NOVA IMS Information Management School

MGI

Mestrado em Gestão de Informação
Master Program in Information Management

Supply Chain Risk Management

Risk Management in Supply Chain Integration Using a Business Intelligence Optimization Approach

Frederico José Pereira Serrano

Dissertation report presented as a partial requirement for obtaining the Master’s degree in Information Management

NOVA Information Management School
Instituto Superior de Estatística e Gestão de Informação
Universidade Nova de Lisboa

NOVA Information Management School
Instituto Superior de Estatística e Gestão de Informação
Universidade Nova de Lisboa

SUPPLY CHAIN RISK MANAGEMENT

RISK MANAGEMENT IN SUPPLY CHAIN INTEGRATION USING A BUSINESS INTELLIGENCE OPTIMIZATION APPROACH

by

Frederico José Pereira Serrano

Dissertation report presented as a partial requirement for obtaining the Master's degree in Information Management, with a specialization in Knowledge Management and Business Intelligence

Advisor: Professor Doutor Vitor Manuel Pereira Duarte dos Santos

November 2022

ABSTRACT

The goal of this proposal is to develop a theoretical model that will assist organizations in building and adapting their supply chains to a new, better, and more robust model, using technology and tools that were not available just a few years ago. The coronavirus pandemic has uncovered resilient weaknesses in countries and organizations, and we hope to use Data Analytics and Business Intelligence approaches to turn those weak spots into strengths and competitive advantage through this study. Having this in mind, this study aims to identify the association between supply chain risk management (SCRM) and business intelligence architectures. Thus, this study aims to fill the gap of information and studies in this area by providing relevant inputs that may be used on other studies in this field.

KEYWORDS

Supply Chain Risk Management; Data Analytics; Business Intelligence; COVID-19

INDEX

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

BI	Business Intelligence
CSCMP	Council of Supply Chain Management Professionals
DW	Data Warehouse
KPI	Key Performance Indicator
SC	Supply Chain
SCD	Slowly Changing Dimension
SCI	Supply Chain Intelligence
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SCRM	Supply Chain Risk Management
UML	Unified Modelling Language

1 INTRODUCTION

1.1 Background and Problem Identification

Competition among businesses has increased as a result of economic globalization, integration, and the emergence of the knowledge economy. In the changing market context, the classic company management and operations management approach is no longer effective. Supply chain management principles are increasingly being used by businesses to establish synergy and internal control of the internal and external environments (Jiang, 2019).

The unprecedent situation associated with the global explosion of the COVID-19 has made clearer that the essential role of the logistics industry is to keep supply chains operating around the globe. Supply chains were broken without workers during the coronavirus, which led to many companies around the world being unable to adapt their operations to the stagnant distribution of their products and services and to the decline in sales. On the other hand, many companies are accelerating the formulation of management strategies with supply chain restructuring in mind for the post-COVID-19 era grounded in the digital transformation.

Disruptions encountered can be both instantaneous, triggered by some single-point failure interruption in material flows (e.g., fires or tsunamis) and long-term crisis such as pandemics, financial or political crises, or wars. COVID-19 pandemic has brought a massive disruption which was characterized by transformations of production from insourcing to outsourcing, from local to global, and from redundant to lean, and that's why supply chain risk management has never appeared more important than today since global supply chains have been punched heavily by the pandemic.

There have always been issues with information sharing in supply chain collaboration, such as information distortion, information loss, and information delay (Jiang, 2019). In supply chain management, effective information coordination has become a challenge, and it is one of the key reasons of supply chain disruption.

Following this, the COVID-19 pandemic shown us how important is to have an integrated supply chain with lowest levels of disruptions across supply chains. So, the present proposal aims to analyze the differences that the pandemic brought to the supply chains and help companies to mitigate the risks of a catastrophe like this, by analyzing the information between the links of a supply chain through business intelligence architectures.

There is no secret formula for success, as each organization has had to face distinct challenges. The world is changing, and businesses and supply chains are also changing with it. It is necessary to provide enterprises with the finest tools and strategies for adapting to the new reality.

1.2 Motivation

Several difficulties in today's competitive environment, such as diminishing resources, growing costs, short product life, consumer preferences shifting with demand unpredictability, technological obsolescence, and market globalization, are putting many businesses at risk, prompting them to invest in Supply Chain Management (SCM).

Supply chains are typically linear, with a clear sequence of design, plan, source, manufacture, and delivery. Many supply chains, on the other hand, are evolving from a static sequence to a dynamic, interconnected system that can more easily integrate ecosystem partners and grow to a more optimal state over time.

The pandemic has accelerated the transition from linear, sequential supply chain activities to an interconnected, open system of supply operations, which could pave the way for future business competition and lead to a new normal, in which industries and supply chains will not be the same as they were before the virus, and where innovation and scaling new technologies such as robotics and automation, IoT, and a new supply chain management system will be critical.

It is important to accomplish supply techniques to organizations and individuals that will contribute to a trend toward maximum effectiveness and efficiency in the present and future, based on a business intelligence strategy that will increase the value of information and data shared across the supply chain that will culminate in good risk management.

Change is difficult, but the digitization of data and the use of advanced innovative technologies offer the chance to deliver commercial value throughout the supply chain. Furthermore, digital disruption has the potential to alter supply networks in any industry. It is now critical to comprehend how digital transformation may support firms in achieving success while minimizing disruption.

In brief, it is necessary to give organizations the knowledge into how data and information exchanged across all supply chain linkages may be collected and stored, and then implement a business intelligence strategy/architecture to help mitigate exposure to risks like pandemics.

1.3 Study Objectives

We want to show organizations how to deploy a well-structured BI solution so that they can ensure the quality of information exchanged throughout their supply and prevent possible risks. It will also enable more accurate and timely reporting, as well as the optimization of procedures and, as a result, increased employee satisfaction. Instead of manual repetitious duties, team members will be able to devote their time to more demanding and meaningful projects. Finally, through boosting adaptability, it will provide businesses a competitive advantage in the market. It will also be able to cope with the effects of a change in the warehouse management system.

Thus, the goal of this research is to create a model for the use of business intelligence to optimize risk management in supply chain integration.

We plan to accomplish this goal while responding to a few questions, such as:

- What are the characteristics of a new normal relevant supply chains?
- What are the long-term lasting lessons to consider as a supply chain decision maker?
- What steps should be performed and what success factors should be considered in order to construct a future-proof supply chain?

1.4 Study relevance and importance, and expected contributions

The purposed study has a theoretical application since it aims to show what this pandemic has changed in organizations at the logistics and supply chain level, but also to develop and present a model that companies can implement to mitigate the risks of a catastrophe happening again by analyzing the data shared between all the links of the supply chain.

On the other side, and from a practical standpoint, we want to provide organizations with insights and solutions that they can incorporate into their processes, allowing them to adapt to this new reality while also gaining a competitive advantage over their competitors.

One of the goals of this research is to allow supply networks to play a bigger role in strategic planning and decision-making. To this purpose, organizations can create and leverage a variety of competitive advantages to complement various aspects of their strategy and more effectively target specific demands.

2 METHODOLOGY

Following a design science research methodology sounds like the ideal approach to get things done after some thinking about what should be the process for building a BI model that would help organizations mitigate risks in their supply chain.

This master's thesis aims to provide an artifact based on a model for using business intelligence to improve supply chain risk management. Although it is crucial to remember that the output artifact from DSR approaches may not be a tangible product/service, artifacts from DSR techniques may also be conceptual ones such as "design theories, constructs, methods, models, design principles, technology rules” (Gregor & Hevner, 2013).

The choice of this methodology was based on the fact that the design of artifacts is based on a problem-solving approach that starts with identifying business needs and ends with finding a solution to organizational problems (Hevner et al., 2004), which is supported by combining synthesis brought by design fundamentals and an analytic point of view that comes from a scientific background (Baskerville et al., 2015).

2.1 DESIGN SCIENCE RESEARCH

When determining whether or not to adopt the DSR methodology, keep in mind that "nothing is really ‘new’. Everything is made out of something else or builds on some previous idea" (Gregor & Hevner, 2013).

DSR's mission is to improve products, processes, services, technology, and ideas by developing more efficient and effective solutions, which is the desired output of this master dissertation, an output artifact that will help companies to mitigate risks in their supply chain by analyzing data. Researchers must deal with a known application environment for which useful solution artifacts are either unavailable or plainly suboptimal. Researchers will design novel artifacts as solutions to major challenges based on a strong understanding of the problem context. The main challenge is to show that the improved answer actually improves on earlier knowledge (Gregor & Hevner, 2013).

The quest for a solution based on extensive scientific investigation ensures that the final proposed artifact is coherent and credible. A crucial phase that should not be overlooked is good communication of the finished product (Hevner et al., 2004).

Six stages of DSR approach are mentioned to better describe the methodology (Peffers et al., 2007):

- **Identify problem and motivation:** Define the research challenge in detail and justify the importance of a solution. Because the problem specification will be used to create an artifact that will deliver an effective solution. Justifying the worth of a solution serves two purposes: it stimulates the researcher and the research audience to pursue the answer and accept the conclusions, and it aids in comprehending the reasoning behind the researcher's grasp of the problem.
- **Define objectives and a solution:** From the problem definition and knowledge of what is achievable and doable, infer the goals of a solution. The objectives can be quantitative, such as the terms in which a desirable solution would be preferable to present ones, or qualitative,

such as a description of how a new artifact is intended to enable answers to problems that have not been addressed previously. The objectives should be logically deduced from the problem description. Knowledge of the current state of problems, as well as existing solutions, if any, and their efficacy, are essential resources.

- **Design and development:** The artifact will be created in this stage. Potential structures, models, procedures, or instantiations (all defined broadly) (Hevner et al., 2004) or "novel qualities of technical, social, and/or informational resources" are examples of such artifacts. A design research artifact can be defined as any created object that incorporates a research contribution into the design. This activity entails identifying the desired functionality and architecture of the artifact, as well as building the artifact itself. Knowledge of theory that can be applied to a solution is one of the resources required for shifting from objectives to design and development.
- **Demonstration:** Demonstrate how the artifact can be used to solve one or more problems. This could include using it in experiments, simulations, case studies, proofs, or other relevant activities. Effective understanding of how to use the artifact to solve the problem is one of the resources required for the demonstration.
- **Evaluation:** Examine and assess how well the artifact supports a problem-solving solution. This activity entails comparing a solution's objectives to actual observable results from the demonstration's use of the artifact. It necessitates an understanding of key measurements and analysis methods. Evaluation can take different shapes depending on the nature of the problem and the artifact. At the conclusion of this activity, the researchers can choose whether to return to activity 3 to increase the artifact's effectiveness, or to go on to communication and leave further improvement to future initiatives. Whether or not such iteration is possible depends on the nature of the research venue.
- **Communication:** When applicable, communicate the problem and its significance, the artifact, its utility and novelty, the rigor of its design, and its efficacy to researchers and other relevant audiences such as practicing professionals. The nominal structure of an empirical research process (problem definition, literature review, hypothesis development, data collection, analysis, results, discussion, and conclusion) is a common structure for empirical research papers, and researchers may use the structure of this process to structure the paper in scholarly research publications. Communication necessitates familiarity with the disciplinary culture.

Although this method is constructed in a nominally sequential order, there is no expectation that researchers will always progress from activity 1 to activity 6 in that order. In truth, they can begin at practically any step and work their way outward, as described in figure 1 (Peffers et al., 2007).

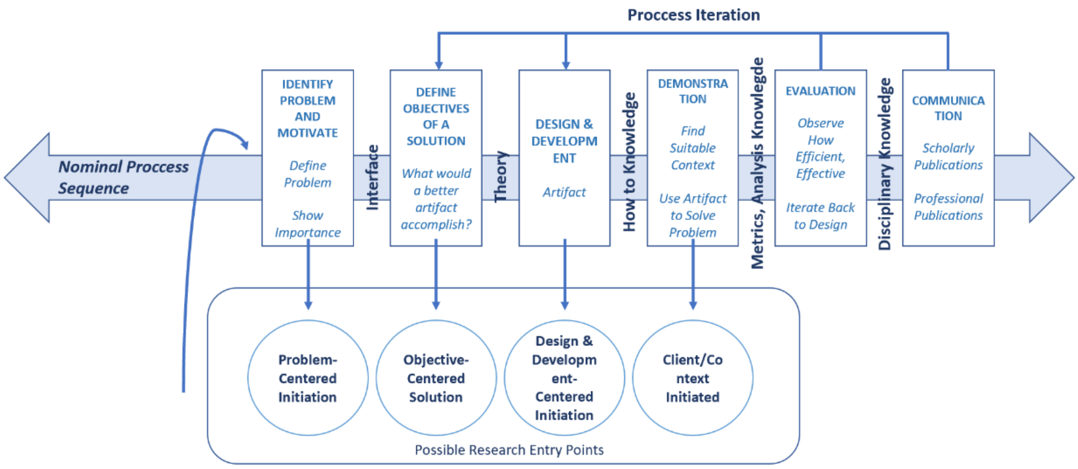


Figure 1 *– DSR Method Adaptation (Peffers et al., 2007)*

2.2 Research Strategy

This part will explain how all of the above-mentioned stages will be used in this study, as well as the activities that will be assigned to each of them.

As previously stated, this study began with the design objectives and solution stages, since it was motivated by an objective-driven solution to construct a model that will assist companies in mitigating supply chain risks through the usage of a BI model.

To begin, it was necessary to **define objectives** and a solution centered on the **major problem** outlined in the previous paragraph, in order to determine which subjects the study's foundation should include based on requirements that matched the solution's purpose.

The **design and development** stage begins with outlining the main risks that can affect an organization's supply chain, followed by an assessment of qualitative and quantitative criteria by the organization's decision makers. When analysing the criteria, one thing to keep in mind is that the decision makers have varying levels of expertise and knowledge. As a result, and after having defined the different risks and respective criteria, different weights were allocated to decision maker ratings for various factors. The Best-Worst Method (BWM), a new multi-criteria decision-making method, was used to weight the assessment criteria.

During the **demonstration**, we will create a report based on a business intelligence model that will assist members of the organization in making decisions to avoid risks, as well as **evaluate** the model's efficacy and efficiency.

3 LITERATURE REVIEW

Some literature review on these topics will be presented to further contextualize the existing questions.

3.1 SUPPLY CHAIN RISK MANAGEMENT

3.1.1 Concepts

The term SCM was originated by consultants in the early 1980s, as previously stated. Since then, it has been applied to material planning, material control, logistical activities, and information flows within and between businesses as shown in figure 2 (Chen & Paulraj, 2004).

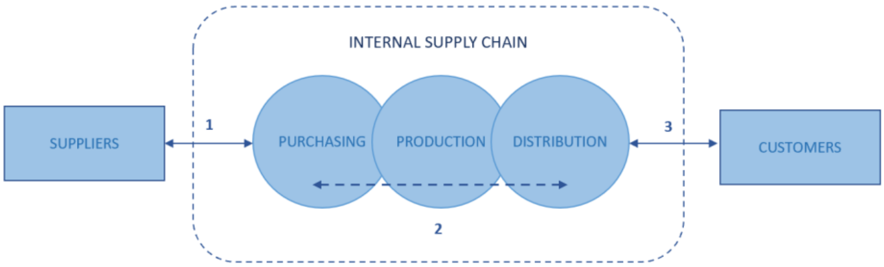


Figure 2 *– Typical Supply Chain of a Company (adapted from Chen & Paulraj, 2004)*

Supply chain management (SCM) is defined by the Council of Supply Chain Management Professionals (CSCMP), an international organization, as the process of planning, operating, and controlling all activities associated with the identification and selection of suppliers (sourcing & procurement), the transformation and addition of value to the product/service (conversion), and all logistics activities. Coordination and collaboration between supply chain partners, such as suppliers, intermediaries, logistics operators, and clients, are also part of SCM.

Supply chain management (SCM) is a systematic method to planning, implementing, and regulating the flow of materials, services, and information as raw materials are transformed into finished products and subsequently supplied to the end user throughout the production process (Basu & Nair, 2012; Brito & Botter, 2012; More & Babu, 2012; Szekely Bulcsu, n.d.). This approach is essential for ensuring operational efficiency inside a company. SCM aims to cut down on inefficiencies and miscommunications both inside and outside the company. All interactions with outsourcing resources, vendors, various departments, and office locations, as well as the client, fall under this category (Biswas & Sarker, 2008; Hu et al., 2088; Jain & Benyoucef, 2008).

Cutting needless procedures that occur throughout these interactions will decrease costs, save time, and restrict the demand for specific resources, allowing an organization to focus on other elements of the business (Pettersson & Segerstedt, 2012; Pradhananga et al., 2011). So, why is it so critical to control these processes? The capacity to optimize consumer value and maintain a competitive edge over those who supply similar goods and services lies in the ongoing management of supply chain processes inside a business (Camuffo & Grandinetti, 2011).

The systematic integration and monitoring of organizational processes, including planning, product demand, procedure design, quality control, logistics, customer responsiveness, and others have a significant impact on the final product supplied and how it is presented to the customer (Browning & Heath, 2009; Cavaleri, 2008; Grewal, 2008). As a result, SCM is tasked with harmonizing all of these processes while also lowering the risks associated. There are risks in every supply chain decision and reducing those risks can go a long way toward optimizing the organization's success. For example, trust is essential for a successful and efficient supply chain, and any company that invites others to join its chain must recognize that they will be sharing sensitive information (Chan et al., 2008; Drejer & Riis, 2000).

3.1.2 Supply Chain Risk Management (SCRM)

Due to a variety of causes, including increased global competitiveness, rising cost pressures, rising consumer demands, and ever-increasing complexity, managing risk has recently become a critical concern for supply chain managers (Daultani et al., 2015). The type and degree of unpredictable developments, as well as the impact of an action, have become difficult, if not impossible, to foresee due to the rising complexity and interdependence of modern supply chains (Helbing et al., 2006). As described in figure 3, risks and uncertainties regularly disrupt the supply chain's operating efficiency, thereby impacting a company's profits (Kumar et al., 2010).

Table 1.1 Drivers of global supply chain risks

		%
Environmental	Natural disasters	59
	Extreme weather	30
	Pandemic	11
Geopolitical	Conflicts and war	46
	Export/Import restrictions	33
	Terrorism	32
	Corruption	17
	Organized crime	15
	Maritime piracy	9
	Nuclear/biological weapons	6
Economic	Sudden demand shocks	44
	Volatility in commodity prices	30
	Border delays	26
	Currency fluctuation	26
	Global energy shortage	19
	investment restrictions	17
	Shortage of labor	17
Technical	Information and communication disruptions	30
	Transport infrastructure failure	6

influenceable, controllable, uncontrollable

***Figure 3** – Drivers of global supply chain risk (Kumar et al., 2010)*

The success of selling goods or services to clients is no longer the only business problem. There is a shift in this thinking at this time, with the success of selling goods and services being the outcome of risk management success rather than an efficient marketing strategy. Risk management is the process of finding, assessing, analyzing, and acting on a variety of unknowns that are thought to cause failure. Risk management is emphasized in every function (procurement, production, quality, and engineering) and every line in a corporation, according to this definition. (Fan & Stevenson, 2018).

Unexpected incidents that resulted in losses for the company are referred to as risks. These are events that will take place in the future and are marked by uncertainty and a lack of information. As a result, risks can be classified into two categories: predictable and unpredictable.

Risk management is critical in ensuring that the supply chain system is not interrupted. These risks can arise from a variety of situations, such as a natural disaster, an economic downturn, or even a global pandemic, all of which can have serious effects for the company. Supply Chain Risk Management is an important area of interest for dealing with such concerns (SCRM). SCRM was created to design a variety of methodologies for defining, assessing, mitigating, and monitoring supply chain risks (Ozgur, Ceyhun, 2020).

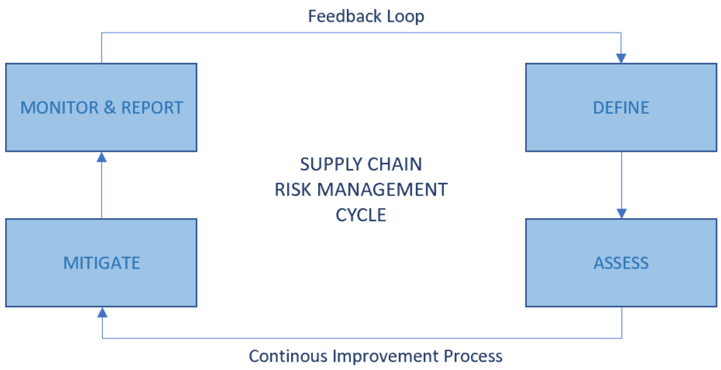


Figure 4 *– Supply Chain Risk Management*

There are three dimensions of risks according to Ritchie & Brindley (2007):

1. Likelihood/probability of the occurrence of particular events/outcomes.
2. Consequences/severity of the occurrence of particular events.
3. Causal pathways leading to these events (detection).

Risk = Likelihood x Severity x Detection

The various levels of risk are defined by a risk matrix, which takes into account both risk likelihood and risk effect. This is a straightforward approach for increasing risk visibility and assisting management decision-making (Kester, 2013). A risk matrix can be used for both qualitative and quantitative supply chain risk analysis, with probability and impacts as subjective and objective values, respectively (Norrman & Lindroth, 2004). The two major variables, probability of occurrence and risk effect, are crucial in determining the need for a supply chain risk mitigation activity, as shown in figure 5.

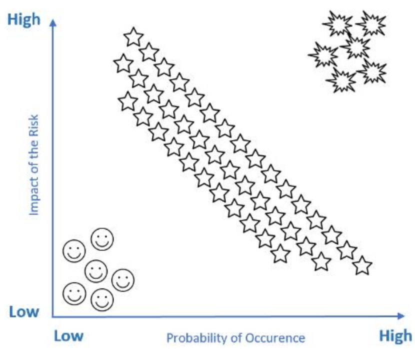


Figure 5 *– Probability-Impact Matrix (Norrman & Lindroth, 2004)*

According to figure 6, Sheffi (2005) categorizes risks based on the likelihood (high or low) of an event occurring and the consequences (light or severe). Companies should consider building a robust organization that can endure and recover from any sort of disruption, regardless of its source, due to the varieties of disruption.

The identification of risk variables to be studied is a crucial stage in managing risk management in the supply chain, because it is feasible to build a plan for mitigation with the goal of minimizing or eliminating the possibility of chain discontinuity based on this identification.

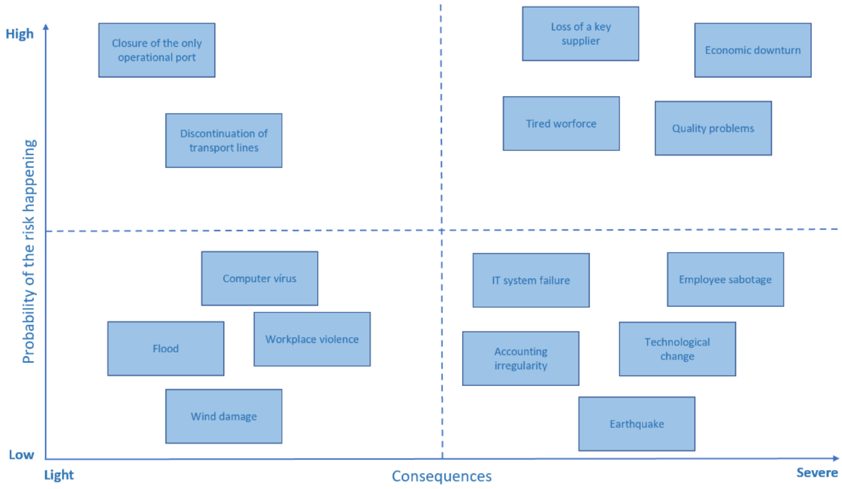


***Figure 6** – Company vulnerability map (Sheffi, 2005)*

Depending on whether the risk incident's impact is limited to a single place within the supply chain or affects the entire supply chain, the consequences may be local or global. The entire supply chain is affected by global effects. Local consequences have an impact on a specific market or location (Sodhi & Tang, 2012). As a result, analysing supply chain risk requires knowing where a risk incident could occur as well as what the repercussions might be. Supply-chain hazards can be classified as those that occur worldwide, affecting the entire supply chain, or those that occur locally, affecting only one supply chain organization (Sodhi & Tang, 2012).

The supply chain's global risks are defined in the context of the global environment in which it functions. Social or political instability, credit crunch problems, and commodity price spikes are all examples of comparable uncertainty. Local risks are identified within certain supply chain entities. Natural catastrophes, labour strikes, supplier bankruptcies, polluted industrial processes, or the loss of intellectual property rights at a single supply chain organization are all potential risk occurrences. Local risks could also be caused by the bad behaviour of specific supply chain partners (Sodhi & Tang, 2012).

As shown in figure 7, identifying the point of occurrence of each type of risk and the repercussions would provide a shared understanding of the various risks and their possible impact on various supply chain partners. This technique can help supply chain partners better define their roles and responsibilities, as well as build support for collaborative risk-mitigation activities (Sodhi & Tang, 2012).

		Consequences *(Region of possible eventual impact)*	
		Local *(impact to a particular supply chain entity or market)*	***Global*** *(impact to the entire supply chain or multiple markets)*
Supply Chain Risk Driver *(Point of possible occurence)*	***Local*** *(originating at a supply-chain entity or in a particular market)*	Local risks stemming from supply, demand, or failure match supply and demand.	Risks originating in a plant or region whose consequences eventually impact the entire supply chain or markets.
	Global *(originating supply-chain-wide or globally)*	Global risks that affect a particular supply chain entity.	Global risks that can affect the entire supply chain as a whole.

Figure 7 *– Supply chain risk drivers and consequences (Sodhi & Tang, 2012)*

Different types of supply chain risk have been identified. However, we divide it into three distinct categories.

3.1.2.1 Supply Risk

Supply risks refer to supply side risk events such as supplier defaults or other unexpected changes in supply cost, delivery, quality, or reliability. This category includes outsourcing hazards, which are becoming more important as more manufacturers limit the number of direct suppliers and source abroad. While managing fewer suppliers is more efficient, it also exposes the organization to more risk (Sodhi & Tang, 2012).

Supply risks are any risk that may occur on the supply side regarding the input material, e.g., disruptions and delays in supply, inventory, and schedules, or delays in inbound logistics. Consider the following types of risks on the supply side:

- **Supplier failure**: This risk is related to cases in which a supplier becomes unavailable, for example, as a consequence of its financial instability (Wagner & Johnson, 2004) , the occurrence of an adverse event (e.g. an earthquake or fire that shuts down plant operations) (Kleindorfer & Saad, 2005), or its vertical integration by a direct competitor of the buying firm, forcing the end of the relationship (Chopra & Sodhi, 2004). In these cases, the occurrence of risks can lead to a strong reduction in the firm's operational and financial performance (Wagner & Bode, 2006). Managers perceive supplier failure risk as one of the most important forms of supply chain vulnerability (Thun & Hoenig, 2011).
- **Supply Commitment**: If a purchasing organization is forced to commit to long-term purchases from a supplier without the ability to adjust amounts, it may face unmet demand or excess inventory over time. This arrangement restricts the company's capacity to respond to demand fluctuations.
- **Supply Cost**: This refers to unanticipated increases in acquisition costs resulting from supplier price hikes or from fluctuating exchange rates. Price increases are more likely when a company uses only one supply source.

3.1.2.2 Demand Risk

Demand risks are any risk that may occur on the customer side, e.g., variations in demand. Product demand unpredictability is one of the supply chain concerns that all organizations must deal with when it comes to volume and product mix. Many businesses sell their products in multiple nations to boost revenue. Not only is the total demand volume unpredictable for companies that sell several items, but so is the demand mix, or the demand for each of the product versions. As a result, demand risk includes both volume and mix uncertainty (Sodhi & Tang, 2012).

- **Forecasting**: The mismatch between a company's prediction and actual demand causes forecast risk. If the prognosis proves to be inaccurate, there may not be enough things to sell. If the projection proves to be too optimistic, the low demand will result in excess inventories and price reductions. Long production lead times, seasonal demand, a wide range of products, and short product life cycles all contribute to forecast mistake. Forecast errors also result from information distortion within the supply-chain. The *bullwhip effect* occurs when distortion grows in the supply chain as you get further away from the final consumer (Lee et al., 1997). Companies can mitigate the impact of the bullwhip effect by altering pricing and incentives to limit order variance. Increasing demand information visibility across the supply chain is also beneficial.
- **Change in technology or in consumer preference**: Longer-term patterns of changes in technology introduced by competitors and changes in consumer choice, whether due to the change in technology or anything else, are closely linked to forecast risk. Such shifts not only erode a company's demand, but also make capacity investment overly optimistic, resulting in missed ROI targets. Companies should invest in continuous product development as well as customer research in various market categories. One strategy is to conduct research and keep track of current and potential consumers not only through sales but also through internet forums and social networking sites.

3.1.2.3 Process Risk

Process risks are any risk that may occur during manufacturing and warehousing, e.g., machine breakdowns, human resource errors, operations failures, and financial problems. The last component exists between supply and demand risks. These risks are often related to design, manufacture, and distribution within the organization's internal supply chain. Consider the following supply-chain risk categories (Sodhi & Tang, 2012):

- **Design**: Many firms are still at danger from products produced as a result of improper design or manufacture, despite major attempts to implement Total Quality Management (TQM).
- **Yield**: If a plant's manufacturing yield is unpredictable, the corporation may find itself unable to match supply to demand.
- **Inventory**: Financial performance is harmed by excess inventory. The magnitude of the inventory risk is determined by 1. the product's worth, 2. its rate of obsolescence, and 3. demand or supply uncertainty. Excess inventory for high-value or short-life cycle products might be prohibitively expensive, while it can be beneficial for low-value commodity products with low obsolescence rates. Naturally, the more a company's product variety, the greater its inventory risk. Three tried-and-true methods can assist managers in reducing inventory risk: 1. pooling inventory, 2. generating similar components across products, and 3. deferring or

delaying the final step of production until orders are received, from which product variety originates.

- **Capacity**: Insufficient capacity means that a corporation may be unable to meet demand, resulting in unmet demand. Companies can err on the side of excess capacity to avoid this. However, developing excess capacity is usually a smart decision because ramping capacity up or down takes considerably longer and costs far more than adjusting inventory levels. Furthermore, excess capacity has a negative impact on financial performance by lowering returns on investment and on investment. Managers can reduce the danger of excess capacity by increasing the flexibility of current capacity. Flexibility is a type of pooling that allows the same capacity to be used for several products. Lastly. By serving geographically dispersed consumers from the same location, a corporation can reduce surplus capacity.

To summarize, companies are seeking to control supply chain risk while reducing costs, increasing profit, and maximizing net present value where risks might be found on the supply side, demand side, or process side.

3.2 Risk Assessment

The consequences and probabilities for identified risk events are combined to establish the level of risk during the analysis (ISO, 2009a). Risk analysis methods take on either a qualitative or quantitative approach; in some cases, it can be a combination of the two methods depending on the type and amount of data available.

It was possible to perceive that these risks could present cause-effect relations, for example, the risks of demand, capacity, and inventory. In fact, these risks have a strong relation with each other, since the risk factors pointed out are correlated, such as unexpected fluctuations in customer demand and difficulties in the planning of production capacity, which may lead to customer service disruptions due to lack of items in stock.

While the risk taxonomy identifies and organizes risks according to their scope of influence it does not enable the explanation of how one risk can affect another. For example, poor financial status of a supplier (an industrial, input market risk) and lack of raw material availability (an organizational, operating risk) are two independent taxonomical risks. However, poor financial status of a supplier could eventually affect that supplier's internal performance and consequently their ability to deliver material in a timely manner, thus increasing the chance of raw material shortage. The development of a causal risk network map to capture all such interdependencies is therefore crucial to subsequent modelling and analysis of these propagating effects. Risk management also requires studying the influences of various risks on enterprise and SC performance. Therefore, it is also important that the risk network map captures the relationship between the risks and key performance measures. Literature, case studies, news events, and expert knowledge was used to generate a risk network map that captures interdependencies between risks identified in the taxonomy as well as between those risks and widely used performance measures (Badurdeen et al., 2014).

Finding a method to efficiently examine the influence of risks while taking into account their interacting effects is a crucial step in Supply Chain risk modelling. For this kind of study, FTA (Fault Tree Analysis), FMEA (Failure Mode and Effects Analysis), and BBN (Bayesian Belief Network) appear to be the quantitative methodologies best suited to Supply Chain risk management. BBN are the ideal solution for modelling these interdependencies given the complicated interaction between various risks and performance criteria. Each risk and performance measure in a BBN represents an event; as a result, the risk network may be seen as a straightforward illustration of the spread of the likelihood of a certain chain of occurrences based on the cause and effect relationships between the various risks and performance measures. Conditional probabilities of event occurrences are used to represent these relationships given the occurrence of the event's immediate parents (or direct causes).

3.2.1 Bayesian Belief Network

In the straightforward situation, where we have a parent risk, D, and a child performance metric, M, Bayes' theorem can be written as follows:

$$P(D \setminus M) = \frac{P(M \setminus D)P(D)}{P(M)} = \frac{P(D \cap M)}{P(M)}$$

The Bayes theorem's chain rule application can be used to determine the likelihood of each event happening. The estimated probabilities of the independent first-level events and the conditional probabilities of the occurrence of the dependent event are then needed inputs if one kid (risk) event depends on two parents. Each node has a Node Probability Table (NPT) adjacent to it that lists the odds of that event happening. For instance, the NPT for event C has a separate probability associated with both events being true (T, T), one being true and the other being false (T, F and F, T), or both being false. This is because event C ("weather/natural disaster delays") depends on the status of both events A ("supplier risk mitigation for unanticipated delays") and B ("geographic risk due to weather/natural disasters") (F, F) (Badurdeen et al., 2014).

The Bayes theorem's chain rule application yields the following results for the likelihood of delays brought on by weather or other natural disasters. Given all potential conditions for A and B, the marginal probability of C is equal to the total of the probabilities of C:

$$P(C) = P(C \mid A, B)P(A)P(B) + P(C \mid A, \sim B)P(A)P(\sim B) + \\ P(C \mid \sim A, B)P(\sim A)P(B) + P(C \mid \sim A, \sim B)P(\sim A)P(\sim B)$$

The BBN approach also has the important advantage of allowing back propagation, which enables one to proclaim a child node as though it has occurred with concrete proof and then determine posterior probability for other network dangers. The probability of parent nodes are then changed to reflect the observation of the child node. Because it provides root cause analysis, this capability is especially helpful for SC risk management. For instance, if a red flag, such as rising costs, occurs, back propagation can be used to identify which component of the system is most likely to be the cause of this rise (Badurdeen et al., 2014).

There are many benefits to using BBN calculations, but there are a few key things to keep in mind. A significant amount of data is needed when there are several hazards being considered for the study. As a result, while gathering information from managers or users, a well-structured approach must be adopted. The computational complexity, which increases exponentially as more parents are exposed to the risks, is another difficulty (Badurdeen et al., 2014).

3.3 The COVID-19 Context in Supply Chain Research

During pandemics, supply chain activities are characterized by a long-term disruption in the supply network, an unstable current condition, and uncertainty regarding future market, supply base, and capacity developments (Sodhi et al., 2021).

The field of supply chain resilience has a well-developed body of knowledge on how to deal with short-term disturbances. The COVID-19 pandemic, on the other hand, is a unique situation that demands more than a moment-by-moment knowledge and can be regarded as a supply chain catastrophe. A supply chain crisis is a long-term disrupted state characterized by an unstable current situation and uncertainty about future developments in markets, supply bases, and capacities, all of which contribute to the risk of supply chain collapses and interruptions in the provision of goods and services on the market.

The existing research on pandemic supply chain impacts focuses on two areas: how to predict pandemic supply chain impacts and how to investigate supply chain reactions to the epidemic.

Furthermore, studies have urged for supply chain viability – "the ability of a supply chain to maintain itself and thrive in a changing environment through a redesign of structures and replanning of performance with long-term impacts" – due to the severity and magnitude of the pandemic disruption (Dolgui, Ivanov & Rozhkov 2020; Dolgui, Ivanov, & Sokolov, 2020).

3.4 Business Intelligence

3.4.1 Concepts

The concept of Business Intelligence was first proposed in the mid-90s of the 20th century in Western industrialized countries, although there was no specific definition of Business Intelligence from the start (Liu, 2010). The diverse definitions, however, have two things in common: to begin, data is the processing object; to continue, the ultimate goal is to assist in decision-making. Therefore, Business Intelligence is a technology integration aimed to assist organizations in making better use of data to improve decision-making quality and business operations, and it is the process of extracting information and data value from large amounts of data. Simply said, it is the process of combining business, data, and data value (Liu, 2010).

Three key applications of BI have been documented in several studies. First, BI unifies a variety of data sources into a single repository, allowing for a single enterprise-wide view via management dashboards and reports (Wu & Chang, 2012). Second, BI transforms data into information that managers can use to make decisions (Acar et al., 2010). Third, BI provides the ability to uncover the root cause of problems by allowing users to drill down into data (Hočevar & Jaklic, 2010).

In highly changing situations, BI gives insights based on data analysis to assist managers in making decisions (Işık et al., 2013). According to Shanks et al. (2010), using BI in an organization helps managers take value-creating activities by relying on facts or information offered by BI query and reporting. Although some studies have looked at the impact of business intelligence (BI) on SC performance (Trkman et al., 2010), there has been little systematic and extensive research on how BI may help firms with Supply Chain Management.

According to Liu (2010), in today's highly competitive market, SCM has become a means of gaining an advantage. According to the author, rivalry is no longer between businesses, but between supply networks. By ensuring effective integration and cooperation throughout the supply chain, a significant competitive advantage can be gained. Effective information flow and analysis are required for a higher level of integration, which can only be achieved by using the necessary practices and technologies (Liu, 2010).

By forecasting and reacting to uncertainty before their competitors, BI helped managers to be more responsive to market demand (Yusuf et al., 2014). SC managers can use BI to plan the best course of action for dealing with change.

3.4.2 Models

Organizations must coordinate their operations in order to collaborate effectively. The first step in developing a BI system is to determine the combined information demands of all people who might utilize it.

Operational data store (ODS), data warehouse (containing data and metadata), data mart (data warehouse that focuses on a specific subject area inside the firm), ETL tools, OLAP engine, analytical tools (reporting, data mining, etc.) and web portals are the essential pieces of a BI solution. A variety of different scenarios are formed by combining these aspects, which are dependent on the concrete organizational and informational structure of a company and a supply chain (Bramer, 2009).

This framework, on the other hand, evolved into what is seen in figure 8. Data marts were created because the "central data warehouse couldn't expand to satisfy the varied workloads and high concurrency expectations of end users," according to Hansen (2020). Data lakes, on the other hand, were usually used to store raw data until the standard data warehouse "couldn't store and process massive data (in terms of volume, variety, and velocity)" (Hansen, 2020).

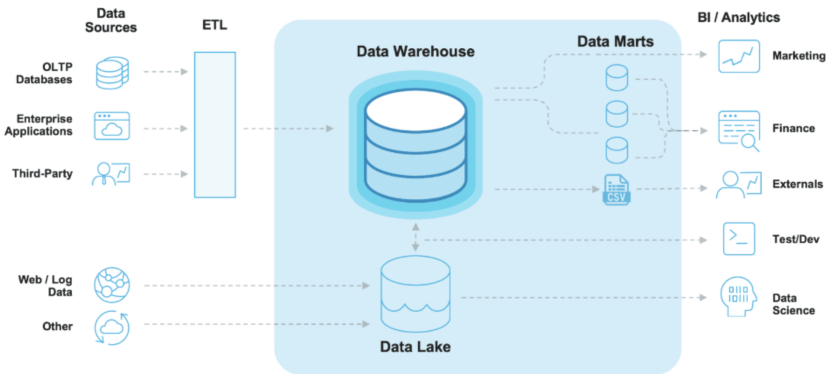


Figure 8 *– Modern data architecture (adapted from Hansen, 2020)*

Supply Chain Intelligence (SCI) is a new project that uses collaborative decision making to discover opportunities to reduce costs, drive revenue, and improve customer satisfaction. SCI takes a broader, multidimensional picture of the supply chain, allowing useful information about the data to be uncovered using patterns and rules.

Figure 9 shows an adequate supply chain intelligence (SCI) model, according to Nenad Stefanovic, Vidosav Majstorovic, and Dusan Stefanovic (2006).

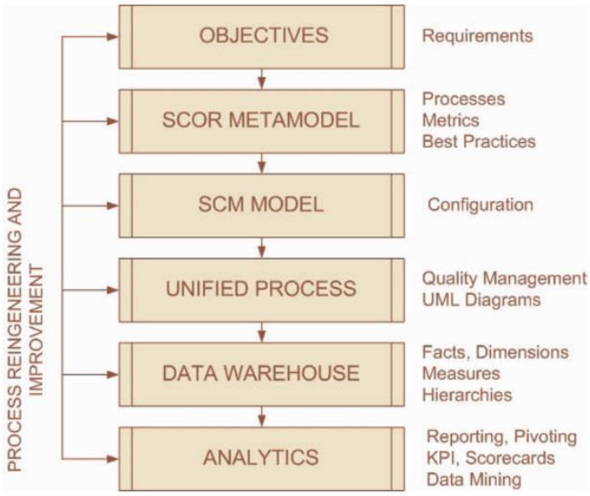


***Figure 9** – SCI Global Model*

The global SCI model begins with the definition of business objectives and the gathering of requirements, and then moves on to the design of supply chain configurations using the Supply Chain Operations Reference (SCOR) model. The SCOR model is a generic approach to supply chain management that may be used in a variety of industries. SCOR is a framework that blends business process engineering, benchmarking, and best practices into one. Standard descriptions of management processes are included in the process reference model: a framework of linkages between standard processes, standard metrics for measuring process performance, and best-in-class management practices (Stefanovic et al., 2006).

In the next phase, the end result is a variety of Unified Modelling Language (UML) diagrams (use case, activity, class, component, database, and so on) that serve as the foundation for ODS, ERP systems, and SCI solutions. Designing a data warehouse is the next stage. With specific fact tables, dimensions, measures, hierarchies, and aggregations, we can now construct star schemas and snowflakes. The next phase is to develop front-end analysis programs that clients can use, such as KPI (Key Performance Indicator) systems, balance scorecards, reporting systems, and data mining solutions (Stefanovic et al., 2006).

3.4.3 Data Warehouse

As stated by Inmon (2002), a data warehouse is a data repository that serves as the "heart of the architected environment," assisting management in making choices. A data warehouse (DW) should have the following properties, according to the author: subject oriented, integrated, nonvolatile, and time varying.

- **Subject Oriented**: Rather than giving data on a company's ongoing operations, the data warehouse should be organized around specific topics of interest. Sales, marketing or operations, for example, can be subject areas.
- **Integrated**: This, according to Inmon (2002), is the most crucial feature of a data warehouse. The data should maintain consistency while it is extracted from numerous data sources,

transformed, and loaded. Within the company, naming and formatting rules should be uniformly followed. This means that there should be a "one physical corporate image" after the data is stored into the data warehouse.

- **Nonvolatile**: The author means that data in the data warehouse is not updated or deleted like it is in the operating environment. The record is retained and a new snapshot record is written if the data changes (Inmon, 2002). This aids in the examination and comprehension of historical data.
- **Time Varying**: Data in the data warehouse is always linked to a certain point in time. At some moment in time, every record is valid. Some even have a time stamp on them (Inmon, 2002).

According to Kimball & Ross (2011), there are four key decisions to take into account when designing a dimensional model: 1. Select the business process (operational activities performed by the organization); 2. Declare the grain (level of detail associated with fact table measurements); 3. Identify the dimensions (provide the context surrounding a business process); 4. Identify the facts (measurements that result from a business process event).

The authors Kimball & Ross (2011) propose the use of star schemas to construct dimensional models in relational database systems. It is the most basic type of schema and is commonly used in the building of data marts. The term comes from the fact that they have a star-like structure, as shown in figure 10.

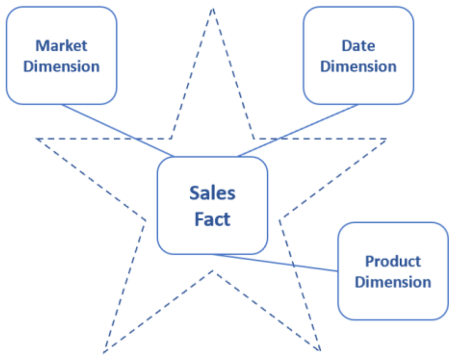


***Figure 10** – Star Schema (adapted from Kimball & Ross, 2011)*

The fact table, as shown in the figure 10, makes up the center of the star. In a dimensional model, the performance measures resulting from an organization's business process events are stored in this table (Kimball & Ross, 2011). Dimension tables, on the other side, are essential partners to a fact table. The textual context associated with a business process measurement event is stored in the dimension tables. They include information about the "who, what, where, when, how, and why" of the event.

3.4.4 Information Visualization and Dashboard Design

As stated by Ware (2019), “One of the greatest benefits of data visualization is the sheer quantity of information that can be rapidly interpreted if it is presented well”. We can deduce from this description that data visualization is a concise representation of a huge amount of data. However, in order for this information to be quickly interpreted, it must be presented well. This benefit of effective presentation can be extended to a 'Information dashboard,' which is a collection of different visualizations organized in a logical manner. As a result, an information dashboard can be defined as a succinct means of expressing a large and frequently dense collection of data at a single glance (Ware, 2019).

According to Ware (2019), visualization has several benefits, including the following:

- The ability to comprehend vast amounts of data.
- The ability to spot patterns and gain insights that might otherwise go unnoticed.
- The improvement of data quality control; visualization provides a better understanding of how data was acquired and whether there are any issues with it.
- Visualization also aids in the development of hypotheses.

There are four major stages to the visualization process: 1. data collection and storage; 2. data cleaning to make it easier to work with; 3. data transformation into a visual representation; 4. Information processing, both visual and cognitive. Figure 11 presents a diagram with the visualization process.

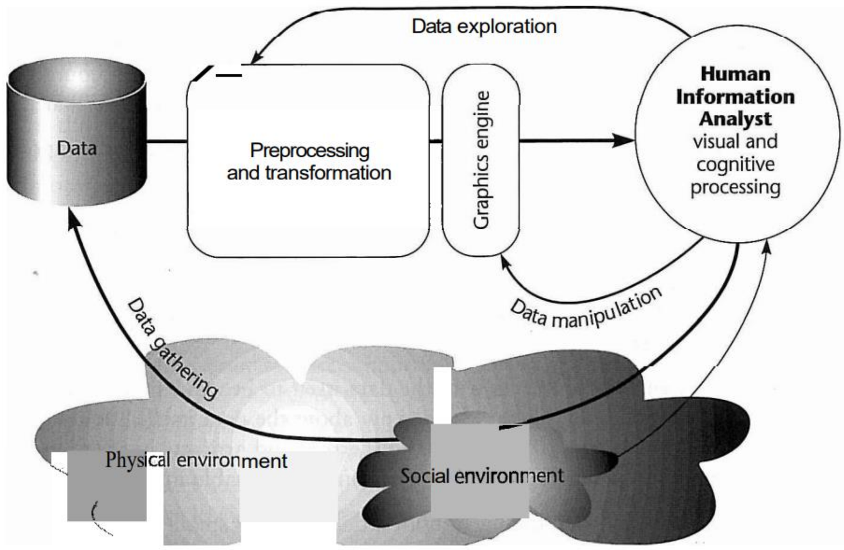


Figure 11 *– Visualization process (adapted from Ware, 2019)*

Measurements are crucial for three reasons, according to Hubbard (2014): 1. they aid decision-making; 2. some measurements have a market value and can be sold to interested parties (for example, the findings of consumer surveys); and 3. measurements can be amusing in nature, satisfying user curiosity or providing clarity.

Dashboards are visual representations of data. Dashboards are useful in theory. They are beneficial if they assist their users in achieving their objectives. This approach, according to Janes et al. (2013), focuses on two aspects: picking the "correct" data and selecting the "right" visualization technique.

1. **Picking the correct data**: The authors propose a Goal – Question – Measurement (GQM) model, as presented in the figure 12:

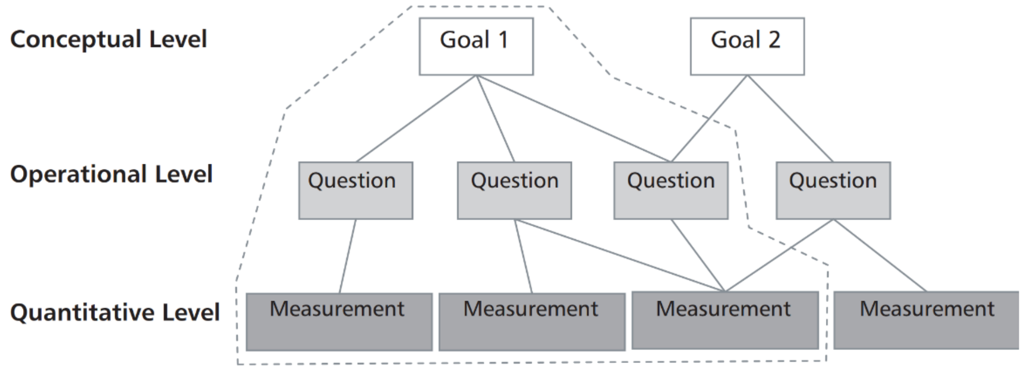


Figure 12 *– GQM model (Janes et al., 2013)*

- **Goal**: The "goal" element (conceptual level) consists of identifying the study's objective, which provides a sense of purpose, environment, points of view, and what factors to consider in order to produce the ultimate outcome.
- **Question**: The "question" component (operational level) evaluates which elements, procedures, and attributes are important, taking into account the "objective" and what is required to achieve it.
- **Measure**: The "measure" section (quantitative level) considers the issues posed in the previous level and determines whatever data would be appropriate to collect in order to answer them.

2. **Selecting the right visualization technique**: For this step, we should concentrate on visualizations that reduce the amount of time required to comprehend what needs to be communicated, and the following procedures should be considered:
   - It should be simple to visualize the dashboard. It may, for example, be exhibited on monitors strategically placed across the firm.
   - Interactions with the dashboard should be avoided, which means the display should be sufficient for the user to comprehend the information. Interactions should be used only when the user wishes to learn more.
   - Visualizing and comprehending the dashboard should be a simple and quick procedure, which necessitates avoiding design modifications (always display the same information in the same area).
   - Use strategies to direct the user's attention to the most crucial information without going overboard.
   - Make the dashboard's design and aesthetics appealing to consumers in order to draw their attention to it and pique their interest in it.

Finally, Bakusevych (2018) discusses the dashboard design. The visualizations, according to the author, should present the most important information. Users' attention is pulled to the top left corner of dashboards because they "read" them in the same way they read texts. Figure 13 depicts how users often glance through dashboard content.

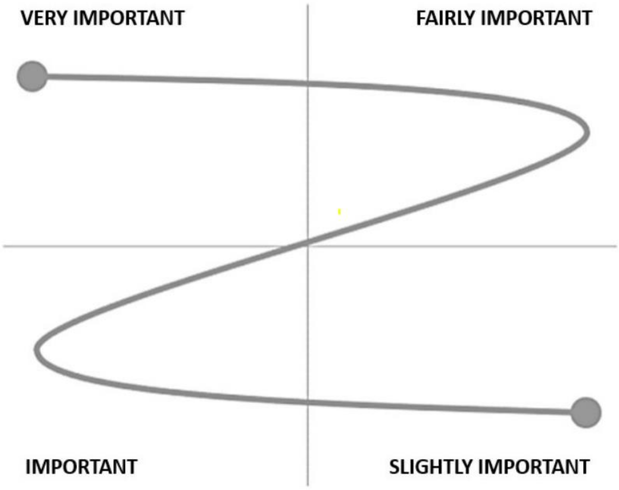


Figure 13 *– Reading gravity (adapted from Reporting Impulse, 2019)*

3.4.5 Business Intelligence in Supply Chain Analytics

Organizations that can exploit information about their customers, marketplace, and business operations will be able to benefit from business opportunities and maintain a competitive advantage in an emerging and rapidly changing business environment (Berson et al., 2002).

Access to information and an appropriate data management method are required for monitoring operations and measuring the success of a firm's business processes in real time. In businesses, information systems collect and analyze huge amounts of data in numerous forms, making it difficult to comprehend and evaluate information about an organization's processes. Business intelligence (BI) is a broad term that refers to a set of analytical software and solutions for obtaining, aggregating, analyzing, and disseminating data in a way that helps an organization's employees make better decisions (Adelman et al., 2002).

In other words, the goal of investing in BI is to shift a company from a reactive to data environment to a proactive one.

3.5 Best-Worst Method

3.5.1 Concepts

Identifying and selecting an alternative from a group of alternatives based on the decision-preferences makers can be regarded as decision-making in general Because this identification and selection process usually involves numerous criteria, these challenges are referred to as multi-criteria decision-making problems. Different decision-makers place different weights on the various criteria. Several multi-criteria decision-making methods have been introduced in recent decades to assist decision-makers in determining the values of criteria and alternatives depending on their preferences (Ishizaka & Nemery, 2013; Köksalan et al., 2011; Triantaphyllou, 2000).

The Best-Worst Method (BWM) (Rezaei, 2015) is a comparison-based method that conducts comparisons in a highly structured manner, using less information and resulting in more consistent comparisons. In some circumstances, BWM produces multioptimality, which means that several sets of weights for the criteria are produced when the problem is solved.

3.5.2 BWM Steps

There are several steps of BWM that can be used to derive the weights of the criteria (Rezaei, 2015):

1. Create a list of criteria for making a decision. In this step, the decision-maker identifies n criteria $\{c_1, c_2, \ldots, c_n\}$ that are used to make a decision.
2. Determine the most desirable (e.g., most important) and least desirable (e.g., least important) criteria.
3. Determine the best criterion's preference over all other criteria by assigning a number between 1 and 9. The best-to-others (BO) vector as a result would be:

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn}),$$

   where a_{Bj} represents the preference of the best criterion B over criterion j. The value of a_{Bj} will be equal to 1 if criterion j is the best criterion ($a_{BB} = 1$).
4. Also, choose a number between 1 and 9 to represent the preference of all criteria over the poorest criterion. The others-to-worst (OW) vector as a result would be:

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})^T,$$

   where a_{jW} represents the preference of criterion j over the worst criterion W. The value of a_{jW} will be equal to 1 if criterion j is the worst criterion ($a_{WW} = 1$).
5. The next step is to determine the optimal weights ($w^*_1, w^*_2, \ldots, w^*_n$) based on the decision maker's assessments. The optimal weights for risk criterion meet the following criteria: i) $w_B/w_j = a_{Bj}$, and (ii) $w_j/w_W = a_{jW}$. As a result, we must reduce the maximum absolute differences $\left|\frac{w_B}{wj} - a_{Bj}\right|$ and $\left|\frac{\omega_B}{\omega_w} - a_j w\right|$ for all *j*. The sum of the weights should be 1 and all of the weights should be nonnegative. This problem was formulated by Rezaei (2015) as the following linear problem:

   $min\varepsilon$ s.t. $\left|w_B - a_{Bj}w_j\right| \leq \varepsilon$, for all $j\left|w_j - a_{jW}w_W\right| \leq \varepsilon$, for all $j \sum_j w_j = 1 w_j \geq 0$, for all j

The optimal value of the objective function (ε^*) and the weights ($w^*_1, w^*_2, \ldots, w^*_n$) are obtained by solving this problem. ε^* measures the comparability of the comparisons, with values near 0 indicating a high level of comparability (Rezaei, 2015). If ε^* is equal to zero, it means that the comparison system is fully consistent (Kara & Fırat, 2018a).

4 A MODEL FOR THE USE OF BUSINESS INTELLIGENCE TO OPTIMIZE RISK MANAGEMENT IN SUPPLY CHAIN INTEGRATION

4.1 PROBLEM DEFINITION AND SOLUTION APPROACH

As stated by Kara & Fırat (2018), one company has a variety of suppliers for the various parts and equipment needed to manufacture their final product. Based on the Case Study (Badurdeen et al., 2014) and as represented in figure 14, our supply chain will have 11 suppliers, one manufacturer and three clients. Supplier performance has a significant impact on the company's performance and long-term viability. The company's supplier evaluation and selection procedure is based on a number of traditional factors. However, by ignoring supplier-related issues, companies are exposed to severe supply risk. By eliminating unreliable and dangerous suppliers at the start of the procurement process, supply risk can be reduced. This can be accomplished by taking supplier risk levels into account throughout the supplier selection process. The aim of the case study is to propose a dashboard constructed based upon a Business Intelligence model architecture for supplier evaluation and selection problem considering supply risk.

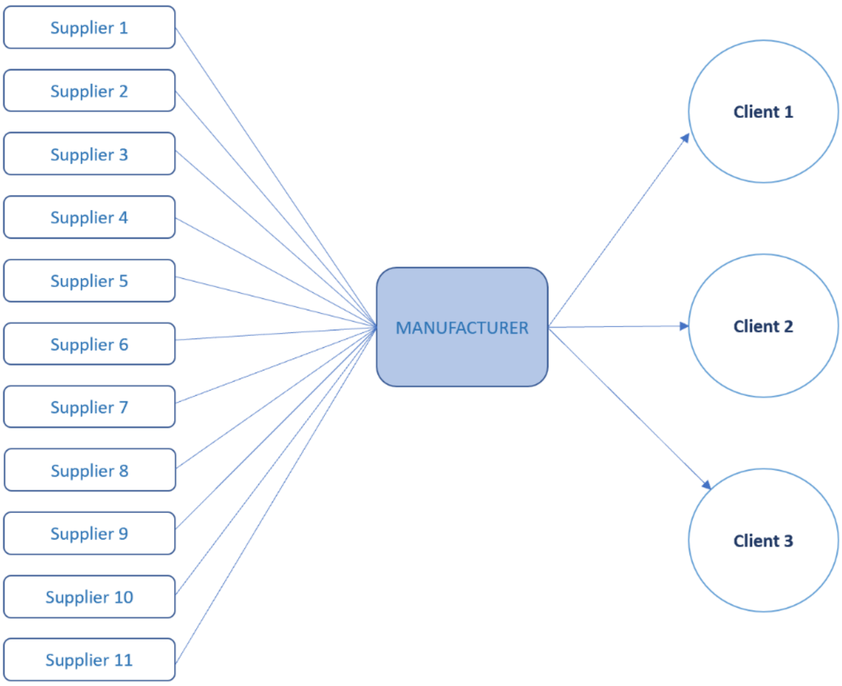


Figure 14 *– SC map*

Supplier evaluation and management criteria differ, depending on the organization's strategy, sector, risk mindset, and needs (Chan & Kumar, 2007). As a result, the case study organization holds multiple iterative and structured meetings and discussions with management and purchasing employees to identify the criteria that will be used in the analysis. Under eight risk dimensions, four quantitative and 13 qualitative criteria have been identified. The weights of the risk criteria are determined by using the Best-Worst Method (BWM) that is proposed by Jafar Rezaei (Rezaei, 2015). First, among a collection of criteria, the best (most important) and worst (least important) criteria are chosen. The decision maker then weighs the importance of the best and worst risk criteria in comparison to the other risk criteria.

For the supplier evaluation and selection problem, many studies use a single decision maker or numerous decision makers. However, previous studies have demonstrated that collective decision-making produces better results than individual decision-making (Kar & Pani, 2014). Therefore, three decision makers are used both in the weighting of the criteria and assessment of the suppliers. These decision makers assessed the 17 criteria using the BWM stages, and then calculated the weights. By averaging the findings of the BWM solutions, the final weights of the criterion are calculated.

The purchasing department provides information on four quantitative criteria. The subjective opinions of the three decision makers determine the values of the other 13 qualitative criteria. The following describes the decision makers' role, position, and expertise (Kara & Fırat, 2018):

1. **Decision Maker 1** is the commercial manager of the company and has a high effect on the selection of the suppliers. He has a high authority in the determination of SC stakeholders and makes regular field visits both to the foreign and local suppliers. He has a high expertise about the sector and general conditions (e.g., facility, technology level) of the supplier.
2. **Decision Maker 2** is selected as a domain expert from the purchasing department. She has a high expertise about the procurement processes and has a closer contact with suppliers.
3. **Decision Maker 3** is a mechanical engineer and works in the purchasing department. He has a high level of technical knowledge and expertise in engineering related issues, such as manufacturing processes, quality level, and technological capability of suppliers.

Because the three decision makers have varied backgrounds and knowledge, the general manager and the business development engineer can also assess their opinions by considering their positions, duties, and experiences. The data on the 17 criteria is scaled within a given range using the weighted scores of the suppliers.

4.2 MODEL

The goal of this research is to create a model for the use of business intelligence to optimize risk management in supply chain integration. To accomplish the results of this study the model will be divided into seven different phases as shown in figure 15. In the Supplier Risk Assessment Criteria step, we'll define the sort of risk we're looking at, whether it's supply, demand, or process-related, and then identify the many criteria's that could affect our supply chain. Then, we will determine the importance of the criteria according to the decision makers in the Weighting of the Risk Criteria by Using the Best-Worst Method stage after this has been set. According to the BWM method, the best and worst method are identified, first by the decision makers, followed by pairwise comparisons conducted between each of these two criteria and the other criteria (Rezaei, 2015). After, it is in Supplier Risk Data stage that we are going to get the data based on the subjective evaluations of the decision makers. We will move on to the Identify Relationships stage to identify and capture interdependencies for each Supply Chain partner once the pertinent risks have been identified. After that we will develop the conditional probabilities and impact for all events. This is followed by the Developing of the Business Intelligence Model stage, in which we will construct a BI data model that will allow to analyze the data obtained through the application of the different methods and transform it into useful information, so that, in the final stage, the report can provide good insights to decision makers that will help the company in supplier risk mitigation.

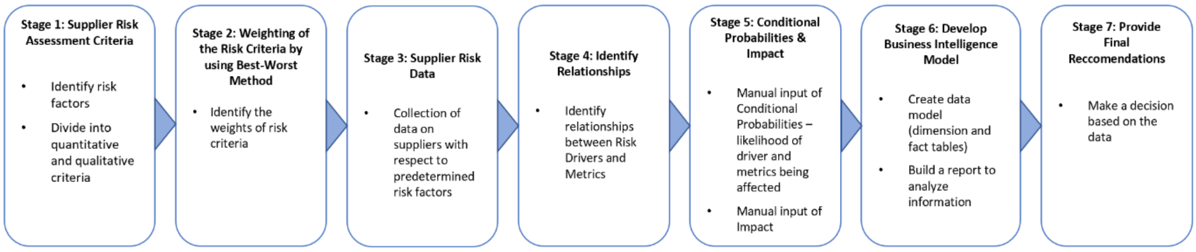


***Figure 15** – Different Stages of the Model*

4.2.1 Supplier Risk Assessment Criteria

The efficacy of the suggested supplier evaluation and selection process is dependent on the identification of supplier risk factors. Various strategies have been used in the literature to detect and define supplier risks. Supplier evaluation and selection criteria vary depending on the organization's business strategy and needs (Chan & Kumar, 2007). As a result, after multiple iterative and structured meetings and discussions with management and purchasing personnel, the final set of criteria is established. Various factors are examined while determining risk criteria, including the company's specific requirements and risk mindset, as well as the sector's structure.

According to Kara & Fırat (2018), supplier evaluation criteria includes 17 different risk related criteria: $C = \{c_1, c_2, \ldots, c_{17}\}$ that are grouped under eight risk dimensions (categories). Four quantitative criteria (c_4, c_8, c_{10}, and c_{11}) are typical numbers, averages and percentages. Some of the risk categories are difficult to translate into quantitative data. The values of the other 13 criteria (c_1, c_2, c_3, c_5, c_6, c_7, c_9, and c_{12}-c_{17}) are determined by subjective evaluations of the three decision makers in the risk management team. These criteria are utilized as risk indicators for a variety of difficulties, such as poor operational performance, insufficient quality management efforts, low service levels, and communication challenges. In addition to operational risk types, the study includes one criteria relating to catastrophic risks. The diversified set of risk criteria aids in the incorporation of various aspects of supply risks into the model, as well as the development of a thorough supplier evaluation procedure (Kara & Fırat, 2018).

The risk criteria that are used to evaluate suppliers are explained in the following (Kara & Fırat, 2018):

1. **Previous supplier assessments (c_1)**: A company for each purchasing activity, conduct a supplier evaluation survey with the purchasing staff. On a scale of one to five, suppliers are rated on five criteria: quality system, process control, references, technological structure, and delivery performance. For each provider, the weighted rating averages are generated. The total weighted points are used as an indicator of previous supplier experience. It is a crucial metric that indicates the suppliers' past performance and dependability (Chen, 2011; Lee, 2009).
2. **Purchase (commodity) price variance (c_2)**: The level of the supplier's pricing within the standard sector price is represented by this indicator. A "1" point signifies a very cheap price, a "5" point represents an average price, and a "9" point denotes a very high price level. It indicates the price's competitiveness (Chan & Wang, 2013; Punniyamoorthy et al., 2011).
3. **Financial condition of the supplier (c_3)**: This metric measures the supplier's financial risk by considering its economic state, debt structure, market share, annual revenue and growth,

and financial stability (Chan & Kumar, 2007; Chen, 2011). It is an indicator of poor financial health of the supplier (Kull & Talluri, 2008). Nine points indicates a high likelihood of supplier bankruptcy.

4. **Percentage of supplier's work commonly subcontracted (c_4)**: It is the ratio of the supplier's work that is subcontracted (Guertler & Spinler, 2015; Kannan & Tan, 2002). For this part of their work, suppliers rely on their subcontractors. As a result, a high level of subcontracting entails a high amount of risk and uncertainty.

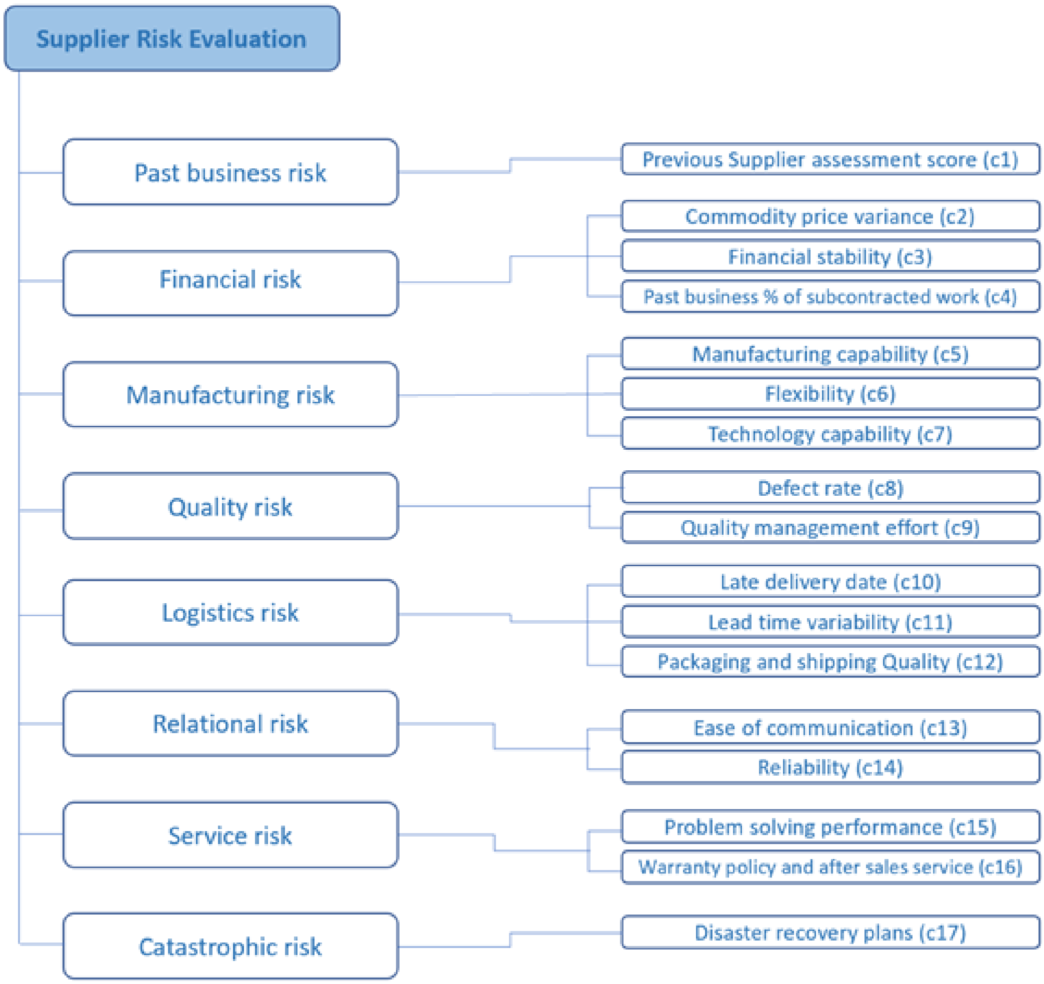


Figure 16 *– Main risk categories and risk types considered in the supplier assessment process (Kara & Fırat, 2018)*

5. **Manufacturing capability (c_5)**: This metric measures the supplier's manufacturing capability in terms of the conditions, qualifications, adequacy, and capacity of the supplier's production facilities, machinery, equipment, and employees (Luthra et al., 2017; Thanaraksakul & Phruksaphanrat, 2009). For a first assessment, the focus firm visits and assesses possible suppliers. During their instructions, they also pay regular visits. The evaluations and observations made during these field visits are used to determine this ranking.

6. **Flexibility (c_6)**: Supplier flexibility is described as the supplier's capacity to adjust to changing customer needs and requirements (Kull & Talluri, 2008; Lee, 2009; Luthra et al., 2017). Suppliers are evaluated on their volume, product mix, product design, and delivery date flexibility. While one point shows a supplier's high level of flexibility, nine points indicates a supplier's lack of flexibility.
7. **Technological capability (c_7)**: It is a measure of a supplier's technological systems' capacity and robustness, and it is used to assess technology risk (Govindan et al., 2015; Heidarzade et al., 2016). It takes into account the supplier's manufacturing technologies and R&D capabilities. Suppliers with a score of nine have a poor level of technological proficiency and are unable to respond to technology needs and advances.
8. **Average defect rate of the supplier (c_8)**: The defect rate is the percentage of items that fail to fulfil quality standards compared to the total number of units provided by the supplier (Guertler & Spinler, 2015; Nekooie et al., 2015). It's generated by averaging the values from quality inspection data over the previous five years. Poor quality is indicated by noncompliance with quality specifications.
9. **Quality management effort (c_9)**: It refers to the supplier's rating based on its quality efforts (commitment to quality). During supplier evaluations, quality-related certificates, quality control activities, the competency of quality management systems, quality improvement initiatives, and the documentation of quality inspections are all taken into account (Govindan et al., 2015; Paul, 2015). A score of nine shows that quality management activities and programs are lacking.
10. **Late delivery rate of the supplier (c_{10})**: It's the number of late deliveries divided by the total number of orders (Chan & Wang, 2013; Wu & Olson, 2008). This indicator is derived from historical data.
11. **Supplier lead time variability (c_{11})**: This indicator is measured by dividing the difference between quoted and actual supplier lead time by the quoted lead time (in days). It is an indicator of the variation from promised delivery lead time.
12. **Packaging and Shipping quality (c_{12})**: The risk rating of the supplier's packaging and shipping functions, both in terms of quality and compliance with standards, is represented by this indicator (Punniyamoorthy et al., 2011; Thanaraksakul & Phruksaphanrat, 2009). A score of nine indicates that the supplier's packaging and shipping quality is poor, and that the provider is likely to have a problem with packaging and shipping.
13. **Ease of communication (c_{13})**: This metric represents the supplier's total communication rating. It considers issues and challenges in communicating with suppliers, such as unstable and inefficient communication networks, difficulty in contacting persons/sales representatives (e.g., unavailability or discontinuity of the responsible person), supplier misinterpretation of emails, imprecise and slow communication, lack of transparency, unwillingness, and privacy for information sharing (Chen, 2011; Guertler & Spinler, 2015; Kull & Talluri, 2008). This indicator aids in the detection of supplier communication and coordination issues.
14. **Reliability (c_{14})**: It shows the supplier's level of reliability based on previous business compliance with contract terms and conditions, correctness and trustworthiness of documents and information provided by suppliers, sector reputation, and references. The strength of commercial partnerships and information sharing is influenced by the level of trust in the buyer-supplier relationship (Punniyamoorthy et al., 2011).

15. **Problem solving performance (c_{15})**: This metric measures the level of risk associated with ineffective and inadequate sales and technical assistance. The response time of suppliers to a complaint, quality concern, or emergency situation, problem solving capability, complaint processing, technical support level, and remedy to repair a quality fault are all factors in problem solving performance (Chan & Kumar, 2007; Chan & Wang, 2013). The supplier's unresponsiveness is represented by a nine-point scale.
16. **Warranty policy and after sales service (c_{16})**: This metric pertains to the supplier's after-sales support, as well as its warranty and claim procedure (in terms of coverage of warranty and service agreements, warranty period, and satisfaction about claims) (Cheraghi et al., 2004; Thanaraksakul & Phruksaphanrat, 2009).
17. **Disaster recovery plans to deal with major disruptions (c_{17})**: This metric refers to a supplier's score based on their disaster recovery strategies. The majority of the suppliers are in close proximity. As a result, ranking suppliers based on their risk exposure to catastrophic risks like earthquakes, tsunamis, and floods is pointless. Inadequate disruption management strategies raise a company's risk exposure (Paul, 2015). Effective disaster recovery plans can help suppliers withstand catastrophic catastrophes.

4.2.2 Weighting of the Risk Criteria by Using Best-Worst Method

The weights of the risk factors that are used to evaluate suppliers will be determined using the BWM approach. This approach was chosen for a variety of reasons:

1. To increase the efficiency and widen the scope of the analysis on supplier risk behavior, a large number of risk criteria are determined. As a result, adopting the usual Multi-Criteria Decision-Making (MCDM) process to weight these criteria will be challenging. BWM was chosen to overcome the existing approaches' computational complexity. Because it is a vector-based method, it necessitates fewer comparisons than matrix-based MCDM methods (Rezaei, 2016).
2. It's difficult to put a numerical value on the preference for diverse factors. It is the single most important component that contributes to inconsistency. BWM simplifies the pairwise comparison procedure and improves evaluation consistency. According to Rezaei (2015), in terms of consistency ratio, minimal violation, total deviation, and conformance, BWM produces better outcomes.

According to Kara & Fırat (2018a), three decision makers made their evaluations on risk-related criteria individually. To begin, they all chose the best (most important) and worst (least important) criteria from the 17 previously discussed criteria. Their choices for the best and worst criteria are given in table 1.

Table 1 – *The best and worst risk criteria identified by the three decision makers*

Decision Makers	Best Criteria	Worst Criteria
Decision maker 1	Commodity price variance (c_2)	Percentage of subcontracted work (c_4)
Decision maker 2	Manufacturing capability (c_5) and commodity price variance (c_2)	Percentage of subcontracted work (c_4)
Decision maker 3	Reliability (c_{14})	Disaster recovery plans (c_{17})

Using the nine-point scale in table 2, each decision maker selected their preference for their best criterion over all other criteria. Then, using the same scale, they determined the preference of all the criteria over their worst criterion (Kara & Fırat, 2018).

Table 2 *– Nine-point pairwise comparison scale used in the Best-worst method (adapted from Saaty, 2008; Schoenherr et al., 2008)*

Intensity of Importance	Verbal Meaning for Risk Criteria Comparison
1	Equally important
2	Equally to moderately more important
3	Moderately more important
4	Moderately to strongly more important
5	Strongly more important
6	Strongly to very strongly more important
7	Very strongly more important
8	Very strongly to extremely more important
9	Extremely more important

Table 3 shows pairwise comparisons of the three decision makers for the best and worst criteria. Each decision maker performed 31 ($2n - 3$) pairwise comparisons due to the reciprocal property of the pairwise comparison matrix. As shown in Table 3, a criterion's preference for itself receives a value of 1 (Kara & Fırat, 2018).

Table 3 *– Pairwise comparisons of the decision makers for the best and worst criteria*

	Decision Maker 1		**Decision Maker 2**		**Decision Maker 3**	
Criteria	Best Criterion: c_2	Best Criterion: c_4	Best Criterion: c_5	Best Criterion: c_4	Best Criterion: c_{14}	Best Criterion: c_{17}
C_1	4	7	6	3	3	8
C_2	1	9	1	9	3	7
C_3	3	7	9	2	4	5
C_4	9	1	9	1	8	2
C_5	6	7	1	8	2	8
C_6	8	4	2	7	5	6
C_7	6	7	2	6	1	9
C_8	2	9	4	4	2	8
C_9	5	7	2	8	6	5
C_{10}	2	8	3	7	2	7
C_{11}	2	8	3	6	2	8
C_{12}	3	5	2	7	2	8
C_{13}	5	5	4	6	4	6
C_{14}	4	4	2	8	1	9
C_{15}	3	6	2	8	1	9
C_{16}	5	5	2	8	1	9
C_{17}	8	3	2	8	9	1

The linear BWM problem is solved separately for each decision maker, providing optimal weights. In the three linear BWM issues, the objective function value (ε) that measures the consistency level of the decision makers is as follows: $\varepsilon_1 = 0.048$, $\varepsilon_2 = 0.028$, $\varepsilon_3 = 0.027$. Because all of these numbers are near to zero, the comparisons of the three decision-makers can be recognized as valid (Kara & Fırat, 2018).

The final weights of the criterion are determined by averaging the weights discovered by the three BWM issues. The average optimum values of the weights of the 17 criteria are shown in table 4. In the analysis section, these values are used as the weights of the criteria (Kara & Fırat, 2018).

__Table 4__ – Averages of the three Best-Worst method (BWM) solutions

Weights of the Criteria	Values	Weights of the Criteria	Values	Weights of the Criteria	Values
w^*_1	0.0393	w^*_7	0.0700	w^*_{13}	0.0363
w^*_2	0.1063	w^*_8	0.0673	w^*_{14}	0.0757
w^*_3	0.0387	w^*_9	0.0437	w^*_{15}	0.0813
w^*_4	0.0130	w^*_{10}	0.0710	w^*_{16}	0.0723
w^*_5	0.0703	w^*_{11}	0.0710	w^*_{17}	0.0343
w^*_6	0.0403	w^*_{12}	0.0677		

*Averages of the optimal weights.

4.2.3 Supplier Risk Data

Suppliers are rated based on 17 qualitative and quantitative risk related criteria. Four criteria include ratios and are calculated by using past data on suppliers (c_4, c_8, c_{10} and c_{11}). The remaining 13 criteria comprise qualitative data based on the three decision makers' subjective assessments ($c_{1\text{-}3}$, $c_{5\text{-}7}$, c_9, $c_{12\text{-}17}$) (Kara & Fırat, 2018).

The weighted average of prior subjective evaluations in the company is used to calculate criterion c_1. After each order, suppliers are graded on a five-point scale from 1 to 5 based on five factors (1 = high performance and 5 = low performance). Quality system, process control capability, references, technological framework, and delivery performance are among the criteria. The weights of the criteria are 0.15, 0.15, 0.05, 0.05, and 0.60 respectively. Because she is in charge of acquiring price quotations, data on criterion 2 (commodity price variance) is only received from decision maker 2 (Kara & Fırat, 2018a).

Three decision makers used a nine-point Likert scale to grade providers based on the remaining 11 qualitative criteria (see table 5). One represents extremely low and negligible risk level. Nine represents an extremely high and serious risk level (Kara & Fırat, 2018).

***Table 5** – Nine-points Likert scale used in rating suppliers (adapted from Saaty, 2008)*

Risk Rating	Verbal Meaning
1	Extremely low and negligible risk level
2	Very low risk level
3	Low risk level
4	Slightly low risk level
5	Moderate risk level
6	Slightly high risk level
7	High risk level
8	Very high risk level
9	Extremely high and serious risk level

Data about suppliers is acquired during three separate sessions with each decision maker. Each session takes place on a different week, and each session evaluates suppliers using a different set of criteria. In this study, the supplier risk ratings for the 13 qualitative criteria are considered to be intervals (Kara & Fırat, 2018).

Each decision maker has varying levels of competence, knowledge, and experience. They also contact with suppliers regarding a variety of topics related to their obligations. As a result, distinct weights are first applied to the decision makers' judgments for each factor. table 6 has the weights. The general manager and the work development specialist, who is an industrial engineer, are in charge of assigning these weights. For the 11 criteria listed in table 6, weighted averages are determined. Because each risk factor has a varied amount of importance for the organization, all numbers are multiplied by the current criteria's weight (See table 4). On the weighted data set, the pre-processing and additional analysis are carried out (Kara & Fırat, 2018).

Table 6 – *Weights of the evaluations of decision makers for different criteria.*

		Weights of the Evaluations of Decision Makers		
Nº	**Criteria**	**Decision Maker 1**	**Decision Maker 2**	**Decision Maker 3**
1	Financial condition of the supplier (c_3)	0.6	0.3	0.1
2	Manufacturing capability (c_5)	0.3	0.2	0.5
3	Flexibility (c_6)	0.2	0.4	0.4
4	Technological capability (c_7)	0.3	0.2	0.5
5	Quality management effort (c_9)	0.2	0.4	0.4
6	Packaging and shipping quality (c_{12})	0.2	0.4	0.4
7	Ease of communication (c_{13})	0.2	0.5	0.3
8	Reliability (c_{14})	0.2	0.4	0.4
9	Problem solving performance (c_{15})	0.2	0.4	0.4
10	Warranty policy and after sales service (c_{16})	0.2	0.4	0.4
11	Disaster recovery plans (c_{17})	0.6	0.2	0.2

4.2.4 Identify Relationships Between Risk Drivers

After the risks are identified, interdependencies between these risks are going to be discussed. This risk network matrix (see table 7) will be developed to identify and capture the interdependencies for each Supply Chain partner. Any cell in the table with a value suggests a correlation between the risk in the row and the specific column. A visual tool for assessing hazards and their interconnections is created using the risk network table to create a risk network map. This risk analysis will be done based on the Badurdeen et al. (2014) and Kara & Fırat (2018) papers.

	PREVIOUS SUPPLIER ASSESSM. SCORE	COMMOD. PRICE VARIANCE	FINANC. STABIL.	PAST BUSINESS % OF SUBCONTR. WORK	MANUFACT. CAPABILITY	FLEXIB.	TECHNOL. CAPABIL.	DEFECT RATE	QUALITY MANAG. EFFORT	LATE DELIVERY DATE	LEAD TIME VARIAB.	PACK. & SHIPP. QUAL.	EASE OF COMM.	RELIAB.	PROBL. SOLV. PERFOR.	AFTER SALES SERVICE	DISAST. RECOV. PLANS
PREVIOUS SUPPLIER ASSESSMENT SCORE														1			
COMMODITY PRICE VARIANCE				1													
FINANCIAL STABILITY					1	1	1					1					
PAST BUSINESS % OF SUBCONTRACTED WORK		1															
MANUFACTURING CAPABILITY			1									1					
FLEXIBILITY			1		1		1								1		
TECHNOLOGY CAPABILITY			1			1											
DEFECT RATE										1							
QUALITY MANAGEMENT EFFORT												1					
LATE DELIVERY DATE											1						
LEAD TIME VARIABILITY										1							
PACKAGING & SHIPPING QUALITY			1		1				1								
EASE OF COMMUNICATION														1			
RELIABILITY	1												1				1
PROBLEM SOLVING PERFORMANCE						1											1
AFTER SALES SERVICE																	1
DISASTER RECOVERY PLANS														1	1	1	

Table 7 *– Sample Risk Network Matrix*

Based on the Sample Risk Network Matrix and according to Kara & Fırat (2018b), it was possible to group the 17 risk variables into four factors, as shown in figure 17. Factor 1 includes risk categories linked to the suppliers' overall organizational structure, production capabilities, and technological and logistical capabilities. Risks associated with prior evaluations, a supplier's ability to solve problems, reliability, communication, and after-sales support are all part of Factor 2. Factor 3 addresses the risks associated with the suppliers' performance in terms of quality and delivery (operational performance). Only the percentage of work that is subcontracted and the variation in commodity prices are covered by Factor 4. Companies that employ subcontractors are likewise responsible for their profits.

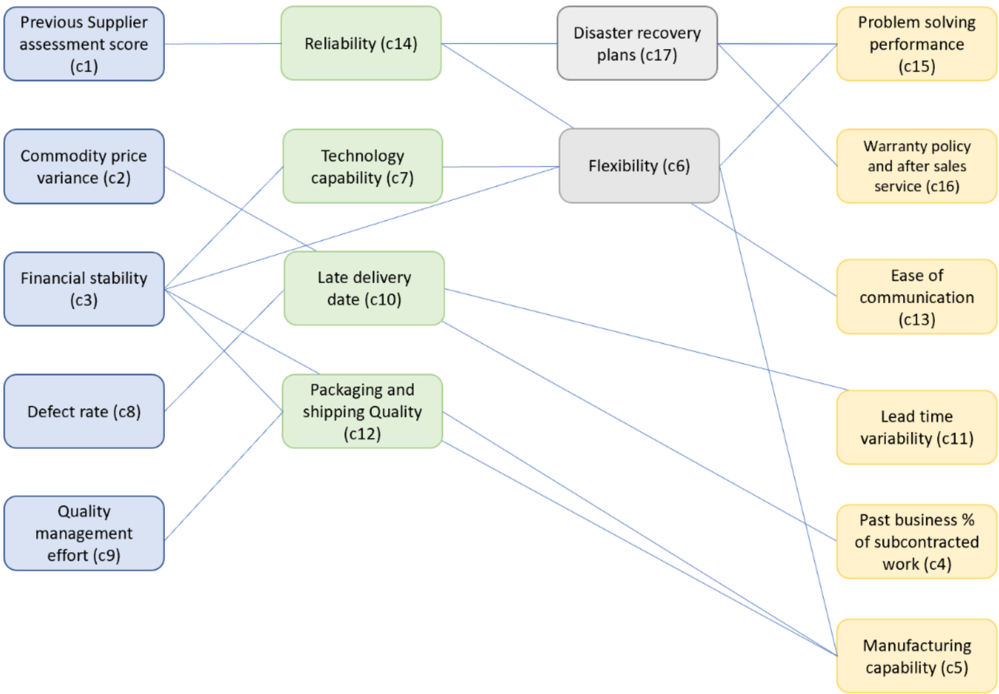


***Figure 17** – Supply Chain Risk Network Map*

4.2.5 Manual Input of Conditional Probabilities and Impact

The gathering of information for the Bayesian Belief Network is the initial stage in a quantitative risk analysis. We may define the conditional probability for each occurrence using the Risk Network Map. It is essential to create data collecting sheets to gather the conditional probabilities for each node in order to acquire this type of data. Since the conditional probabilities are primarily computed based on expert opinion, we adapted the probabilities from the case study (Badurdeen et al., 2014) for this study.

Based on the experience with the suppliers, conditional probabilities were updated, and the supplier data supplemented. The conditional probabilities employed were founded on a synthesis of the contributions of several experts. On table 8, the posterior risk probabilities are compiled.

__Table 8__ – Risk Probability for SC

Risk	ID_Risk_group	Sup 1	Sup 2	Sup 3	Sup 4	Sup 5	Sup 6	Sup 7	Sup 8	Sup 9	Sup 10	Sup 11
Previous Supplier Assessment Score	1	0.04	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01
Commodity Price Variance	7	0.56	0.38	0.25	0.00	0.87	0.13	0.55	0.27	0.72	0.66	0.00
Financial Stability	7	0.40	0.40	0.40	0.40	0.40	0.20	0.20	0.20	0.60	0.20	0.40
Past Business % of Subcontracted Work	7	0.05	0.25	0.05	0.50	0.25	0.75	0.05	0.75	0.25	0.75	0.05
Manufacturing Capability	5	0.05	0.05	0.05	0.45	0.45	0.05	0.45	0.05	0.05	0.45	0.05
Flexibility	5	0.41	0.39	0.37	0.42	0.35	0.37	0.35	0.38	0.41	0.41	0.42
Technology Capability	5	0.37	0.27	0.68	0.55	0.47	0.61	0.14	0.25	0.65	0.79	0.62
Defect Rate	4	0.55	0.03	0.11	0.42	0.16	0.15	0.36	0.75	0.20	0.00	0.83
Quality Management Effort	4	0.83	0.84	0.91	0.74	0.97	0.39	0.08	0.56	0.84	0.70	0.59
Late Delivery Date	6	0.25	0.30	0.30	0.75	0.20	0.20	0.40	0.40	0.10	0.73	0.27
Lead Time Variability	6	0.15	0.69	0.96	0.36	0.58	0.07	0.60	0.38	0.45	0.34	0.24
Packaging & Shipping Quality	6	0.92	0.36	1.00	0.60	0.91	0.25	0.22	0.68	0.94	0.80	0.10
Ease of Communication	2	0.90	0.15	0.04	0.85	0.86	0.99	0.85	0.38	0.04	0.30	0.27
Reliability	2	0.19	0.67	0.32	0.22	0.98	0.21	0.04	0.93	0.33	0.81	0.89
Problem Solving Performance	3	0.31	0.44	0.29	0.58	0.18	1.00	0.69	0.72	0.05	0.31	0.73
After Sales Service	3	0.74	0.86	0.75	0.94	0.68	0.24	0.38	0.23	0.34	0.04	0.98
Disaster Recovery Plans	1	0.05	0.08	0.06	0.09	0.05	0.06	0.10	0.05	0.05	0.09	0.07

The focus company's exposure to high probability risks can be determined by examining the probabilities. It is feasible to see the dangers with higher probabilities through table 8, and we may also make inferences about specific suppliers.

The risk analysis's learnings could be applied to improve managerial decision-making. This may have an impact, for instance, on how supplier management staff must dedicate time and resources to increase the dependability of the more risk-prone suppliers; improved cooperation with such suppliers may aid in early detection of risk occurrences and the development of mitigation methods.

According to Ward (1999), utilizing probability-impact grids is a method that is frequently used to rank hazards. Individual sources of risk must typically be described as risk events with an estimated likelihood of occurrence and degree of impact in order to be included in such grids. This makes it possible to assign a single "risk rating" to each risk. In certain ways, the danger is more significant the higher the risk rating. Risk managers are more likely to pay attention to highly rated hazards than lowly rated risks.

It is interesting to calculate risk ratings in this manner since the calculation is similar to the one for unconditional expected impact = (expected impact x probability). One way to order sources of risk would be to place them in descending order of expected impact. Putting sources of risk in descending order of projected impact would be one method to arrange them.

For this case study, we identified the following ranking as the risks that, according to Ward (1999), will likely have a greater influence on the company's processes, as shown in table 9.

***Table 9** – Ranking Table*

Risk Group	Ranking
Catastrophic	8
Financial	7
Logistics	6
Manufacturing	5
Quality	4
Service	3
Relational	2
Past Business	1

4.2.6 Develop BI Model

To attend the main goal of this case study, this conceptual model must be designed to not only answer to Company X needs, but to present a solution to similar problems that help companies to mitigate the supplier risk of, for example, unanticipated delays and so help companies on their supplier procurement.

4.2.6.1 Select the Business Process

Our data for this case study will be based on a variety of risks, each of which will be assigned a probability, impact, and weight. We will utilize this information to determine which supplier our hypothetical company should choose, while attempting to reduce the risks, in order to avoid any issues with future orders.

4.2.6.2 Define the Granularity

According to Kimball & Ross (2011), the term "granularity" is used to refer to the level of information connected with the fact table. Identifying the granularity is a fundamental step in dimensional design. Through its identification, we can know what each line of fact tables represents. This step is very important and must be done before choosing the dimensions and facts because these have to be in accordance with the granularity.

- Who is the supplier with higher risk probability?
- Which risk has higher impact?
- Which is the group risk with higher impact?
- Which supplier have the highest number of sales and market share by time?
- Which risk is more important? That is, the risk with higher weight?
- Which supplier is more exposed to a natural disaster based on its location?
- Sales by location.

4.2.6.3 Identify the Dimensions

Which dimensions will be the core ones, can be deduced from the granularity that was previously set. Although each organization has unique characteristics and business strategies, which may lead to fewer or more dimensions, it is still necessary to note.

The management and storage of both past and present data is a final point to be made. Records for some dimensions, in particular fields, may evolve through time. These Slowly Changing Dimensions (SCD) can have three different types: Type 1, Type 2 and Type 3.

Identifying the dimensions allow us to define the "who, what, where, when, why, and how" context surrounding a business process event. Dimension tables contain the descriptive attributes used by BI applications for filtering and grouping the facts. Dimension tables are very important because they contain the entry points and descriptive labels that enable the DW/BI system to be used for business analysis (see table 10).

***Table 10** – Dimensions of the Model*

DIMENSION	OLTP ENTITIE	PARENT DIMENSION
Location	Dim_Location	*none*
Risk	Dim_Risk	*none*
Risk Group	Dim_RiskGroup	*none*
Supplier	Dim_Supplier	*none*
Date	-	*none*

- **Location dimension**: the Location dimension show the location of each geometric feature within an object or view.
- **Risk dimension**: the Risk dimension gives the description of each risk.
- **Risk Group dimension**: the Risk Group dimension groups each one of the risks in its specific group.
- **Supplier dimension**: the Supplier dimension gives the description of each supplier.
- **Date dimension**: the Date dimension is essential because it facilitates more effective data analysis and reporting. Calculations are simpler and more precise if a model include the date and time dimensions.

4.2.6.4 Identify The Facts

The last step proposed by Kimball & Ross (2011) is to identify the fact tables (see table 11). Facts are the attributes that allow us to measure the business process and are almost always numeric.

__Table 11__ – Fact tables of the model

FACT TABLE	BUSINESS NEED	MEASURES	FORMULA	OLTP FIELD
Impact	Group risk with higher impact	Impact	Max(Ranking)	Fact_Impact
Probability	Supplier with higher risk probability	Probability	Max(Valor)	Fact_Probability
Weight	Risk with more decision weight	Weight	Max(BWM_Weight*Decision Maker 1*Decision Maker 2*Decision Maker 3)	Fact_Weight
Sales	Sales by Location	Location_Sales	∑(Quantity*Price)	Fact_Sales
	Sales Evolution	Sales_Evolution	((∑Sales-∑SalesLastYear)/ ∑SalesLastYear) *100	
	Supplier market share	Market_Share	(Quantity*Price/∑(Quantity*Price))*100	
	Total sales by supplier	Sales	∑(Quantity*Price)	

- **Impact** fact table: the Impact Fact Table's goal is to identify the risks that, if they materialize, will have the greatest impact on the company supply chain.
- **Probability** fact table: the Probability Fact Table objectives are to determine which risk is most likely to occur as well as the likelihood that each risk will occur for each of the suppliers.
- **Weight** fact table: the Weight Fact Table's goal is to determine the relative importance of each risk to the company in question. This is how we will be able to filter the risks to determine which one carries the most weight for the organization using the BWM method and the knowledge of three separate decision-makers.
- **Sales** fact table: the purpose of the Sales Fact Table is to allow you to know the total sales per supplier and per location. Thus, through this table, we can observe how the business of the suppliers is performing. Associated with the total sales, this table also allows us to know the evolution of sales compared to the previous years, and consequently also allow us to know the supplier market share evolution.

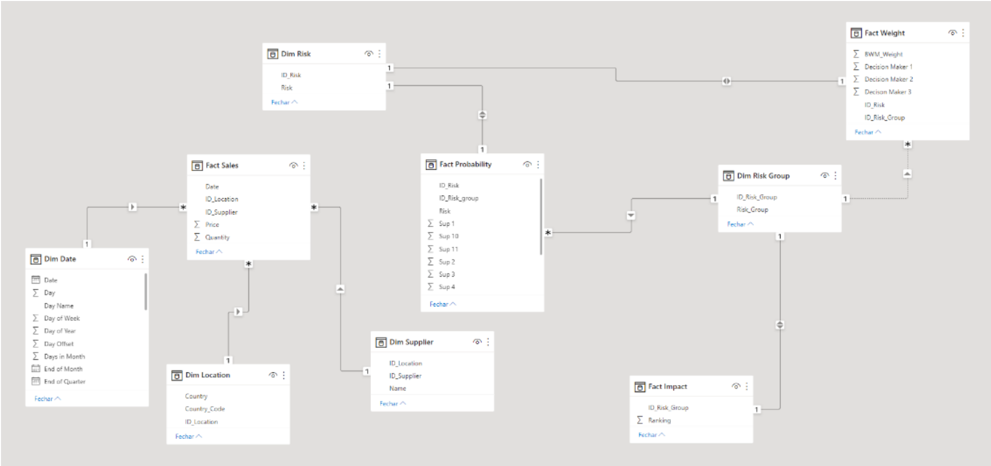


Figure 18 *– Data Model*

4.3 DEMONSTRATION – CASE STUDY

4.3.1 Data Sources

To complete the goal of this study we had to develop some of the data to give context to the analysis. Our main and only data source is an Excel file (flat file) composed by eight sheets. The Fact_Probability, Fact_Impact and Fact_weight sheets are composed by the data we extracted from previous study's. The Fact_Sales is a sheet developed so we can have more information that let us approximate to a real scenario, that also happens with the Dim_Supplier and Dim_Location sheets. The Dim_Risk and Dim_RiskGroup have information regarding the different type of risks. The Dim_Date table originates from a power query script develop in language M.

	Name	Data	Item	Kind
1	Fact_Probability	Table	Fact_Probability	Sheet
2	Fact_Impact	Table	Fact_Impact	Sheet
3	Fact_Sales	Table	Fact_Sales	Sheet
4	Fact_Weight	Table	Fact_Weight	Sheet
5	Dim_Risk	Table	Dim_Risk	Sheet
6	Dim_RiskGroup	Table	Dim_RiskGroup	Sheet
7	Dim_Supplier	Table	Dim_Supplier	Sheet
8	Dim_Location	Table	Dim_Location	Sheet

***Figure 20** – Data Source Details*

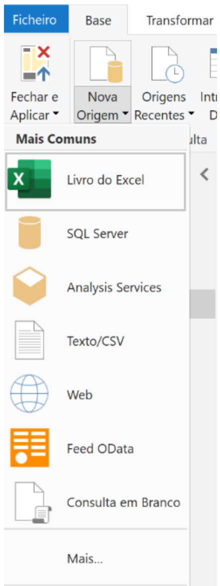


***Figure 19** – Data Source*

4.3.2 Data Transformations

We needed to use the Power Query engine in Power BI to complete our analysis. Power Query is a data preparation and transformation engine. Power Query includes a Power Query Editor for implementing transformations as well as a graphical interface for obtaining data from sources. You can process data through extract, transform, and load (ETL) using Power Query.

Making a parameter was the first transformation we took. This option provides a convenient location to store and maintain a reusable value. In this specific instance, the option that we have defined will give us the ability to dynamically change the location of our files on our machine/computer.

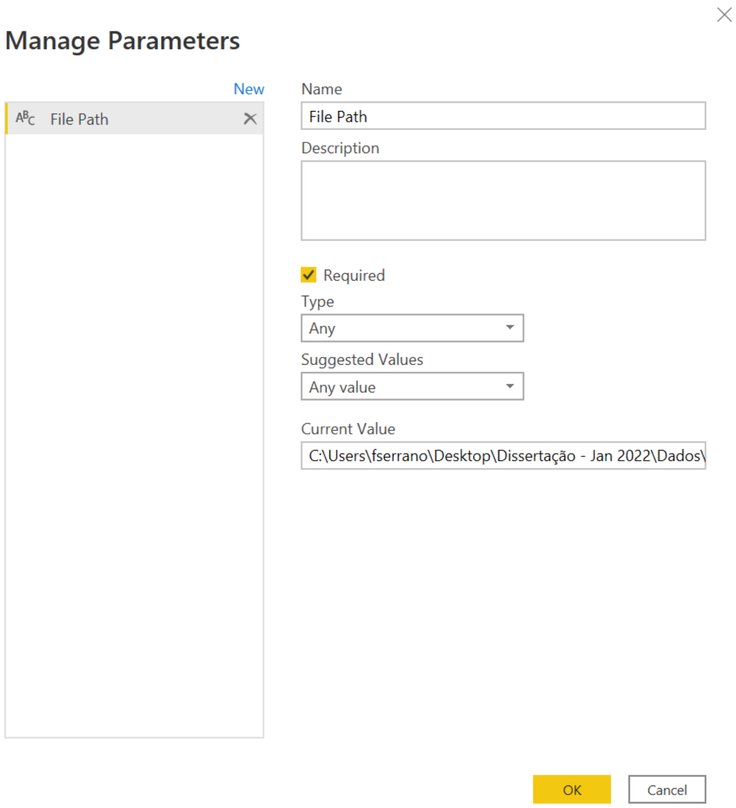


Figure 21 *– Power Query Parameter*

The second thing we did was modifying the format of our fact table: “Fact probability”, by using the "Unpivot columns" option in power query. Since this is a best practice for a tabular model, we performed this transformation to the columns (Sup 1, ..., Sup 11) in order to transform the columns into lines so that we could improve our analysis of the data.

And finally our last modification to our data was to merge the tables: “Fact Probability”, “Fact Weight” and “Fact Impact” into just one table, “Fact Information”. The greatest motivation that led us to carry out this transformation was the fact it didn’t make sense to have three separate fact tables with the same keys, and also, it was easier and made our data model more cohesive (Star Schema) in terms of data analysis as we show below. These factors were the main driving forces behind this transformation, as shown in figure 22.

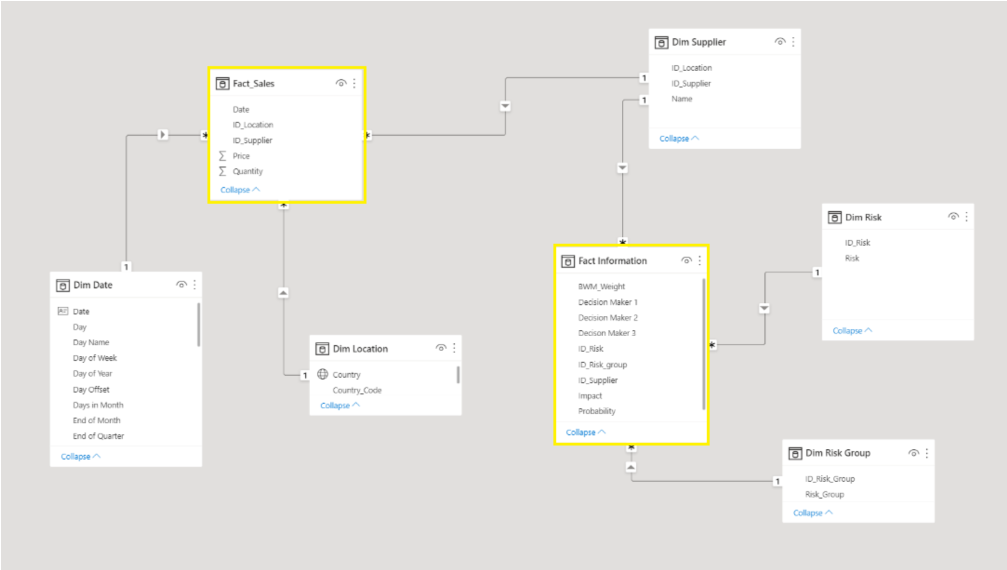


Figure 22 *– Data Model Updated Version*

4.3.3 Dashboard

For the project's final dashboards, a conceptual model was created in accordance with the goals and objectives that were specified.

A BI system should be specific and in line with the business plan, as was mentioned in the prior articles. Therefore, the conceptual model put out in this chapter is merely an idea for a potential solution for issues that the company in question is experiencing.

The measures, indicators, and KPIs shown in the dashboards may differ from one firm to the next in addition to their format. Despite the fact that a list of suitable metrics and indicators was provided, a corporation might not have the data necessary to obtain them. As a result, the models for the dashboards shown below could alter when specific scenarios are taken into account.

In this case our dashboard is composed by two pages: Supplier and Details. This report will help us to choose the Supplier for a particular company based on the risks that may happen.

On the Supplier page we can make the following analyses:

1. Through a visual called "Visual Map", we can view the "Sales by Location" and identify the country's where suppliers ship the majority of their orders.
2. We have three "Cards", one that shows the "Total Sales", another that shows the "Market Share" for each supplier and another one that shows the "Sales Evolution" comparing the previous year to the one selected in the filter. In the "Sales Evolution" card we applied other features of the Power BI. If the evolution is negative, the KPI will appear with the color red and the arrow will be face down, but if the KPI is positive the car will appear with the color green and the arrow will be face up.
3. We also have a visual called "Sales Over Time", a line chart that allow us to make conclusions about the Sales over the years and also, we can make a "Drill-Down" to the day, that is, we can see the sales over the years, months and days.

4. The most important information on this dashboard comes through the “Supplier Risk” table. Here, on this table, is the information that when analyzed will help us to choose the Supplier for our company. On this table we have the Supplier name column and we have another one column with the “Result” metric. This metric is a multiplication between various fields: Probability, Impact, BWM_Weight, Decision Maker 1, Decision Maker 2 and Decision Maker 3. The supplier who have the smaller “Result” is the one that we should select since is the one that will have smaller risk for our company. But we should also have in consideration the sales size and market share (competitive advantage). Finally, we have added a conditional formatting (Background color) to the “Result” column that help us to identify the Supplier more easily based on the visual impact (the supplier we should select will have a greener color).
5. We also have two slicers, that work as filter for our page: “Supplier” and “Year”.

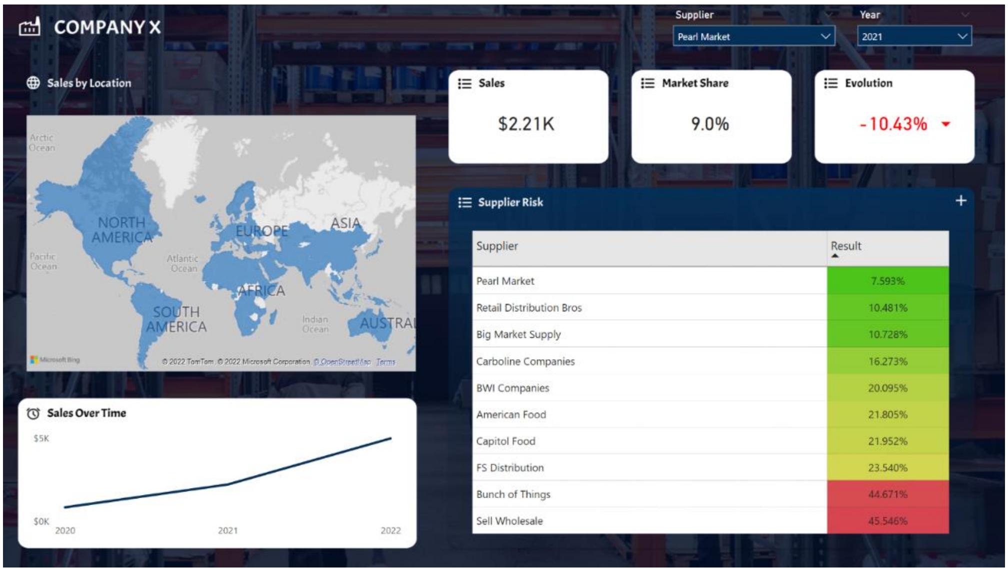
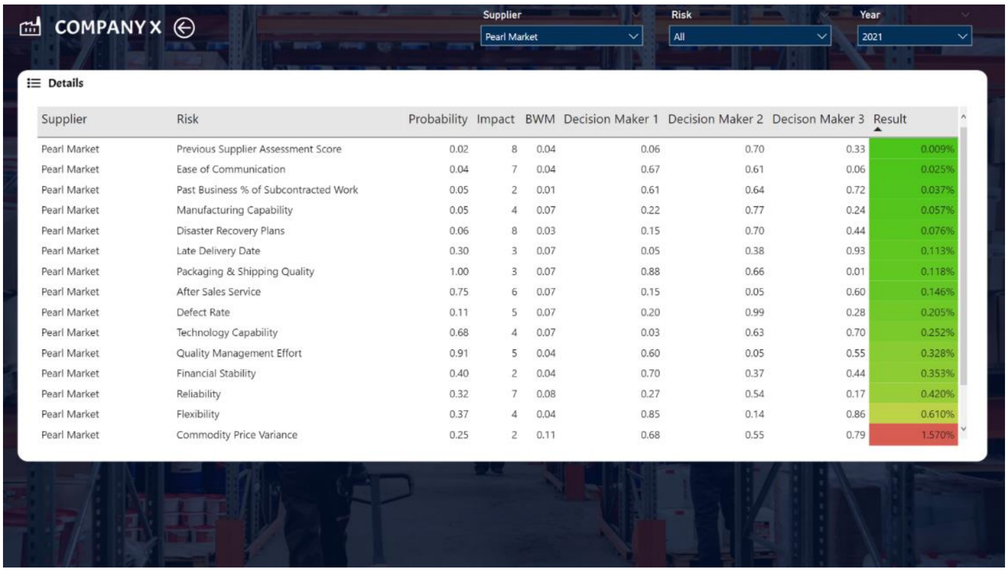


Figure 23 *– Supplier Dashboard*

When we click the plus sign on the “Supplier Risk” table, we will be taken to the second page we added to our report, called the "Details" page. The filters on this dashboard are “Supplier”, "Risk", "Risk Group”, and “Year”. We can see the “Result” for each supplier risk in a table on the “Details” page, which also demonstrates how we arrive at the “Result” value for each Supplier in more detail.



Supplier	Risk	Probability	Impact	BWM	Decision Maker 1	Decision Maker 2	Decison Maker 3	Result
Pearl Market	Previous Supplier Assessment Score	0.02	8	0.04	0.06	0.70	0.33	0.009%
Pearl Market	Ease of Communication	0.04	7	0.04	0.67	0.61	0.06	0.025%
Pearl Market	Past Business % of Subcontracted Work	0.05	2	0.01	0.61	0.64	0.72	0.037%
Pearl Market	Manufacturing Capability	0.05	4	0.07	0.22	0.77	0.24	0.057%
Pearl Market	Disaster Recovery Plans	0.06	8	0.03	0.15	0.70	0.44	0.076%
Pearl Market	Late Delivery Date	0.30	3	0.07	0.05	0.38	0.93	0.113%
Pearl Market	Packaging & Shipping Quality	1.00	3	0.07	0.88	0.66	0.01	0.118%
Pearl Market	After Sales Service	0.75	6	0.07	0.15	0.05	0.60	0.146%
Pearl Market	Defect Rate	0.11	5	0.07	0.20	0.99	0.28	0.205%
Pearl Market	Technology Capability	0.68	4	0.07	0.03	0.63	0.70	0.252%
Pearl Market	Quality Management Effort	0.91	5	0.04	0.60	0.05	0.55	0.328%
Pearl Market	Financial Stability	0.40	2	0.04	0.70	0.37	0.44	0.353%
Pearl Market	Reliability	0.32	7	0.08	0.27	0.54	0.17	0.420%
Pearl Market	Flexibility	0.37	4	0.04	0.85	0.14	0.86	0.610%
Pearl Market	Commodity Price Variance	0.25	2	0.11	0.68	0.55	0.79	1.570%

***Figure 24** – Details Dashboard*

The conclusion we can take from analyzing our dashboard, is that the supplier we should select for our company is the one called “Pearl Market” that have a “Result” of 7.593%, a total “Sales” of 4.99K for the 2022 year, a “Market Share” of 9% and a “Evolution” of sales of 125.91%.

4.4 Evaluation & Discussion

4.4.1 Validation

We have conducted several interviews with experts to validate the proposed implementation framework.

This qualitative methodology aims to solve several research gaps in the area of supply chain risk management that have not been well addressed by scientific research. We decided to consult several professionals to help us enhance our framework since this subject is quite general and can be used to many different fields, and because we couldn't locate many publications that could answer our queries about supply chain management and risk management.

An interview guide, which serves as the primary data collection tool for qualitative interviews, was created to address the framework of a qualitative expert interview. The purpose of the interview guide is to give structure to the interview process and assist in the analytical evaluation of the acquired expert knowledge. The interviewer's objectivity and openness to new ideas, facts, and opinions are particularly crucial.

In order to prevent interviewees from having biased opinions, the proposed model that was given to them was purposefully created on a fairly holistic level, as shown in figure 25.

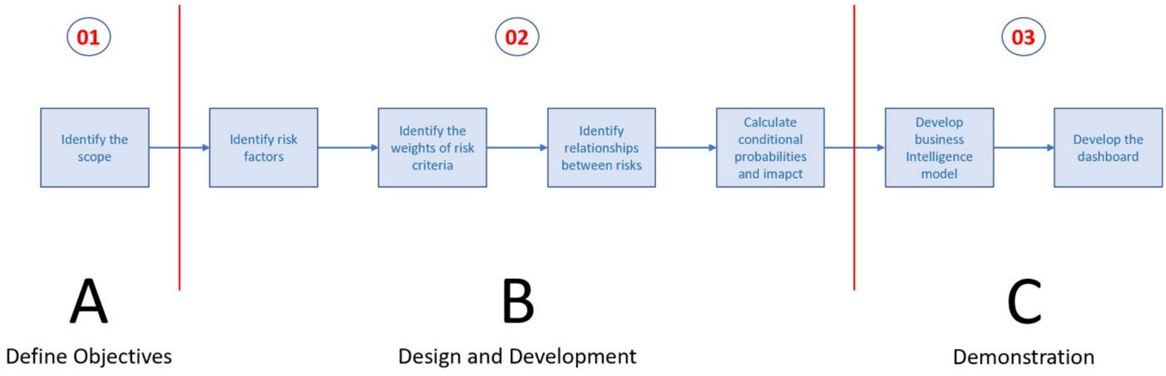


***Figure 25** – Framework presented to the experts*

Participants from the academic and industrial sectors contribute to the expert composition. The knowledge of the professionals is derived from their practical experience in the areas of technology, supply chain, operations management, and logistics. Additionally, the specialists that were questioned are either employed by firms or hold a PhD from universities. The experts who were spoken with are listed in the following table along with a brief summary of their field of expertise (see table 12).

***Table 12** – Participants expert interview*

#	Field of employment	Area of expertise	Domain
E1	Logistics, Supply-Chain	Logistics & Transport Manager @ Covet Group	Industry
E2	Professor with a PhD in the field of Management, with specialization in Operations Management and Technology	Professor @ ISCTE Business School	Academics

Each expert on the list was contacted separately for the interviews. All agreed to be recorded with the intention of including each interview's transcription in the annex section. The interviews took place from October to November of 2022.

4.4.2 Discussion

Our research and literature study indicate that because supply chains have not kept up with technological improvements, they are not ready for the kinds of risks that can occur today. There aren't any frameworks or established skeletons being used in today's organizations to help in calculating the risk of an event occurring that could affect the supply chain while also assisting companies competing in the current global marketplace.

All experts, E1 and E2, agree that the proposed framework may be used to reduce risks in any sort of business. They note that it is highly helpful and essential and that they are unaware of any other frameworks that could address this particular issue. The experts' mention of this framework's strength is that it may be used in a variety of business settings, including professional and educational ones. This framework can help to improve and elevate these businesses' operations and services.

Since the framework's output is a report or dashboard derived from a BI model, this framework becomes dynamic and adaptable to various risks and situations, allowing for a clearer and more accurate view of the solution-to-problem ratio and the evolution of the implemented solution as a function of the data over time.

In addition to the positive feedback this model has gotten, the experts who were consulted have offered significant suggestions for enhancement that will help the framework remain strong as it is. Theoretical frameworks that offer beneficial input for the model's revision were also discussed.

According to experts, it is crucial to have an instruction manual with the framework so that users can correctly utilize it and understand what to do at each stage because the framework has a lot of steps and may be complicated. They also suggested adding a new phase to the framework, as shown in figure 26, which we all agreed was required to increase its effectiveness. This step will take place between the conclusion of phase B and the start of phase C, and it will involve sending a questionnaire to the manufacturers in this case. The questionnaire will include questions about all the risks and a scale of 1 to 7 (7 is the best answer), which will help the framework's users better assess the probability that each risk will realize.

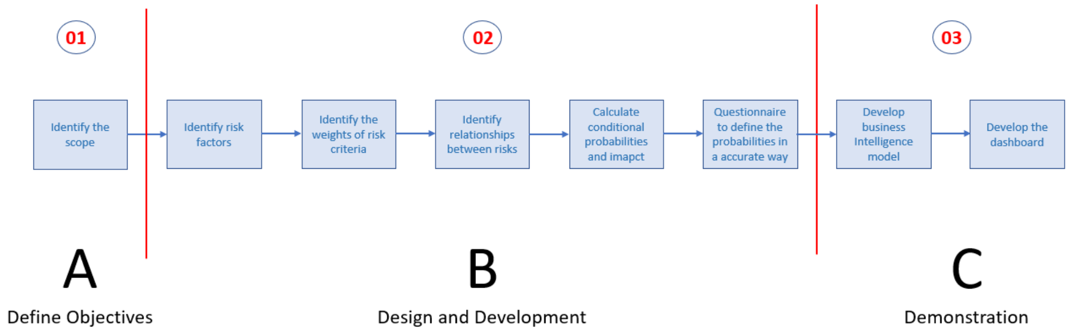


Figure 26 – Revised framework

Overall, all of the experts agreed that this was a highly significant and practical framework, one that is much more vital today. It may assist firms in staying ahead of the market, which results in a competitive advantage.

5 CONCLUSION

The creation of a conceptual model based on a BI system that acted as a solution for any business looking to reduce risks in their supply chain was the major objective of the current framework and dashboard. It was essential that this solution not be company-specific, instead, it need to offer a solution for all businesses struggling with comparable issues.

The project was organized using the DSR technique, and each stage was finished. A detailed review of the literature was undertaken in order to find the best answer to the issue. Frameworks and dashboards are recognized as project outcomes.

Many challenges were faced throughout the project, it is significant to note that the fact and dimension tables model's initial suggested structure was not the one that would best serve the project's objectives. Therefore, some model modifications were required in order to get accurate analyses back from the dashboard.

Even with certain difficulties, it is still conceivable to state that the project's outcome was successful. Many businesses, not just those that rely on supply chains for their operations, can use the solution offered by the conceptual model/framework. We may presume that any organization that implements this BI model into their operations will be able to reduce any risk that they deemed crucial to the operation. All of this leads to an improvement in the decision-making process as a result.

Regarding the project's visualization component as well, the end result was a collection of logical and well-organized dashboards, where the large figures are displayed at the top of the page and more in-depth information is displayed at the bottom to make it simple for users to understand the data.

5.1 SYNTHESIS OF THE RESEARCH

The method used in this dissertation was organized followed the steps below: The first phase involved defining a goal, which was "How the Business Intelligence may help to mitigate the risks on a supply chain." The most recent scientific publications were then reviewed in order to demonstrate the relevance and significance of data analytics for the supply chain. Investigating how to define, manage, and calculate the many types of risks was also crucial. The knowledge that emerges from the literature review serves as the foundation for developing the framework suggested for putting the BI model into practice.

After reviewing the literature review, we made the decision to design our BI model to assist manufacturers in choosing their suppliers based on the weight, impact, and probability that a list of different risks have for each supplier.

By conducting expert interviews, the model validation was done using a qualitative methodology. Experts from several fields, including business, and academics, made up the group.

It is still feasible to describe the project's end result as successful despite some difficulties. The conceptual model created offered an answer to Company X and all other businesses with comparable needs.

5.2 RESEARCH LIMITATIONS

One limitation that this research faced was the fact there is little documentation and research, including papers, journals, conference proceedings, or sufficient best practices around the concepts for the implementation of a BI model with the purpose to mitigate the risks on the supply chain. We believe that this lack of information is due to the fact that there is extremely difficult to define the risks that can affect the supply chain and even more difficult is to quantify the impact, probability and weight that every risk has.

Having access to the data was another limitation of this study. This was quite challenging because there was not enough study done on it, and we also didn't have access to data about a specific company, so we had to make up our own data based on the findings of other academics. In the worst situation, this can mean that our final analysis is less useful than we anticipated, but we want to emphasize that this was designed to be flexible for every business, and if everything is in order, the final dashboard will provide us with the data we need to reduce the risks.

The validation method also exhibits another limitation. The model, which have received additional feedback from the expert interviews, cannot be re-validated due to the time constraint. As a result, although the DSR technique was used, it was not completely utilized.

5.3 FUTURE WORK

Future research in the subject of this dissertation can, therefore, primarily concentrate on the data. Real and accurate data will be necessary to achieve successful results. We propose that, with regard to the weight of each risk, assigning a different weight to each decision maker – that is, considering each decision maker's perspective while assigning various weights to the decision makers' opinions – could provide greater insights. Although it is highly challenging to estimate probability, we recommended that you base your information on statistics from past years in order to get more accurate estimates. The same exercise for the impact.

Regarding the risks it would be interesting to develop a model that helps the decision makers choosing the risks that can affect each company and also to help choosing the type of each risk.

In order for different persons to have access to the files and be able to change and refresh the data automatically, it is crucial to have the files integrated in a database or to have them in an online platform (such as a Sharepoint folder). Additionally, Integration Services (SSIS) may be used in place of generating the ETL transformation in the Power BI Desktop so that when we access Power BI, we already have the data accessible to begin building the visualizations and subsequently the report.

Related to the Power BI, it will be very interesting to see what happens when we post the report on the Power BI Service's web platform in a real-world scenario and take various activities to extract more insights from the report. We may choose which employees inside our company should have access to the data using the Power BI Service. We can also utilize the artificial intelligence (AI) tools to generate various visuals from the data we submitted.

6 BIBLIOGRAPHY

Acar, Y., Atadeniz, S. & Schipperijn, P. (2010). A decision support framework for global supply chain modelling: An assessment of the impact of demand, supply and lead-time uncertainties on performance. *International Journal of Production Research*, *48*, 3245-3268. https://doi.org/10.1080/00207540902791769

Adelman, S., Moss, L. & Barbusinski, L. (2002). I found several definitions of BI. *DM Review*.

Armour, F., Espinosa, J. A., Money, W. & Kaisler, S. (2013). Big data: Issues and challenges moving forward. *46th Hawaii International Conference on System Sciences*, 995-1004.

Badurdeen, F., Shuaib, M., Wijekoon, K., Brown, A., Faulkner, W., Amundson, J., Jawahir, I., Goldsby, T. J., Iyengar, D. & Boden, B. (2014). Quantitative modeling and analysis of supply chain risks using Bayesian theory. *Journal of Manufacturing Technology Management*.

Bakusevych, T. (2018). 10 rules for better dashboard design. *UX Planet, Published Jul*, *17*.

Banerjee, M. & Mishra, M. (2015). Retail supply chain management practices in India: A businessintelligence perspective. *Journal of Retailing and Consumer Services*.

Baskerville, R. L., Kaul, M. & Storey, V. C. (2015). Genres of inquiry in design-science research. *Mis Quarterly*, *39*(3), 541-564.

Basu, P. & Nair, S. k. (2012). Supply Chain Finance enabled early pay: Unlocking trapped value in B2B logistics. *International Journal of Logistics Systems and Management*. https://doi.org/10.1504/IJLSM.2012.047605

Berson, A., Smith, S. & Thearling, K. (2002). *Building Data Mining Applications for CRM*. McGraw-Hill Education.

Biswas, P. & Sarker, B. R. (2008). Optimal batch quantity models for a lean production system with in-cycle rework and scrap. *International Journal of Production Research*. https://doi.org/10.1080/00207540802230330

Bramer, M. (2009). Artificial Intelligence: An International Perspective. *Lecture Notes in Computer Science*, Vol. 5640. https://doi.org/10.1007/978-3-642-03226-4

Brito, T. B. & Botter, R. C. (2012). Feasibility analysis of a Global Logistics Hub in Panama. *International Journal of Logistics Systems and Management*. https://doi.org/10.1504/IJLSM.2012.047601

Browning, T. R. & Heath, R. D. (2009). Reconceptualizing the effects of lean on production costs with evidence from the F-22 program. *Journal of Operations Management*, 23-44.

Camuffo, A. & Grandinetti, R. (2011). Italian industrial districts as cognitive systems: Are they still reproducible? *Entrepreneurship & Regional Development*. https://doi.org/10.1080/08985626.2011.577815

Cavaleri, S. A. (2008). Are learning organizations pragmatic? *The Learning Organization*, 474-485.

Chan, F. T. & Kumar, N. (2007). Global supplier development considering risk factors using fuzzy extended AHP-based approach. *Omega*, *35*(4), 417-431.

Chan, F. T. S., Kumar, V. & Tiwari, M. K. (2008). The relevance of outsourcing and leagile strategies in performance optimization of an integrated process planning and scheduling model. *International Journal of Production Research*. https://doi.org/10.1080/00207540600818195

Chan, H. K. & Wang, X. (2013). An integrated fuzzy approach for aggregative supplier risk assessment. In *Fuzzy Hierarchical Model for Risk Assessment*, 45-69.

Chen, I. J. & Paulraj, A. (2004). Towards a theory of supply chain management: The constructs and measurements. *Journal of Operations Management*, 119-150.

Chen, Y.-J. (2011). Structured methodology for supplier selection and evaluation in a supply chain. *Information Sciences*, *181*(9), 1651-1670.

Cheraghi, S. H., Dadashzadeh, M. & Subramanian, M. (2004). Critical success factors for supplier selection: An update. *Journal of Applied Business Research (JABR)*, *20*(2).

Chopra, S. & Sodhi, M. (2004). Supply-chain breakdown. *MIT Sloan Management Review*, *46*(1), 53-61.

Dashboard Design Rule No.3: Develop Along Reading Gravity. (2022, 06). *REPORTINGIMPULSE – BLOG*. https://reporting-blog.com/tag/reading-gravity/

Daultani, Y., Kumar, S., Vaidya, O. S. & Tiwari, M. K. (2015). *A supply chain network equilibrium model for operational and opportunism risk mitigation. International Journal of Production Research, 53(18), 5685-5715.* https://doi.org/10.1080/00207543.2015.1056325

Deshpande, S., Jakhar, S., Rathod, U. & Hudnurkar, M. (2017). Supply Chain Risk Classification Schemes: A Literature Review. *Operations and Supply Chain Management: An International Journal*, *10*, 182-199. https://doi.org/10.31387/oscm0290190

Dolgui, A., Ivanov, D. & Rozhkov, M. (2020). Does the ripple efect infuence the bullwhip efect? An integrated analysis of structural and operational dynamics in the supply chain. *International Journal of Production Research*, 1285-1301.

Dolgui, A., Ivanov, D. & Sokolov, B. (2020). Reconfgurable supply chain: The X-network. *International Journal of Production Research*, 4138-4163.

Drejer, A. & Riis, J. O. (2000). New dimensions of competence development in industrial enterprises. *International Journal of Manufacturing Technology and Management*. https://doi.org/10.1504/IJMTM.2000.001370

Fan, Y.-W. & Stevenson, M. (2018). A review of supply chain risk management: Definition, theory, and research agenda. *International Journal of Physical Distribution and Logistics Management*, 205-230.

Govindan, K., Rajendran, S., Sarkis, J. & Murugesan, P. (2015). Multi criteria decision making approaches for green supplier evaluation and selection: A literature review. *Journal of Cleaner Production*, *98*, 66-83.

Gregor, S. & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. *MIS Quarterly*, 337-355.

Grewal, D. S. (2008). *Network Power – The Social Dynamics of Globalization*. New Haven: Yale University Press. https://doi.org/10.12987/9780300145120

Guertler, B. & Spinler, S. (2015). Supply risk interrelationships and the derivation of key supply risk indicators. *Technological Forecasting and Social Change*, *92*, 224-236.

Hansen, J. (2020). *Beyond "Modern" Data Architecture*. https://www.snowflake.com/blog/beyond-modern-data-architecture/

Heidarzade, A., Mahdavi, I. & Mahdavi-Amiri, N. (2016). Supplier selection using a clustering method based on a new distance for interval type-2 fuzzy sets: A case study. *Applied Soft Computing*, *38*, 213-231.

Helbing, D., Ammoser, H. & Kühnert, C. (2006). Disasters as Extreme Events and the Importance of Network Interactions for Disaster Response Management. In S. Albeverio, V. Jentsch & H. Kantz (Eds.), *Extreme Events in Nature and Society*, 319-348. Springer Berlin Heidelberg. https://doi.org/10.1007/3-540-28611-X_15

Hevner, A. R., March, S. T., Park, J. & Ram, S. (2004). Design science in information systems research. *MIS Quarterly*, 75-105.

Hočevar, B. & Jaklic, J. (2010). Assessing Benefits of Business Intelligence Systems A Case Study. *Management : Journal of Contemporary Management Issues*, *15*, 87-119.

Hu, G., Wang, L. & Bidanda, B. (2088). A multi-objective model for project portfolio selection to implement lean and Six Sigma concepts. *International Journal of Production Research*. https://doi.org/10.1080/00207540802230363

Hubbard, D. W. (2014). *How to measure anything: Finding the value of intangibles in business*. John Wiley & Sons.

Inmon, W. H. (2002). Building the Data Warehouse, John Wiley & Sons. *Inc.*, *ISBN:978-0-471-08130-2*

Irsyadillah, N. Y. & Dadadng, S. (2020). A Literature Review of Supply Chain Risk Management In Automotive Industry. *Journal Of Modern Manufacturing Systems And Technology*.

Ishida, S. (2020). Perspectives on Supply Chain Management in a Pandemic and the Post-COVID-19 Era. *IEEE Engineering Management Review*.

Ishizaka, A. & Nemery, P. (2013). *Multi-criteria decision analysis: Methods and software*. John Wiley & Sons.

Işık, Ö., Jones, M. C. & Sidorova, A. (2013). Business intelligence success: The roles of BI capabilities and decision environments. *Information & Management*, *50*(1), 13-23. https://doi.org/10.1016/j.im.2012.12.001

Ivanov, D. (2021). *Exiting the COVID-19 pandemic: After-shock risks and avoidance of disruption tails in supply chains*.

Jain, V. & Benyoucef, L. (2008). What's the buzz about moving from 'lean' to 'agile' integrated supply chains? A fuzzy intelligent agent-based approach. *International Journal of Production Research*. https://doi.org/10.1080/00207540802230462

Jaklič, J. (2008). Assessing Benefits of Business Intelligence Systems – A Case Study. *Management: Journal of Contemporary Management Issues (Mbuble@efst.Hr), 15*(1).

Janes, A., Sillitti, A. & Succi, G. (2013). Effective dashboard design. *Cutter IT Journal*, *26*(1), 17-24.

Jiang, W. (2019). An Intelligent Supply Chain Information Collaboration Model Based on Internet of Things and Big Data. *IEEE Access*, *7*, 58324-58335. https://doi.org/10.1109/ACCESS.2019.2913192

Kannan, V. R. & Tan, K. C. (2002). Supplier selection and assessment: Their impact on business performance. *Journal of Supply Chain Management*, *38*(3), 11-21.

Kar, A. K. & Pani, A. K. (2014). How can a group of procurement experts select suppliers? An approach for group decision support. *Journal of Enterprise Information Management*, *27*(4), 337-357. https://doi.org/10.1108/JEIM-10-2012-0076

Kara, M. E. & Fırat, S. Ü. O. (2018). Supplier risk assessment based on best-worst method and K-means clustering: A case study. *Sustainability*, *10*(4), 1066.

Kester, Q.-A. (2013). Application of Formal Concept Analysis to Visualization of the Evaluation of Risks Matrix in Software Engineering Projects. *International Journal of Science, Engineering and Technology Research (IJSETR), 2*, 220-225.

Kimball, R. & Ross, M. (2011). *The data warehouse toolkit: The complete guide to dimensional modeling*. John Wiley & Sons.

Kleindorfer, P. R. & Saad, G. H. (2005). Managing disruption risks in supply chains. *Production and Operations Management*, *14*(1), 53-68.

Köksalan, M. M., Wallenius, J. & Zionts, S. (2011). *Multiple criteria decision making: From early history to the 21st century*. World Scientific.

Kull, T. J. & Talluri, S. (2008). A supply risk reduction model using integrated multicriteria decision making. *IEEE Transactions on Engineering Management*, *55*(3), 409-419.

Kumar, S. K., Tiwari, M. K. & Babiceanu, R. F. (2010). Minimisation of supply chain cost with embedded risk using computational intelligence approaches. *International Journal of Production Research*, *48*(13), 3717-3739. https://doi.org/10.1080/00207540902893425

Lee, A. H. (2009). A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. *Expert Systems with Applications*, *36*(2), 2879-2893.

Lee, H. L., Padmanabhan, V. & Whang, S. (1997). The bullwhip effect in supply chains. *Sloan Management Review*, *38*, 93-102.

Liu, L. (2010). Supply Chain Integration through Business Intelligence. *2010 International Conference on Management and Service Science*, 1-4. https://doi.org/10.1109/ICMSS.2010.5576813

Luthra, S., Govindan, K., Kannan, D., Mangla, S. K. & Garg, C. P. (2017). An integrated framework for sustainable supplier selection and evaluation in supply chains. *Journal of Cleaner Production*, *140*, 1686-1698.

More, D. & Babu, A. S. (2012). Benchmarking Supply Chain Flexibility using Data Envelopment Analysis. *International Journal of Logistics Systems and Management*. https://doi.org/10.1504/IJLSM.2012.047603

Nekooie, M. A., Sheikhalishahi, M. & Hosnavi, R. (2015). Supplier selection considering strategic and operational risks: A combined qualitative and quantitative approach. *Production Engineering*, *9*(5), 665-673.

Norrman, A. & Lindroth, R. (2004). *Categorization of supply chain risk and risk management. In: Supply chain risk*. Ashgate.

Ozgur, C. (2020). *The Effect of Supply Chain Disruptions on Business*.

Paul, S. K. (2015). Supplier selection for managing supply risks in supply chain: A fuzzy approach. *The International Journal of Advanced Manufacturing Technology*, *79*(1), 657-664.

Peffers, K., Tuunanen, T., Rothenberger, M. A. & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, *24*(3), 45-77.

Pettersson, A. I. & Segerstedt, A. (2012). Measurements of excellence in a supply chain. *International Journal of Logistics Systems and Management*. https://doi.org/10.1504/IJLSM.2012.048671

Pradhananga, R., Hanaoka, S. & Sattayaprasert, W. (2011). Optimisation model for hazardous material transport routing in Thailand. *International Journal of Logistics Systems and Management*. https://doi.org/10.1504/IJLSM.2011.040058

Punniyamoorthy, M., Mathiyalagan, P. & Parthiban, P. (2011). A strategic model using structural equation modeling and fuzzy logic in supplier selection. *Expert Systems with Applications*, *38*(1), 458-474.

Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega*, *53*, 49-57.

Rezaei, J. (2016). Best-worst multi-criteria decision-making method: Some properties and a linear model. *Omega*, *64*, 126-130.

Ritchie, R. & Brindley, C. (2007). Supply chain risk management and performance: A Guiding framework for future development. *International Journal of Operations & Production Management*.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83-98.

Schoenherr, T., Tummala, V. R. & Harrison, T. P. (2008). Assessing supply chain risks with the analytic hierarchy process: Providing decision support for the offshoring decision by a US manufacturing company. *Journal of Purchasing and Supply Management*, *14*(2), 100-111.

Shanks, G., Sharma, R., Seddon, P. & Reynolds, P. (2010). The impact of strategy and maturity on business analytics and firm performance: A review and research agenda. *ACIS 2010 Proceedings – 21st Australasian Conference on Information Systems*.

Sheffi, Y. (2005). Weathering the storm. *CPO Agenda*.

Sodhi, M. M., Tang, C. S. & Willenson, E. (2021). Research opportunities in preparing supply chains of essential goods for future pandemics. *International Journal of Production Research*. https://doi.org/10. 1080/00207543.2021.1884310

Sodhi, M. S. & Tang, C. S. (2012). *Managing supply chain risk*, 172. Springer Science & Business Media.

Souza, G. C. (2014). Supply Chain Analytics. *Business Horizons*, 595-605.

Stefanovic, N., Majstorovic, V. D. & Stefanovic, D. (2006). *Supply Chain Business Intelligence Model*.

Szekely, B. (2011). The process of liberalising the rail freight transport markets in the EU: The case of Hungary. *International Journal of Logistics Systems and Management*. https://doi.org/10.1504/IJLSM.2011.040061

Thanaraksakul, W. & Phruksaphanrat, B. (2009). *Supplier evaluation framework based on balanced scorecard with integrated corporate social responsibility perspective*. *2*, 18-20.

Thun, J.-H. & Hoenig, D. (2011). An empirical analysis of supply chain risk management in the German automotive industry. *International Journal of Production Economics*, *131*(1), 242-249.

Triantaphyllou, E. (2000). Multi-criteria decision making methods. In *Multi-criteria decision making methods: A comparative study*, 5-21.

Trkman, P., McCormack, K., Oliveira, M. P. V. de & Ladeira, M. B. (2010). The impact of business analytics on supply chain performance. *Decision Support Systems*, *49*(3), 318-327. https://doi.org/10.1016/j.dss.2010.03.007

Wagner, S. M. & Bode, C. (2006). An empirical investigation into supply chain vulnerability. *Journal of Purchasing and Supply Management*, *12*(6), 301-312.

Wagner, S. M. & Johnson, J. L. (2004). Configuring and managing strategic supplier portfolios. *Industrial Marketing Management*, *33*(8), 717-730.

Wang, G., Gunasekaran, A., Ngai, E. W. & Papadopoulos, T.. (2016). Big data analytics in logistics and supply chain management: Certain investigations for research and applications. *International Journal of Production Economics*, 98-110.

Ward, S. C. (1999). Assessing and managing important risks. *International Journal of Project Management*, *17*(6), 331-336.

Ware, C. (2019). *Information visualization: Perception for design*. Morgan Kaufmann.

Wildling, R., Dohrmann, K. & Wheatley, M. (2021). *Post-Coronavirus Supply Chain Recovery*.

Wu, D. & Olson, D. L. (2008). Supply chain risk, simulation, and vendor selection. *International Journal of Production Economics*, *114*(2), 646-655.

Wu, I.-L. & Chang, C.-H. (2012). Using the balanced scorecard in assessing the performance of e-SCM diffusion: A multi-stage perspective. *Decision Support Systems*, *52*(2), 474-485. https://doi.org/10.1016/j.dss.2011.10.008

Yang, J., Xie, H., Yu, G. & Liu, M. (2020). Antecedents and consequences of supply chain risk management capabilities: An investigation in the post-coronavirus crisis. *International Journal of Production Research*. https://www.tandfonline.com/doi/full/10.1080/00207543.2020.1856958

Yusuf, Y. Y., Gunasekaran, A., Musa, A., Dauda, M., El-Berishy, N. M. & Cang, S. (2014). A relational study of supply chain agility, competitiveness and business performance in the oil and gas industry. *Building Supply Chain System Capabilities in the Age of Global Complexity: Emerging Theories and Practices*, *147*, 531-543. https://doi.org/10.1016/j.ijpe.2012.10.009

ANNEXES

Conducted Experts Interview:

<u>Interviewee: Expert 1, Date: 17-10-2022</u>

Q1: Do you consider the proposed framework as useful and why? If not, why do you believe it is not?

Clearly and concisely defines steps through a business intelligence model for a holistic approach to the different problems that arise in supply chains.

Q2: Do you have any criticism towards the proposed framework? Please explain.

No.

Q3: Would you consider to implement the proposed framework? Please clarify why/ why not?

Yes. As already mentioned above in a generalist way, the model has a wide range of applicability not only applied to the supply chain but even to other areas of business.
Based on the analysis and measurement of the data from the constructed dashboard, it is possible to have a much clearer and more real view of the solution vs problem ratio and the evolution of the applied solution as a function of the data over a period.

Q4: Do you have any recommendation or suggestions for further improvements of the proposed framework?

No.

<u>Interviewee: Expert 2, Date: 15-11-2022</u>

Q1: Do you consider the proposed framework as useful and why? If not, why do you believe it is not?

Yes, I do. I think this is a framework, which, depending on its operationalisation, has a generic structure that seems quite solid to me. It identifies the scope, the next person to use it will identify the objectives in the risk identification, depending on the objective they have, so they will end up going more in one direction or another in the risk identification, with the possibility of working with different types of risk. One thing is supply risks, but we can work with different types of risk. Then we have a second big phase, called Design & Development, which means, this phase, I understood as all the construction, not of the tool, because the tool is already given by itself (this global framework), but it needs to be fed with, what are the risks, what are the weights of each risk for the specific case. I find it curious to put here the relation between the risks, because there can be some kind of relation and then see the impact and the probability, I find it very interesting. But this only allows you to identify what it is, then it goes to the development of the BI model. What the framework can bring to a company or industry, I think, is extremely useful and necessary. What I see that some weaknesses may arise, is the operationalization of the framework, but the framework itself seems quite useful.

Q2: Do you have any criticism towards the proposed framework? Please explain.

It's not a criticism, it's just the question of the phase from the end of phase B to the beginning of phase C, which is the question of having the probabilities and then collecting the data. I think there has to be some data collection to identify the probabilities, either through focus groups or through questionnaires that give us some information. Another criticism is related to operationalisation. Although it does not seem that the framework is very complex, it has a set of steps that can translate into some complexity. I think it is structured enough to be clear in the application, but the fact that it is structured and appears with several steps may scare some of the users. But whoever is going to apply it, look at it and allow themselves some time for reflection, to be able to understand the different steps. With a good explanation in the document, I think that those doubts and limitations may be overcome.

Q3: Would you consider to implement the proposed framework? Please clarify why/ why not?

As I am not in a position to have a company, but from a university point of view, where do I see here my suppliers, all the partners who can send us knowledge, all the secondary schools who can send us first year students and all the national and international universities who will send us students.The school will not implement this framework because of the resources (people, time and money) needed for implementation. Which is not to say that framework is not relevant. Increasingly, educational institutions are being asked to do risk assessment and identify contingency plans. From a business school's point of view, it does not make much sense to apply this specific framework, but to adapt it for other types of risks and different types of industries if resources are available. Ending with a dashboard means that the framework is dynamic and can be adapted and updated over time. I won't implement it but I should.

Q4: Do you have any recommendation or suggestions for further improvements of the proposed framework?

If the framework is accompanied by an instruction manual (what to do at each stage), my concerns of now may fade away afterwards. My suggestion is that the framework should be accompanied with a document explaining in detail how to proceed at each stage. It also makes sense to try to see how to calculate probabilities and add a new step in the framework between the end of phase B and the beginning of phase C that helps us calculate probabilities based on e.g. a questionnaire. Remember that those who will use your framework do not have even 10% of your knowledge about the tool.