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Association Analysis of Supply Chain Risk and Company Sales

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Abstract—In recent years, supply chain risk management has captivated both academicians and business practitioners interest, due to increasing catastrophic events and supply chain disruptions. However, the risk management process is highly complex because of the stochastic and dynamic nature and ever growing complexity of supply chains. As the ultimate goal of most enterprises is generating and increasing revenues on the long run, it is valuable to know the effect of specific supply chain risk positions and risk management practices on company sales. In this paper, secondary data on supply chain risk is analyzed and the key risk management strategies responsible for increased company sales are revealed. The novelty of this paper lies in developing a quantifying data mining approach to provide a comprehensive understanding of supply chain risk management (SCRM) and pinpoint focus areas for revenue seeking enterprises. The results prove and showcase that our methodology is capable of providing actionable insights, which were previously unknown or unaddressed.

Keywords—Supply chain management; Supply chain risk positions and risk management practices; Association rule mining.

I. INTRODUCTION

In the last decades companies and researchers have shifted their focus from management of company inherent risks to management of supply chain risk (SCR) [1]. This shift could be explained by not only the increased exposure of companies to SCR as being a part of more vulnerable supply chains, but also the stronger impact of supply chain risks on company sales. One of the reasons for increased supply chain vulnerability is that during recent years, companies have been transformed into global actors by increased competitiveness in the industry and globalization. To stay financially viable, firms adopted processes and practices to align their business within the supply chain. Relevant examples could serve the practices of reducing or eliminating inventories, synchronizing delivery, lean production and outsourcing non-core activities [1] [2]. Even though these actions may increase the performance of companies by implementing leaner operations, reducing tied-up capital and opening new markets, some academicians argue that

these actions amplify the exposure of companies to supply chain disruptions by making them more vulnerable [3]. These concerns raise the problem of measuring the impact of supply chain characteristics on company performance. Recent surveys report an increase both in the number of supply chain risks and the impact magnitude. A study by Zurich Financial Services Group and the Business Continuity Institute involving 559 organizations in over 62 countries and across 14 industries which focused on causes and consequences of supply chains disruptions revealed that 85% of companies experienced at least one disruption in 2011 [4]. It is important to note that, these supply chain incidents caused loss of productivity for about a half of organizations along with a rise in cost of working (38%) and loss of revenue (32%). The occurrence of a large number of very severe natural catastrophes made 2011 the highest-ever loss year. The results of these surveys make it clear that supply chain risk can have detrimental effects on the company's financial performance. With the increase of complexity in supply chain dynamics and its possible effect on company financial outcome, there is a need to evaluate which activities are avoidable, and which risks can be associated with higher sales. The question about the financial impact of supply chain characteristics arises. The answer to this question can improve company's understanding of the critical importance associated with a proactive approach towards management of SCR areas. Analyzing this question one should also address the topic of conflicting logistics targets from avoiding misallocation of scarce resources and at the same time being able to be competitive in fulfilling customer requirements [5]. Given the aforementioned conflicting logistics targets, revenue seeking companies have to concentrate on the activities with highest value with respect to their sales. Focus of business and academic practitioners was drawn to the inability of organizations to cope with SCRs, after news surfaced in the media about this topic and affected companies. Standing examples are the delay of the Airbus XWB 350 airplane delivery because of glitches at the

suppliers [6]; its competitor Boeing faced problems as well with its 787 Dreamliner due to supplier issues, announcing delays multiple times [3]; the devastating earthquake and subsequent tsunami, that hit Japan in 2011, affected not only local automotive production of such giants as Honda and Toyota, but also their overseas production subsidiaries [7]. Such events make obvious the need for an understanding of the extent to which SCR can affect company performance. This paper is motivated by this recent research question, and contributes to the relatively new research that quantifies supply chain risk management (SCRM) and its relationship to company's financial progress. A new way of exploring potential robust supply chains with an iterative association rules mining, in terms of intensity of practices and consequences, is proposed and developed to test hypothesis of customer dependence and global sourcing. We evaluate a set of supply chain characteristics, be it SCR/vulnerability and SCRM, to uncover areas on which executives should focus and manage those activities in a sustainable manner, instead of avoiding them in an attempt to reduce the SCR. Since by avoiding the risks that have a positive impact on company sales, they will only run into the risk of jeopardizing the financial outcome of the company. The remainder of this paper is organized as follows. Section 2 presents a literature review on supply chain risk and shortly presents other empirical research in the field. Section 3 describes the data we use and the employed methodology. Section 4 presents statistical findings and associations between supply chain characteristics and company sales. In Section 5, we discuss the results. The paper concludes in Section 6 with implications for supply chain planning and future research.

II. LITERATURE REVIEW

The focus of the recent research attempts has been increasing efficiency of supply chain operations (decreasing costs), whereas the necessary focus on managing supply chain risk is often lacking. A large number of publications on supply chain models focus on cost management [8]. A possible explanation for this is that managers are trained and incentivized on a continuous basis to improve cost efficiency in the supply chain area as well. Another facet of the problem is that justification of resource allocation for proactive risk measures is problematic given that supply chain disruptions have a low frequency and predictability on top of being difficult to manage. A part of the research focuses on elaborating mathematical models in order to explain how various management techniques of supply chains affect inventories, operating costs, service reliability and agility [9]. Another part of the research has focused on empirical research, in order to find the relationship between supply chain characteristics and company performance [10] [11]. This study is a continuation of the empirical research on companies in the context of supply chain risk conducted by [12] [13]. Even though, substantial research has been

performed to identify the relationship between supply chain characteristics and financial performance, most findings are case-study based or conceptual. Therefore, there is lack of evidence linking company performance and risk in the context of supply chain management.

A. Supply Chain Risk Management

Classifications and descriptions of SCRs and its reasons are widely researched and numerous proposals are made for categorization. SCR can be categorized into macro risks or ones located on a supply chain level (micro events). Macro events include terrorist attacks, wars, natural catastrophes (such as earthquakes, cyclones), epidemics and economic crisis. Referential examples are the volcano eruption in Iceland, disrupting the supply chains of many enterprises in Europe, with automotive producers and grocery stores being amongst the ones in need to look for alternative routes for supplies [6]; the terrorist attacks in US on September 11, 2001 and the Katrina Hurricane, and the earthquake and tsunami in Japan [7]. Micro events, or risks located on a supply chain level [1] involves operational fluctuations such as demand volatility, price variation and supply unpredictability (the delays of the above mentioned aircraft manufacturers stand as examples) and logistical trends such as lean processes, outsourcing and off shoring of large part of activities, reducing inventory. Moreover, Sarkar et al [14] formulated a model to determine the optimal size of a supply chain. Given the variety and complexity of supply chain processes, various studies concentrate on identifying supply chain risk sources. Trkman and McCormack [15] also presented a new method for the assessment of the supply risks. In our paper, we will analyze the risk sources that are extensively examined in [16]. Because of the occurrence of supply chain incidents and their impact on industries a number of academics have discussed the impact of SCR and have highlighted the need to take preventive and corrective actions to counterfeited their effect. In spite of their academic and practical significance, the big majority of the research in the domain does not provide insights based on empirical results, which could lead managerial decision making. There are only a few empirical studies in the context of SCR as observed from the conducted literature review. Hendricks [10] investigate the long-term stock price effects and equity risk effects of supply chain disruptions and examine the association between supply chain glitches and operation performance based on a sample of disruption announcements made during years 1989-2000. Also, Oke and Gopalakrishnan [17] investigated management of supply chain risks faced by large US retailers. Other empirical research reveals that supply chain characteristics such as a firm's dependence on certain customers and suppliers, the level of single sourcing and dependence on global supply sources influence a firm's supply chain risk exposure [16]. Furthermore, the relationship between SCR and company

performance is negative for demand side and supply side risks, whereas regulatory, legal and bureaucratic risks, infrastructure risks, as well as catastrophic risks remain neutral [13]. For their research, Wagner and Bode [12] equate SCR with the detriment of a supply chain disruption, (i.e. realized harm or loss). That is a fundamentally different in our research since we consider risk as leading to both, opportunity and harm. Therefore we examine which risks have negative effect on revenue (proof for realized harm) and which risks have positive impact on companys financial performance (proof for opportunity). Wagner and Bode use ordinary least squares (OLS) method for their research, and their results explain a rather small portion of the variance in the dependent variables. This paper investigates the relationship between specific SCRM techniques, SCRs and vulnerabilities, such as demand side risks, catastrophic risks, single sourcing or supplier concentration, and companys financial performance. Most importantly, we provide a new perspective on the relationship between supply chain characteristics and financial results, by employing the Kruskal-Wallis test and Association Rule Mining (ARM). Moreover, employing such an approach allows us to pin-point which supply chain characteristics need increased attention from executives and are necessary (or unavoidable) to maintain the financial competitiveness of companies.

B. Association Rule Mining

Both academicians and business professionals use association mining frequently to reveal the hidden patterns in the big data. Amazon.com uses association mining as a market based analysis to recommend products based on customer transactions (Sarwar et al. 2000). Wal-Mart also uses association rule mining in order to locate the items which have positive association and trigger the sales of each other (McGarry 2005). A further analysis of business and industry applications of data mining can be found in the book of Giudici and Figini) 2009. Academicians also studied association mining methods for market basket analysis [18], visualization of association mining results[19]. Although association rule mining is one of the widely-studied research topics, the statistical validation of the association rules are often neglected. There are only a few literature studies that validate association rules with statistics (Lallich et al. 2007, Hmlinen and Nyknen 2008). On the other hand, the validation of statistical hypothesis testing has never been implemented via association rule mining. This paper remains the first paper that validates hypothesis testing using association rule mining techniques.

C. Data Mining for Supply Chain Management

Application of data mining in supply chain management is emerging. Association rule mining has been applied as a data mining technique and a clustering procedure for an order batching problem in a distribution center with a parallel-aisle

layout. The approach has better performance in comparison with existing heuristics for various problems. An approach of incorporating data mining techniques is introduced into a dynamically configurable supply chain framework for better effectiveness with respect to comparable static supply chains. Possibility multi-objective programming model is proposed for supplier selection taking risk factors into consideration. The model consists of three levels and uses simulated historical quantitative and qualitative data. The approach of integrating the fuzzy cognitive map and fuzzy soft set model has been introduced for solving the supplier selection problem. This method considers both the dependencies among criteria and the uncertainties on decision making process. Data mining framework for discovering optimal modules can be applied in a delayed product differentiation scenario based on historical product sales data. The framework can be constructed for designing systems that extract the relationship between customer ratings and their reviews. Both qualitative and quantitative experiments are used to evaluate the performance of the BI system developed based on the framework. They show that the system achieved high accuracy and coverage related to rule quality and furthermore created interesting and informative rules with ample support and confidence values.

III. METHODOLOGY

For the statistical testing of the hypothesis and the application of the proposed data mining techniques with the aim to identify previously unknown patterns in SCRM we followed recent calls in the operations and supply chain management literature to use secondary data, which also includes pre-collected survey data. From the secondary data, attributes were obtained that tap firms supply chain risk positions and risk management practices. For each attribute, traditional reliability tests were utilized to check if the data is reliable. After that, the cluster analysis assigned companies to different classes, with respect to the intensity of practices. Consequently, multiple statistical hypothesis testing method was executed for each hypothesis. As a final step, association rule mining verified the hypothesis testing results. Primarily, the useful findings and managerial insights were interpreted through the results. The proposed methodology is shown in Figure 1.

A. Secondary Data

The pre-collected survey data was originally collected from a large number of German firms for the correlation and regression analytical appraisal of determinants to supply chain vulnerability and the influence of supply chain risks on supply chain performance. Subsequently, a graph-theoretical method was developed to assess firms supply chain vulnerability and to compare different firm categories. Now, the present study applies the data to a novel data mining approach. The data covers 760 industrial (71.7%), service

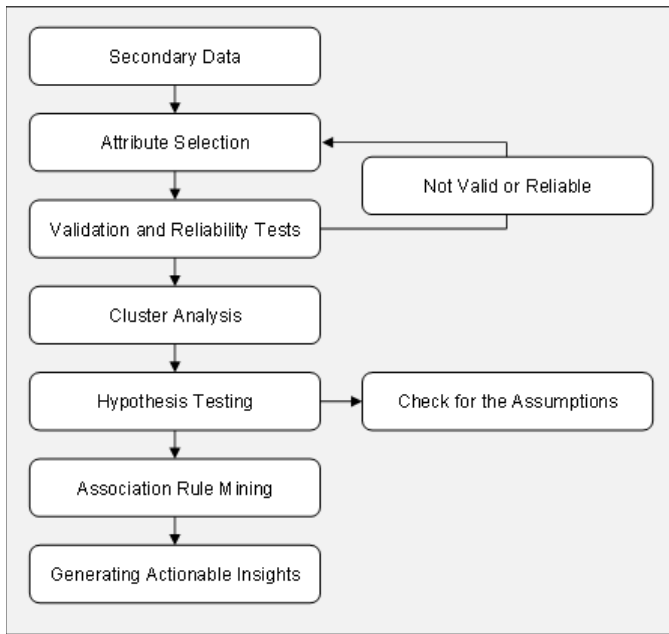


Figure 1: The proposed methodology for generating actionable insights.

(19.5%), and trade (8.8%) firms from Germany. These firms employed from fewer than 100 up to 430,000 (mean 2913) people, and their annual sales ranged from less than US\$ 10 million to US\$90 billion (mean US\$ 60.3 million). The responses came mainly from logistics and supply chain managers (37.5%), other higher-level senior managers or firm owners (23.8%), purchasing (15.0) respectively production/operations (13.9) employees, and a number of others (9.8%). The adequacy of the respondents was ensured, given their average tenure with the firm of 10.9 years, and in their current position of 7.0 years. The data used for the present study captures the firms supply chain risk positions and risk management practices, in particular whether the firms were affected by supply chain disruptions during the last three years, the vulnerability of the firms supply chains, and the SCRM activities. The items were measured on 5-point Likert scales.

B. Attribute Selection

Attribute selection is a fundamental stage of data mining, to determine which attributes are relevant to predict the data, or conversely, which attributes are redundant. As stated earlier, the supply chain risk positions and risk management practices are selected through the review of literature on SCRM. Their attributes can be divided into supply chain risk, supply chain vulnerability, and risk management. First, supply chain risks involve demand side risks; supply side risks; regulatory, legal and bureaucratic risks; infrastructural risks, and catastrophic risks. The demand side risk measure captures the risk stemming from the quality of interaction

with customers and volatility of the market. Likewise, the six items measuring supply side risk capture the risks that rise from events and parties in the upstream supply chain, such as the performance of suppliers or the general supply market conditions. Regulatory, legal and bureaucratic risks include two items related to changes in the political environment as well as administrative barriers imposed by governmental authorities. The four infrastructure risk items cover IT, equipment, and facility failures. The catastrophic risk measure captures risks that originate, for example, from terrorism, socio-political crises, natural disasters, and epidemics, and consists of four items. Second, supply chain vulnerabilities consist of customer dependence, supplier concentration, supplier dependence, single sourcing, and global sourcing. Five single items related to supply chain vulnerability were used. The dependence of the firm on some customers and suppliers is referred to as customer/supplier dependence respectively. Likewise, the concentration of the firms supplier base (supplier concentration), the firms application of single sourcing, and the firms use of global supplier base (global sourcing) are also captured. Third, since the intention of this research is to investigate the effects of supply chain risk positions and risk management practices on annual sales, risk management is also considered. The six items used to operationalize this variable tap risk management or mitigation strategies are related to the strategies frequently proposed in the literature. The items of all supply chain risk positions and risk management practices are summarized in Appendix A.

C. Validation and Reliability Tests

Traditional psychometric approaches were used to evaluate each scales reliability and validity. Reliabilities for all dependent variables were evaluated via Cronbachs alpha coefficient. As a result, all Cronbachs alpha coefficients range from 0.674 to 0.834, and exceed the generally accepted threshold. All items load on distinctive components with factor loadings larger than 0.5 and therefore meet general standards for convergent validity. Reliability test results are included in Appendix A. Overall, the data obtained from the secondary data source and used for the present study is sufficiently reliable and valid.

D. Cluster Analysis

The data pre-processing stages for statistical hypothesis testing involves cluster analysis for each supply chain risk position and risk management practice. In this paper, the structure of cluster analysis is straightforward. For each attribute, the units are divided into three classes, namely high, medium, and low, corresponding to their level. For instance, a unit with high customer dependence represents a supply chain firm having a high-scale response from the customer dependence questions. For multiple-item supply chain risk sources, high corresponds to the responses that

have average scores of (3.66, 5.00]. Likewise, medium and low have average scores of [2.33, 3.66] and [1.00, 2.33] respectively. For only one-itemed attributes, high corresponds to 5; medium is 4 and 3, and low represents 2 and 1. In the cluster analysis, we assume that each risk and vulnerability item has the same possibility of occurrence. For instance, demand side risk measure consists of two responses and both are treated as having the same likeliness to occur. Thus, firms are ordered with respect to their average scores. Primarily, although there are many cluster analysis algorithms in the literature [12] [10], we measured a straightforward cluster analysis due to simplicity and brevity advantages.

E. Hypothesis Testing

Multiple hypothesis testing is applied for each supply chain risk position and risk management practice to reveal their effect on annual sales. Hypothesis tests use previously structured classes, and null hypothesis can be summarized as following:

H_0 There is no significant difference between annual sales of High-Medium-Low selected attribute companies.

Since there are eleven supply chain risk positions and risk management practices, the null hypothesis is tested for 11 times using each attributes. Then, if the results reveal a significant difference on company sales, we analyzed the results with post-hoc analysis in order to statistically analyze the positive or negative effect for each intensity level. Therefore, the alternative hypothesis can be summarized as following:

H_A The higher supply chain risk positions and risk management practices, the higher/lower annual sales.

There are two commonly used statistical tests for this type of hypothesis, namely analysis of variance (ANOVA) and Kruskal-Wallis test. ANOVA is a parametric test, thus assumes that all classes are normally distributed. Conversely, Kruskal-Wallis test is a non-parametric test and requires at least one of the classes to be non-normally distributed. DAstogino-Pearson normality tests show that, for each supply chain risk position and risk management practice, there is at least one class that does not follow normal distribution, leaving Kruskal-Wallis as the suitable test. Moreover, Kruskal-Wallis test has a skewness assumption which suggests each class has the same scaled and shaped distribution; otherwise the test might give inaccurate results. Using MedCalc software, all items proved to hold the skewness assumptions. In summary, Kruskal-Wallis is proved to be a valid test.

F. Association Rule Mining

Association rule mining is a highly popular data mining technique that discovers the interdependencies of variables in a large database. The typical association rule (e.g., $A_1 \& A_2 \& \dots \Rightarrow B$) consists of a number of antecedents (A_x) and a consequence (B) with support and confidence

values. Association rules describe how these items affect each other (Han et al. 2012). Two threshold values help to identify and interpret the rules: support and confidence. Support value of an association rule indicates the percentage of the antecedents appearing in the dataset. In other words, support signifies the frequency of the rule. On the other hand, confidence denotes the conditional probability of B (consequence) appear in the transaction, given that A_x (antecedents) appears in that transaction. Confidence value represents the likelihood of the consequence for specified antecedents. Confidence shows the strength of the association rules, meaning the higher the confidence value, the more reliable the association rule. In this paper, association rules are generated using Apriori algorithm and AssocMiner software.

IV. RESULTS

We estimated eleven supply chain risk positions and risk management practices and their effect on annual sales using the Kruskal-Wallis test with post-hoc analysis. The results are also illustrated graphically. Finally, by mining the association rules, we find evidence to support the hypothesis testing results. Tables 1, 2, 3 and 4 report the results of the hypothesis tests and association rules.

A. Hypothesis Testing Results

Surprisingly, none of the supply chain risks show significant effect on annual sales. Both p-values and test statistics of supply chain risk results imply absence of the significant difference between annual sales. Thus, results reveal that annual sales of companies that are negatively affected by supply chain risks are more or less similar with the annual sales of risk-neutral companies. Conversely, two of the supply chain vulnerabilities explain the significant difference in annual sales: customer dependence and global sourcing. These instances have very low p-values and high test statistics, both supporting the vulnerabilities to be the significant indicators of annual sales, whereas the other vulnerabilities remain as a non-major factor. Post-hoc analysis of these two vulnerabilities will be examined later in this section. Finally, the last hypothesis test result reveal that risk management practices significantly affect company sales. Both p-value and test statistics highlight risk management as primary reason of annual revenue differences. The results of the hypothesis testing are illustrated in Table 1.

Although hypothesis test results indicate the significant difference between classes, it does not analyze which classes have higher or lower annual sales. In other words, Kruskal-Wallis test is incapable of identifying positive or negative effects. Therefore, the relation and difference between risk sources and annual sales is studied by post-hoc analysis using MedCalc software, which specifies the classes having higher (or lower) annual sales. The post-hoc analysis of

Table 1. Kruskal-Wallis test results

Kruskal-Wallis Tests	P-value	Test Statistics	Hypothesis	Significant Impact
<i>Supply Chain Risks</i>				
Demand Side Risk vs. Annual Sales	0.7520	0.5552	H ₁	No
Supply Side Risk vs. Annual Sales	0.0728	4.9639	H ₂	No
Catastrophic Risk vs. Annual Sales	0.1425	3.7956	H ₃	No
Regulatory Risk vs. Annual Sales	0.6615	0.8049	H ₄	No
Infrastructural Risk vs. Annual Sales	0.1122	4.2617	H ₅	No
<i>Supply Chain Vulnerabilities</i>				
Customer Dependence vs. Annual Sales	0.0001	17.7290	H ₆	Yes
Supplier Concentration vs. Annual Sales	0.0873	4.7507	H ₇	No
Supplier Dependence vs. Annual Sales	0.0855	4.7917	H ₈	No
Single Sourcing vs. Annual Sales	0.6709	0.7776	H ₉	No
Global Sourcing vs. Annual Sales	<0.0001	79.9394	H ₁₀	Yes
<i>Risk Management</i>				
Risk Management vs. Annual Sales	<0.0001	51.0856	H ₁₁	Yes

customer dependence revealed that, the less customer dependence, the more annual sales. Low customer dependence leads to more annual sales compared to medium and high. Likewise, high customer dependence firms have less annual sales compared to medium and low (see Figure 2).

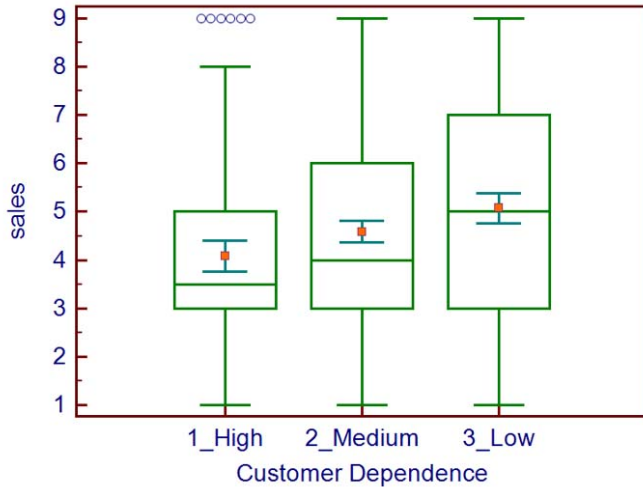


Figure 2: Box-and-Whiskers plot of customer dependence with respect to annual sales.

Similarly global sourcing post-hoc analysis reveals an unexpected result: The higher the global sourcing vulnerability, the higher are annual sales. Companies with high global sourcing practices have significantly higher sales not only than low, but also than medium ones. Vice versa, low global sourcing leads to less annual sales compared to both medium and high (see Figure 3). As highlighted before, a debate arises regarding global sourcing that can lead to either risk or opportunity. With this result, the academicians that define global sourcing as both risk and opportunity seem to be correct considering company sales. The details will be discussed in the next section.

Final post-hoc analysis states that companies with high practices of risk management have more revenue than medium and low ones. The same logic applies for low

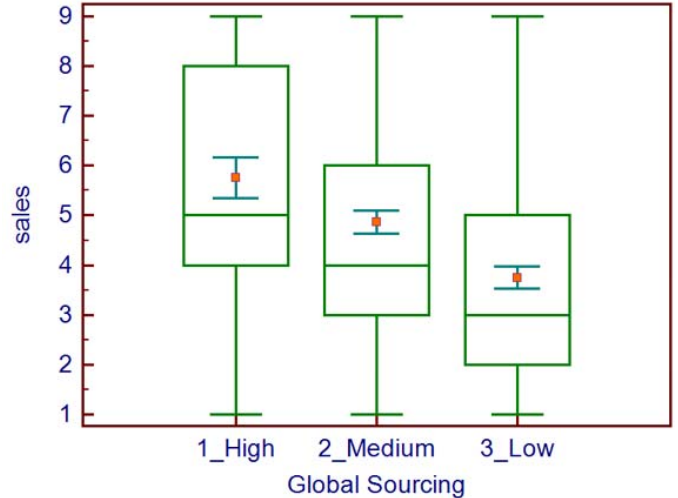


Figure 3: Box-and-Whiskers plot of global sourcing with respect to annual sales.

risk management companies that generate significantly less annual sales than medium and high (see Figure 4). The results of the post-hoc analyses are summarized in Table 2.

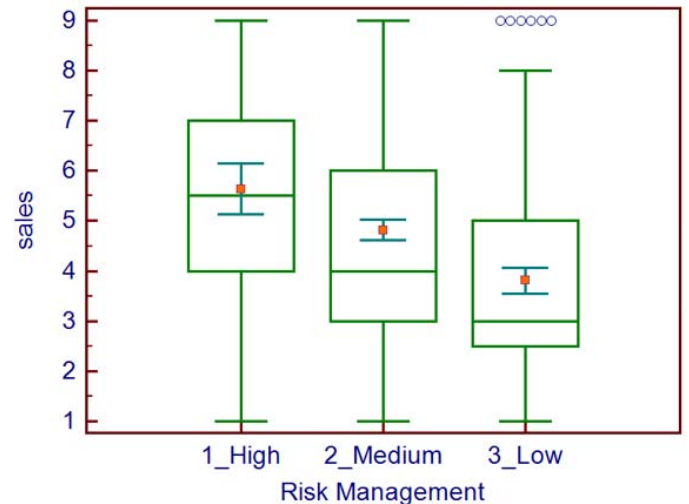


Figure 4: Box-and-Whiskers plot of risk management with respect to annual sales.

B. Association Rule Mining Results

The results of association rule mining show the interdependencies which lead companies to have high sales. Firstly, one antecedent that has high confidence scores for high sales is examined through AssocMiner software. The results are exactly the same with previously highlighted hypothesis testing results. Table 3 summarizes the impacts on company sales, which also support the aforementioned findings. High risk management, high global sourcing and

Table 2. Post-hoc analyses results

Post-hoc Analysis	n	Different (P<0.05) from factor nr.	Average Sales	Average Rank
<i>Customer Dependence vs. Annual Sales</i>				
High (1)	140	(2)(3)	4.079	271.38
Medium (2)	317	(1)(3)	4.587	319.24
Low (3)	182	(1)(2)	5.071	358.73
<i>Global Sourcing vs. Annual Sales</i>				
High (1)	108	(2)(3)	5.759	417.38
Medium (2)	299	(1)(3)	4.869	346.88
Low (3)	232	(1)(2)	3.75	240.02
<i>Risk Management vs. Annual Sales</i>				
High (1)	72	(2)(3)	5.639	408.42
Medium (2)	379	(1)(3)	4.818	339.89
Low (3)	188	(1)(2)	3.809	246.05

low customer dependence are the primary indicators with high confidence values. Finally, the association rules are mined with two antecedents. Table 4 illustrates the results, which can be interpreted as: (1) we are 55.1% confident that Low Customer Dependence and High Global Sourcing companies will have High Sales. (2) With 48.9% confidence, High Risk Management and Low Regulatory Risk strategies lead companies to have High Sales. (3) Companies with Low Regulatory Risk and High Global Sourcing will have High Sales with 43.5% confidence levels. Up to 10 insights can be driven by the same logic via Table 4. To conclude, the hypothesis testing results are verified through association rule mining.

Table 3. Antecedents of high sales (min. 5% support and 30% confidence levels).

Antecedent	Consequence	Confidence	Support
<i>Association Rules of High Sales Companies</i>			
High Risk Management	High Sales	41.7%	11.3%
High Global Sourcing	High Sales	39.8%	16.9%
Low Customer Dependence	High Sales	30.8%	28.5%

Table 4. Both antecedents of high sales (min. 5% support and 40% confidence levels)

Antecedent 1	Antecedent 2	Consequence	Confidence	Support
<i>Association Rules of High Sales Companies</i>				
Low Customer Dependence	High Global Sourcing	High Sales	55.1%	7.7%
Low Regulatory Risk	High Risk Management	High Sales	48.9%	7.4%
Low Regulatory Risk	High Global Sourcing	High Sales	43.5%	9.7%
Low Single Sourcing	High Risk Management	High Sales	43.2%	5.8%
Low Supplier Concentration	High Global Sourcing	High Sales	42.9%	7.7%
Low Infrastructural Risk	High Global Sourcing	High Sales	42.4%	15.5%
Low Infrastructural Risk	High Risk Management	High Sales	42.0%	10.8%
Low Catastrophic Risk	High Risk Management	High Sales	40.6%	10.0%
Low Supplier Dependence	High Global Sourcing	High Sales	40.5%	6.6%
Low Single Sourcing	High Global Sourcing	High Sales	40.3%	9.7%

V. DISCUSSIONS AND IMPLICATIONS

The findings and discussion described in this paper are significant for multiple reasons. Firstly the results of our analysis enrich the existing academic knowledge regarding the impact of supply chain risk on the operational performance of organizations. Furthermore, we fill in the gaps in the literature on empirical research in supply chain.

We found no significant relationship between such SCR as demand side risk, supply side risk, regulatory risk, infrastructural risk and catastrophic risk, sales. However, Wagner

and Bode [12] found that a small portion of variation in supply chain performance can be explained by demand and supply risk (this is due to the fact that SC performance is influenced by many other factors on top of the risks). In their research, Wagner and Bode [13] investigate the impact of SCR on SC performance (defined as total logistics costs, speed of delivery, delivery dependability, order fulfillment capacity, warehouse inventory turns and customer satisfaction). In fact our results are not contradictory in this regards, since as mentioned Wagner and Bode evaluate the relationship of risk with SC performance. Even though the current study is a continuation of their empirical investigation there are a number of significant differences between our studies. In our study we measure the performance purely in terms of sales/revenues (this metric is crucial for most companies, and factors affecting it can support strategic decision making). The disruptions occurring from infrastructure and catastrophic risk are unordinary events, with low chances of occurrence, and can be classified as outliers which might explain their lack of association to company revenue. Our findings that there is no significant relationship between SCRs and sales have to be contrasted as well with the works of Hendricks and Singhal [1]. Hendricks and Singhal investigated the shareholder value effects/impacts of supply chain disruptions based on a sample of disruption announcements made in the media. A close investigation of their papers and our results show that we employed different approaches and also that the findings are not conflicting. Hendricks and Singhal's work not only is constructed on a different sample, but also measures other matters [10] [1]. By analyzing supply chain disruption communicated by the media, they observe only major supply chain disruptions and organizations that were actually impacted by those disruptions. They study if-then situations where risk has struck which sheds undoubtedly important light on the question how supply chain disruptions affect shareholder value and operational performance under the condition that a massive disruption has already occurred. This study also contains a description of operational performance association with supply chain vulnerabilities to support strategic decision making. Although the widespread belief is that supply chain vulnerabilities have a negative association with the performance of organization, our empirical results supporting the contrary. Such an instance is the case of global sourcing, which has been repeatedly cited as a risk. Our findings show that global sourcing and higher revenues are strongly associated. It is not very surprising, since companies which source globally have multiple advantages beyond low cost, including: know-how in particular markets, access to skills or resources unavailable in home market and developing alternate supplier base to stimulate competition. It is however reasonable to argue that the disadvantage of global sourcing is the potential exposure of the company to risks, among them: increased risk of loss of know-how,

increased costs of supplier monitoring and quality assurance, communication barriers due to cultural-linguistic barriers and geographical dispersion, exposure to a foreign politico-financial setting and increased lead times. Executives might try not adapting global sourcing in an attempt to avoid potential associated risks. Our recommendation for executives is to rather focus on SCRM related to global sourcing if it is highly tied to their financial performance instead of avoiding global sourcing. The vulnerability with negative association to company performance is customer dependence. Organizations with higher customer dependence are more likely to make lower sales than companies who are able to balance their relationships with customers. Because of lack of bargaining power, production volumes strongly related to customer production volumes, lost potential sales because of small client base, customer dependence gives numerous reasons for relatively smaller operating performance. Be the customer dependence industry specific, or occur for another reason, it was clear that suppliers needed to act to preserve their profit margins and avoid becoming overly dependent on any single customer as revealed by our study. It is interesting to notice that the other investigated vulnerabilities such as single sourcing, supplier dependence and supplier concentration have displayed no significant relationship to financial performance. Reasons for this might be the scope of a future study. We found that companies with high level of SCRM implementation are more likely to outperform organizations which lack SCRM from their agenda. There is no debate in the research literature on the possible effect of SCRM on company performance. Our findings are consistent with our initial statement that firms and researchers have shifted their focus from management of company inherent risks to management of supply chain risk. High levels of SCRM implementation are very likely to be positively related not only to elevated financial outcomes, but also have such beneficial spillover effects on the company as reduced supply or demand risks. What is more, we substantiate our statistical findings by application of ARM to provide insights into the areas which need increased attention from executives and thus supporting decision making for SCRM and resource allocation. One of the reasons why numerous enterprises are not implementing efficient SCRM policies is that they do not have an overview of the relationship between supply chain characteristics with their company's financial performance. We have found a set of patterns in the context of SC related to higher global sales. These patterns are useful for managers in evaluating their supply chains and companies and in steering their decisions. Moreover, this paper remains the first paper that validates hypothesis testing using association rule mining techniques this way we can provide clear numbers to describe the relationship between company sales and supply chain characteristics. While we showed that certain supply chain risk positions and risk management practices are less important (in terms of

influencing sales) in Germany, managers need to understand which supply chain risk positions and risk management practices are most influential. Thus in the context of revenue seeking organizations, decision-makers should turn their attention to supply chain characteristics which are highly associated to sales. In the same time, supply chain executives are responsible to balance the cost trade-off between their risk reduction efforts and possible benefits. In an attempt of optimization of scarce risk containment resource allocation, our research supports allocation of resources primarily for mitigation of customer dependency and global sourcing risks. To conclude, customer dependence, global sourcing and level of SCRM implementation must certainly be considered for strategic supply chain decisions.

VI. CONCLUSION AND FUTURE RESEARCH

This paper presents an innovative empirical research methodology and its implementation on SCRM for generating actionable insights. To the best of our knowledge, this is the first study in the literature that validates hypothesis testing results using association rules. Another novelty of the paper is that, although we used the survey data that is previously examined [16], we approached from different angle: the financial impact of supply chain risk positions and risk management practices. The methods used in the paper are also dissimilar than the aforementioned papers. Thus, we showed that the same survey data can give various managerial insights and there is not a single or ultimate method to mine the data. Primarily, this paper shows that data mining techniques can be used to corroborate not only the previously mined association rules, that is, Remaining Association Mining, but also the hypothesis testing results. As the results of statistics and data mining techniques validate each other, the practices and managerial insights can be more trustworthy and consistent. Although the practical insights are usable and consistent, this paper does not provide long-term strategies. The reason behind is that strategies are often consider relatively long terms varying up to 50 years depending on the product, market and industry. Strategies often involve the forecasted future of the company and enlighten the projections for the next period of time. However, supply risks are hard to foresee, thus the strategies will be altered when a risk occurs. Therefore this paper does not give strategic plans and but provides practical decision-making insights. The future researchers or practitioners can provide strategic actions considering multi-directional facts and figures. Another important remark for the future research is that our paper only gives an empirical investigation that covers the companies in Germany, a relatively risk averted and economically stable country. Thus, the results only hold for the alike geographic, economic and political environments. Therefore, this research can be extended with the other countries having various risk profiles. The managerial implications of this study are

derived from the significant impacts and interdependencies between the risk drivers and company sales. First, the results indicated that global sourcing have a positive influence on company revenue. The importance of the global sourcing as the financial performance magnifier is underlined in this research contrarily to the generally accepted notion of being supply risk. Second, customer dependency is a very important supply chain risk for achieving high financial performance. Decision-makers should take into profound considerations to decrease the customer dependence. Third, SCRM should be one of focal attentions for companies pursuing financial progress on the long run. According to these findings, companies can utilize better supply chains. Our study promotes better risk management; less customer dependence and higher global sourcing for today's supply chain provisions.

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Appendix A

Table A.1. Items of supply chain risk positions and risk management practices.

Items	Number of items	Cronbach alpha
<i>Demand Side Risks</i>	2	0.724
Unanticipated or very volatile customer demand.		
Insufficient or distorted information from your customers about orders or demand quantities.		
<i>Supply Side Risks</i>	5	0.799
Poor logistics performance of suppliers (delivery dependability, order fill capacity).		
Supplier quality problems.		
Sudden default of a supplier (e.g., due to bankruptcy).		
Poor logistics performance of logistics service providers.		
Capacity fluctuations or shortages on the supply markets.		
<i>Regulatory, Legal and Bureaucratic Risks</i>	2	0.691
Changes in the political environment due to the introduction of new laws, stipulations, etc.		
Administrative barriers for the setup or operation of supply chains (e.g., authorizations).		
<i>Infrastructural Risks</i>	4	0.748
Downtime or loss of own production capacity due to local disruptions (e.g., labor strike, fire, explosion, industrial accidents).		
Perturbation or breakdown of internal IT infrastructure (e.g., caused by computer viruses, software bugs).		
Loss of own production capacity due to technical reasons (e.g., machine deterioration).		
Perturbation or breakdown of external IT infrastructure.		
<i>Catastrophic Risks</i>	4	0.854
Political instability, war, civil unrest or other socio-political crises.		
Diseases or epidemics (e.g., SARS, Foot and Mouth Disease).		
Natural disasters (e.g., earthquake, flooding, extreme climate, tsunami).		
International terror attacks (e.g., 2005 London or 2004 Madrid terror attacks).		
<i>Customer Dependence</i>		
Our firm strongly depends on some of its customers.	1	
<i>Supplier Concentration</i>		
Our firm has concentrated its sourcing activities on a small number of suppliers.	1	
<i>Supplier Dependence</i>		
Our firm strongly depends on some of its suppliers.	1	
<i>Single Sourcing</i>		
Our firm frequently pursues single sourcing strategies.	1	
<i>Global Sourcing</i>		
Our firm relies on a global supplier network (global sourcing).	1	
<i>Risk Management</i>	6	0.794
In collaboration with our customers and suppliers we are working on transparent supply chains and an open sharing of information.		
Our firm has elaborated business continuity or contingency plans addressing several supply chain risks.		
We regularly monitor our suppliers for possible supply chain risks.		
We reduce demand side risks through late product differentiation.		
In our firm, an employee or a team is dedicated to supply chain risk management.		
If possible, we insure against supply chain related risks.		