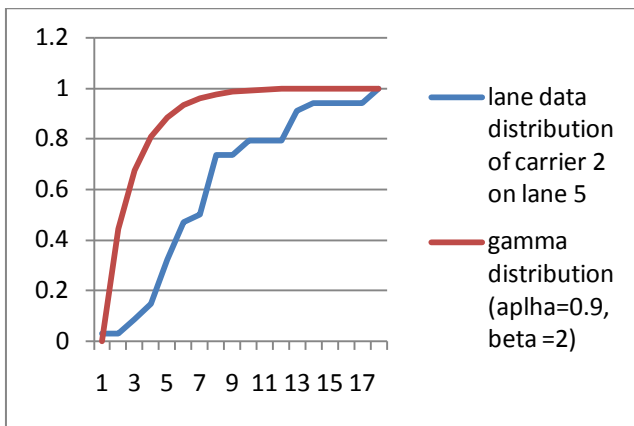


FIGURE 30: LANE DATA DISTRIBUTION OF CARRIER 2 ON LANE 5 COMPARED WITH GAMMA DISTRIBUTION (ALPHA=0.9, BETA=2)

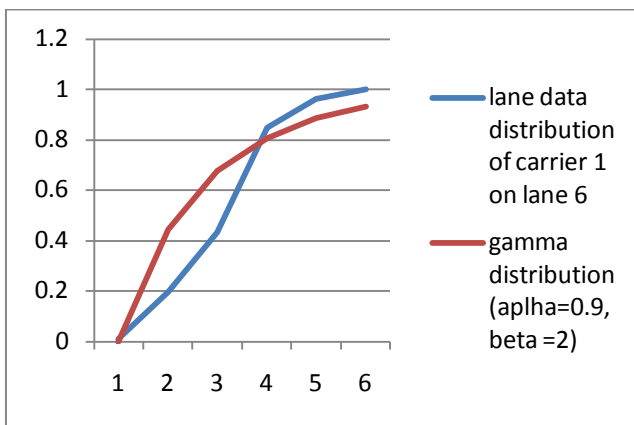


FIGURE 31: LANE DATA DISTRIBUTION OF CARRIER 1 ON LANE 6 COMPARED WITH GAMMA DISTRIBUTION (ALPHA=0.9, BETA=2)

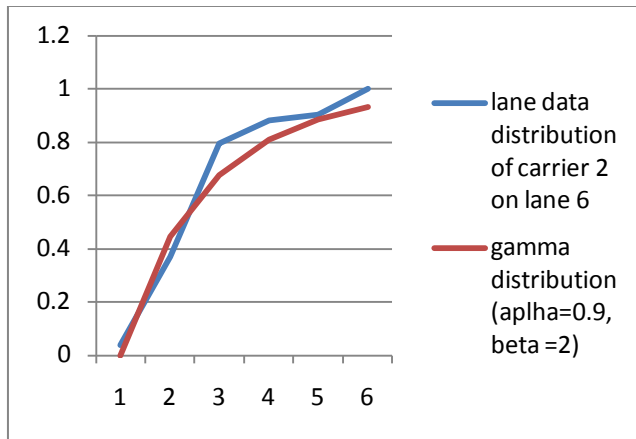


FIGURE 32: LANE DATA DISTRIBUTION OF CARRIER 2 ON LANE 6 COMPARED WITH GAMMA DISTRIBUTION (ALPHA=0.9, BETA=2)

## 10 BIBLIOGRAPHY

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A.T.Kearney. (2011). *JumpStarting your eSourcing Initiative*.

Alonso-Ayuso, A., Escudero, L. F., Garin, A., Ortuno, M. T., & Perez, G. (2003). An Approach for Strategic Supply Chain Planning under Uncertainty based on Stochastic 0-1 Programming. *Journal of Global Optimization* , 97–124.

Arunkumar, N., Karunamoorthy, L., Anand, S., & Ramesh Babu, T. (2006). Linear approach for solving a piecewise linear vendor selection problem of quantity discounts using lexicographic method. *International Journal of Advanced Manufacturing Technology* , 1254–1260.

Aubert, B., Patry, M., & Rivard, S. (2004). A transaction cost model of IT outsourcing. *Information and Management* , 921–932.

Booz, A. H. (2001). *BPO Survey of 100 U.S. Companies*.

*BravoSolution; BravoSolution Launches the Procurement Industry's First Ever Alignment Solution*. (2013). Atlanta, USA: NewsRx.

Carney, H. (1998). The competitiveness of networked production: the role of trust and asset specificity. *Journal of Management Studies* , 457–479.

*Coin or branch-and-cut- Wiki*. (2014, July 1). Retrieved August 14, 2014, from Coin or branch-and-cut: <https://projects.coin-or.org/Cbc>

*CombineNet Market Survey*. (2011).

*CombineNet Reports Results*. (2012). Jacksonville, USA: Close-Up Media, Inc.

Corbett, M. F. (2004). *The Outsourcing Revolution: Why It Makes Sense And How To Do It Right*. Chicago: Dearborn Trade Publishing.

Cousins, P., Lamming, R., Lawson, B., & Squire, B. (2008). *Strategic Supply Management: Principles, Theories and Practice*. Harlow, UK: Pearson Education.

Dabhilkar, M. (2011). Trade-offs in make-buy decisions. *Journal of Purchasing & Supply Management* , 158–166.

Dickson, W. G. (1966). An analysis of vendor selection systems and decisions. *Journal of Purchasing* , 5-20.

Ding, H., Benyoucef, L., & Xiaolan, X. (2004). A Multiobjective Optimization Method for Strategic Sourcing and Inventory Replenishment. *IEEE International Conference on Robotics and Automation*, (pp. 2711-2716). New Orleans, LA.

Ekhtiari, M., & Poursafary, S. (2013). Multiobjective Stochastic Programming for Mixed Integer Vendor Selection Problem Using Artificial Bee Colony Algorithm. *ISRN Artificial Intelligence* , 1-13.

Farahani, R. Z., & Fadaei, M. (2012). A MCDM-based model for vendor selection: a case study in the particleboard industry. *Journal of Forestry Research* , 685-690.

*GAMS- Solver Descriptions*. (n.d.). Retrieved August 14, 2014, from GAMS: <http://www.gams.com/solvers/solvers.htm#CPLEX>

- Ghanti, S., & Jha, D. (2013). *Sustainable Savings through Category Approach*. Tata Consultancy Services.
- Hoetker, G. (2005). How much you know versus how well I know you: selecting a supplier for a technically innovative component. *Strategic Management Journal* , 75–96.
- Holcomb, T. R., & Hitt, M. A. (2007). Toward a model of strategic outsourcing. *Journal of Operations Management* , 464–481.
- Holland, A., & O'Sullivan, B. (2005). Super Solutions for Combinatorial Auctions. In *Recent Advances in Constraints: Joint ERCIM/CoLogNET International Workshop on Constraint Solving and Constraint Logic Programming* (pp. 187-200). Springer.
- Hsu, C., Wang, F.-K., & Tzeng, G.-H. (2011). The best vendor selection for conducting the recycled material based on a hybrid MCDM model combining DANP with VIKOR. *Resources, Conservation and Recycling* , 95-111.
- Huber, B., Gupta, R., & Hegde, M. (2009). *Procurement Outsourcing- Trends, Challenges, Benefits and a Roadmap for Implementation*. InfoSys.
- Hyder, E. B., Kumar, B., Mahendra, V., Siegel, J., Heston, K. M., Gupta, R., et al. (2002). *eSourcing Capability Model for IT-enabled Service Providers*. Pittsburgh: School of Computer Science, Carnegie Mellon University.
- Jacobides, M., & Winter, S. (2005). The co-evolution of capabilities and transaction costs: explaining the institutional structure of production. *Strategic Management Journal* , 395–413.
- Jones, G. (1983). Transaction costs, property rights, and organizational culture: an exchange perspective. *Administrative Science Quarterly* , 454–467.
- Kasilingamand, R. G., & Lee, C. (1996). Selection of Vendors - A Mixed-Integer Programming Approach . *Computers and Industrial Engineering* , 347–350.
- Keskin, B., Ster, K., & Etinkaya, S. (2006). Integration of strategic and tactical decisions for vendor selection under capacity constraints. *Computers and Operations Research* , 2182–2191.
- Khan, M. F., Anwar, Z., & Ahmad, Q. S. (2012). Assignment of Personnels when Job Completion time follows Gamma distribution using Stochastic Programming Technique. *International Journal of Scientific & Engineering Research* .
- Klein, B., Crawford, A., & Alchian, A. (1978). Vertical integration, appropriable rents, and the competitive contracting process. *Journal of Law and Economics* , 297–326.
- Kroes, J. R., & Ghosh, S. (2010). Outsourcing Congruence with Competitive Priorities: Impact on Supply Chain and Firm Performance. *Journal of Operations Management* , 124-143.
- Lam, S. W., & Tang, L. C. (2006). Multiobjective Vendor Allocation in Multiechelon Inventory Systems: A Spreadsheet Model. *The Journal of the Operational Research Society* , 561-578.
- Leung, S., Wu, Y., & Lai, K. (2006). A Stochastic Programming Approach for Multi-Site Aggregate Production Planning. *Journal of the Operational Research Society* , 123–132.
- Limberakis, C. G. (2012). *Advanced Sourcing- Maximizing Savings Identification*. Aberdeen Group.
- Lin, Y.-T., Lin, C.-L., Yu, H.-C., & Tzeng, G.-H. (2010). A novel hybrid MCDM approach for outsourcing vendor selection: A case study for a semiconductor company in Taiwan. *Expert Systems with Applications* , 4796–4804.

Lyons, B. R. (1995). Specific investment, economies of scale, and the make-or-buy decision: A test of transaction cost theory. *Journal of Economic Behavior and Organization* , 431-443.

Poppo, L., & Zenger, T. (2002). Do formal contracts and relational governance function as substitutes or complements? *Strategic Management Journal* , 707-725.

Poppo, L., & Zenger, T. (1998). Testing alternative theories of the firm: transaction cost, knowledge-based, and measurement explanations for make-or-buy decision in information services. *Strategic Management Journal* , 853-877.

Porter, M. E. (2008). The Five Competitive Forces That Shape Strategy. *Harvard Business Review* , 79.

Rassenti, S. J., Smith, V. L., & Bulfin, R. L. (1982). A Combinatorial Auction Mechanism for Airport Time Slot Allocation. *Bell Journal of Economics* , 402-417.

Rossignoli, C., Mola, L., & Zardini, A. (2007). Virtual Network Organizations and E-procurement: A new Outsourcing Perspective. *First Information Systems Workshop on Global Sourcing: Services, Knowledge and Innovation Val d'Isère, France*. Verona, Italy.

Sampaio, L. R. (2009). *E-sourcing Electronic Platforms in real business*. Lisbon: Instituto Superior Tecnico- Universidade Tecnica de Lisboa.

Sandholm, T. (2006). *Expressive Commerce and Its Application to Sourcing*. Pittsburgh, PA: American Association for Artificial Intelligence.

Sandholm, T. (2007). Expressive Commerce and Its Application to Sourcing. *Proceedings of the ninth international conference on Electronic commerce*, (pp. 349-350 ). New York, NY.

Sandholm, T., Levine, D., Concordia, M., & Martyn, P. (2006). Changing the Game in Strategic Sourcing at Procter & Gamble: Expressive Competition Enabled by Optimization. *Interfaces* , 55-68.

*SciQuest, Inc. Revenue & Earnings Per Share (EPS)*. (2014, May 8). Retrieved May 9, 2014, from NASDAQ: <http://www.nasdaq.com/symbol/sqi/revenue-eps>

Shiwei, H., Chaudhry, S. S., Lei, Z., & Baohua, W. (2009). Stochastic vendor selection problem: chance-constrained model and genetic algorithms. *Annals of Operations Research* , 169-179.

Simon, H. (1978). Rationality as process and as product of thought. *American Economic Review* , 1-16.

Smith, P. (2012, August 16). *Spend Matters UK/ Europe*. Retrieved May 21, 2014, from Trade Extensions - boldly going "Beyond Sourcing": <http://spendmatters.com/uk/trade-extensions-boldly-going-beyond-sourcing/>

Smith, P. (2013, September 6). *Spend Matters UK/ Europe*. Retrieved May 19, 2014, from CombineNet and SciQuest- Some further thoughts: <http://spendmatters.com/uk/combinenet-and-sciquest-some-further-thoughts/>

Smith, P. (2014, February 5). *Spend Matters UK/ Europe*. Retrieved May 21, 2014, from Trade Extensions - 2013 was a great year for sourcing software provider: <http://spendmatters.com/uk/trade-extensions-2013-great-year-sourcing-software-provider/>

*SolverStudio*. (n.d.). Retrieved August 15, 2014, from SolverStudio: <http://solverstudio.org/>



- Steenburgh, T., & Avery, J. (2010). *Marketing Analysis Toolkit: Situation Analysis*. Harvard Business School.
- Sucky, E. (2005). A dynamic model for strategic supplier selection. *Operations Research Proceedings*, 118-126.
- Taleizadeh, A., Niaki, S., & Barzinpour, F. (2011). Multiple-buyer multiple-vendor multi-product multi-constraint supply chain problem with stochastic demand and variable lead-time: A harmony search algorithm. *Applied Mathematics and Computation*, 9234–9253.
- Talluri, S., Narasimhan, R., & Nair, A. (2006). Vendor performance with supply risk: A chance-constrained DEA approach. *International Journal of Production Economics*, 212-222.
- van Aken, J. E., Berends, H., & van der Bij, H. (2007). *Problem Solving in Organizations: A Methodological Handbook for Business Students*. Cambridge University Press.
- Weber, C. A., & Current, J. R. (1993). A multiobjective approach to vendor selection. *European Journal of Operational Research*, 173-184.
- Weber, C. A., & Current, J. R. (1993). A multiobjective approach to vendor selection. *European Journal of Operational Research*, 173–184.
- Wernerfelt, B. (1984). A resource-based view of the firm. *Strategic Management Journal*, 171–180.
- Wikipedia. (2014, May 24). Retrieved July 02, 2014, from Second-order cone programming: [http://en.wikipedia.org/wiki/Second-order\\_cone\\_programming](http://en.wikipedia.org/wiki/Second-order_cone_programming)
- Wikipedia. (2014, June 27). Retrieved July 9, 2014, from Error function: [http://en.wikipedia.org/wiki/Error\\_function](http://en.wikipedia.org/wiki/Error_function)
- Wikipedia- Second-order Cone Programming. (2014, May 24). Retrieved August 15, 2014, from Wikipedia: [http://en.wikipedia.org/wiki/Second-order\\_cone\\_programming](http://en.wikipedia.org/wiki/Second-order_cone_programming)
- Williamson, O. (1991). Comparative economic organization: the analysis of discrete structural alternatives. *Administrative Science Quarterly*, 269–296.
- Williamson, O. (1999). Strategy research: governance and competence perspectives. *Strategic Management Journal*, 1087–1108.
- Williamson, O. (1985). *The Economic Institutions of Capitalism: Firms, Markets and Relational Contracting*. New York: Free Press.
- Wilson, D. R., Bergfors, M., & Adams, R. (2013). *Magic Quadrant for Strategic Sourcing*. Gartner Inc.
- Wilson, D. R., Bergfors, M., & Adams, R. (2013). *Magic Quadrant for Strategic Sourcing Application Suites*. Gartner.
- WirelessNews. (2013). *BravoSolution Reports on 2012 Revenue*. Coventry, USA: Close-Up Media, Inc.
- Xu, J., & Ding, C. (2011). A Class of Chance Constrained Multi-objective linear programming with birandom coefficients and its application to vendor selection. *International Journal of Production Economics*, 709–720.

Yahya, S., & Kingsman, B. (1999). Vendor rating for an entrepreneur development programme: a case study using the analytic hierarchy method. *Journal of the Operational Research Society*, 916-930.

Zang, W., Liu, Y., & Li, Z. (2012). Optimizing supplier selection with disruptions by chance-constrained programming. *Advances in Swarm Intelligence* (pp. 108-116). Shenzhen, China: Springer.

Zhang, H., Li, X., & Liu, W. (2005). An AHP/DEA methodology for 3PL vendor selection in 4PL. In W. Shen, K.-M. Chao, Z. Lin, J.-P. A. Barthes, & A. James, *Computer Supported Cooperative Work in Design II* (pp. 646-656). Coventry, UK: Springer.