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Tools for ranking and quantifying supply chain risks

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INTRODUCTION

San Jose, California, 2011, the American multinational technology conglomerate Cisco Systems, Inc., backing from the thriving era due to the technological wave of the 1990s, was unable to perceive the slowing demand of their products they were getting into. Because of bad decisions on their supply chain management, when the market downturned significantly its inventory totalled $2,2 billion[1]. This event, reminded as "Cisco bubble" by the business press caused the halving of the stock price that really stayed close that price level ever since.

Chicago, Illinois, 2003, The Boeing Company, the most estimate designer, manufacturer, and seller airplanes, rotorcraft, rockets, satellites, telecommunications equipment, and missiles worldwide, with the aim to reduce the costs for the realisation of the new Boeing 737 Dreamline outsourced the design and the manufacture of many essential components to a new low cost aircraft that, only few months later, it turned out it had created defective components. In addition, Boeing erroneously estimated the forecast of expenses, which exceeded the established budget by approximately $2 billion[2]. Announcements of supply chain problems, on average, decrease shareholder value by 10.28%[3].

An even more significative case dates back to March 17, 2000 when a lightning hit a power line in Albuquerque, New Mexico causing a fire in the the Royal Philips Electronics manufacturing plants, damaging millions of microchips and determining the production interruption for more than six months. Two opposite responses came back from its major customers Nokia Corporation and Telefonaktiebolaget LM Ericsson. The first, immediately started to switch its chip orders towards others Philips manufacturing plants and others suppliers and thanks its responsiveness and

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1 Lee, H. L. (2004). The triple-a supply chain. *Harvard Business Review, 83* (October), 102–112.

2 Lunsford, J. L. (2007). Jet blues: Boeing scrambles to repair problems with new plane: Layers of outsourcing slow 787 production; "Hostage to Suppliers." *Wall Street Journal*, December 7.

3 Hendricks, K., & Singhal, V. (2003). The effect of supply chain glitches on shareholder wealth. *Journal of Operations Management, 21*(5), 501– 522.

multi-suppliers strategy has only partially been affected by this crisis. Oppositely, Ericsson had developed a single-supplier strategy with Philips that did not change even after the fire. The lack of alternative sources of procurement caused to Ericsson a supply chain disruption that lasted months, implying loss in sales by $400 million[4].

Those described above are only some of the most known cases of supply chain disruptions suffered by multinational firms, each organisation should not take into consideration the possible risks affected its supply chain in case of particular events (like launching of new products, changes in organisational structure, etc), rather it should analyse and evaluate the possible risks that may occur as a continuative process. The discipline whose aim consists in increase the resilience of the supply chain identifying the potential sources of risks and suggesting the suitable measures to mitigate them is defined *supply chain risk management.*[5]

Today, the application of SCRM creates an increasing interest on the firm because of events such as the globalisation, that has lead several organisations to expose themselves to international markets, technological transformation and new policies. Those factors surely promote and simplify the way of doing business but, at the same time, they expose the firms to an increasing vulnerability degree of their supply chain.

The complexity of the environment in which they operate is amplified because of the involvement of all the firms to the supply network on the processes and on the activities that produce value in terms of products and services to the end-consumer. None firm is in this sense isolated, it belongs to a broader network of other interconnected enterprises; so the firms have to coordinate their activities with the others organisations belonging to the same supply chain in order to reach their objectives.

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[4] R. Eglin, "Can Suppliers Bring Down Your Firm?" Sunday Times (London), Nov. 23, 2003, appointments sec., p. 6.

[5] from this point also defined SCRM

Evaluating risks affected the supply chain of a firm requires the maximum degree of objectivity and impartiality in order to not disturb the judgement. It has been proved that the judgements provided by each person in performing such type of analysis, even if involuntary, is influenced by a great level of subjectivity.
The main purpose of the research is to demonstrate the existence of tools to measure and rank risks affected the supply chain permitting the agents involved to develop a risks analysis with objectivity and impartiality.

The dissertation is composed by three chapter.
The first section illustrates the theoretical background of the Supply chain Risk Management discipline. As the notion takes milestones from the two topics on which it is based, the chapter depicts in first instance all relevant elements of risk management and supply chain management. The chapter starts analysing the fundamentals of risk management with its relative features and application fields to move then into the regulation through the ISO 31000. The second part illustrates the topic of supply chain management defining its basic pattern, the conceptual framework of the context and a new paradigm to manage the supply chain defined *strategic supply chain management*. The chapter ends taking the point of risk management and supply chain management defining the main topic of the thesis: supply chain risk management. After an introduction about the historical background and the main features of the topic, would be reported the main supply chain risk classifications and the remedies to carry out.
The second chapter establishes the theoretical basis of those mathematical tools that permit to analyse the risks mitigating the subjectivity of the decision maker. Before to describe the tool in details, the chapter contains an introduction about the theory above this tool. It continues towards the explanation of the Analytic Hierarchy Process technique defining its principles, axioms and characteristics, ending with the mathematical derivation to follow in order to rank preferences alternatives according to the preferences collected.

Chapter 3 is the most practical one. It reports a real case of supply chain risks management analysis applying on a real firm: Rossimoda Spa.
Once introduced the firm to the reader, depicting its historical background, its organization and process, and pointing out the structure of its supply chain, the thesis ends with the explanation of how the analysis has been conducted as methodology and numerical illustration, presenting its relative strong points and limits.

The elaboration of the first and second chapter has required the uses of secondary sources, in particular scientific papers, academic books and web-sites. The second has implied the uses of primary sources collected during my internship and post-internship period at the firm thanks to the daily activities and the meeting with managers in the involved areas.

CHAPTER 1. FROM THE MERGER OF TWO BROAD DISCIPLINES: THE SUPPLY CHAIN RISK MANAGEMENT

1.1 Fundamentals of Risk Management

According to the *Oxford English Dictionary* risk is "a chance or possibility of danger, loss, injury or other adverse consequences", connoting risk as a factor that may have only negative consequences over an entities.

In the recent years, because of the sequence of some events that disrupt the world economy, many more International Organisations start to focus on the discipline of risk, providing real guidelines about risk and how to manage it, in order to support companies during risk management[6] practices.

In business field, one of the most used definition of risk has been provided by the ISO Guide 73:2009[7], defining it as the "effect of uncertainty on objectives". Starting from the ISO's definition, the IRM[8] provides a more practical explanation of the topic, adding to the definition above the risk terms of measurement, representing it as the combination of the probability of an event and its consequence.

Differently from what the standard definition of risk asserts, the notions offered by those International Organisation depict the term risk as something whose consequences can range from negative to positive effects. According to its neutrality in terms of meaning the concept simply relates to an opportunity or a loss or simply the presence of uncertainty for an organisation.

One of the first more important aspect to consider approaching risks of each nature consists in understand the uncontrolled level of all risks that has been identified over

[6] from now also defined RM

[7] Guide elaborated by the International Standards Organisation that provides the definitions of generic terms related to risk management

[8] Institute of Risk Management

time. The uncontrolled level of risk is defined *inherent level* (or absolute/gross risk) and represents the degree of the risk before any actions have been taken to alter its likelihood or magnitude. As we will se in the further section the identification and measurement of the inherent level of each risk is the starting point of the whole RM process. For an organization, the same importance of the inherent levels is associated to the residual or net level, so measured after the control or controls have been put in place.

In order to evaluate to a gross or net risk identified, researchers and practitioner suggest the use of an heat-map organised in a matrix that permits to collocate the risks in terms of its consequence and likelihood of occurrence. An example is proposed in the **Figure 1** below.

Almost certain	Moderate	Major	Critical	Critical	Critical
Likely	Moderate	Major	Major	Critical	Critical
Possible	Moderate	Moderate	Major	Major	Critical
Unlikely	Minor	Moderate	Moderate	Major	Critical
Rare	Minor	Minor	Moderate	Moderate	Major
	Insignificant	Minor	Moderate	Major	Critical

Figure 1 Heat-map for prioritising risks according to their likelihood and consequence

The horizontal axis represents the magnitude while the vertical is used to represent likelihood of occurrence. The term "magnitude" indicates the severity the event/risk would have over the company, technically it represents the inherent level indeed can be used to illustrate compliance, hazard, control and opportunity risks. The expression "Likelihood of occurrence" indicates the frequency, and at the opposite side, the chances of an unlikely event happening. Once the risks have been individuated, in order to define their likelihood and magnitude could be useful classifying them.

Identifying all risks an organisation has to face with may look like easy, in reality is one of the activity that many organisations fail in doing it. Researchers suggest to start sorting risks according to some classification proposed, according to the timescale of their impact, to the nature and the effect of the impact.

In terms of timescale, risks are divided into long-, medium- and short-term impact. The long-term risks will impact over the companies for several years, up to 5 after the occurrence of the event or the decision has been taken; the mid-term regards all risks whom events will impact after about one year after its occurrence or after the decision has been taken; the short-term risks have impact immediately after the event occurs.

Another sorting establishes the classification of risks into four categories: hazard, control, opportunity and compliance.

Hazard risks, also defined *pure*, are insurable-type or perils indeed they are risks that can only inhibit achievement of the corporate mission. They can lead unplanned disruptions for the organization derived by several categories, such as, people, premises, processes and products. Hazard risks related to people may consist of lack of skilled people, premises may concern to damages of physical assets, regarding processes the inadequate information flow or the failure of IT software/hardware while risks associated to products could be caused by disruption caused by failure of supplier or by the failure of outsourced services.

Hazard risks are considered the most difficult to manage since usually their manifestation is unforeseen. The *Orange Book*[9] reports the hierarchy of hazard controls to apply in reference of the situations. In case of the presence of high probability of occurrence with high relative impact, *preventive controls* have to be established to limit or stop the undesirable outcome; researchers suggest to implement an appropriate plan of preventive controls to prevent those risks. *Corrective controls* have to be implemented in case of low impact but high likelihood to limit the scope for loss and correct any undesirable outcomes that have

[9] guidance developed by the HM Treasury

been realised. *Directive controls* consist in giving directions to people on how to ensure that losses do not occur and they have to be executed when an hazard risk with low likelihood but high impact arises. In case of an hazard risk with low likelihood and low impact the organization should implement *detective controls* designed to identify occasions when undesirable outcomes have been realized.

Control risks are those that cause doubt about the ability to achieve the organization's mission and, indeed, they are usually associated with project management. They strongly depend on the successful management of people and effective implementation of control protocols. The management board should offer the necessary resources available to identify and implement the controls order to respond to the consequences of any control risk; the controls and their nature vary in terms of the degree of uncertainty and the nature of the risk the organization will face with.

Opportunity risks are usually sought or embraced deliberately by the organization that arise because the organization is seeking to enhance the achievement of the mission. The opportunity risks should be deeply analysed in terms of opportunities the firm could take advantage but, at the same time, evaluating the amount of investment required to undertake it. This approach seeks to maximize the benefits of taking entrepreneurial risks following the desire to maximize the likelihood of a significative positive outcome from investments in business opportunities.

In addition, each organization has to take into account the several compliance requirements that distinguish the environment in which they operate. Furthermore, they vary according to their business sector and industry. To minimise compliance risks each organisation has to deeply analyse the applicable rules and regulations on which its environment is based on in order to align the activities in the respect of the standards imposed by laws, policies and morals.

1.1.1 Main features and application fields

The notion of risk management emerged around 1950s in US within the Insurance field. In these years even more organisations noticed that insurances had become prohibitive considering also that most of them were not able to offer a sufficient attention to the protection of properties and people. Along these lines, only after two decades emerged the concept of total cost of risk to indicate the existence of many risks the organisations face with, that were not correct by the insurance coverage. Passing the years the link between RM and the insurance fields fails down and, conversely, the discipline starts to expand entering in several areas. Indeed, during the 1960s and 1970s, the RM was adopted mainly by occupational health and safety practitioners while in the 80s on the new project development theory. In the recent years, thanks also to new technologies, this discipline has acquired even more notoriety and today is applied in almost every field: project risk management, clinical/medical risk management, energy risk management, financial risk management, IT risk management, etc.

As well for the definition of risk, due to the multi-disciplinarily of the RM application, providing a suitable universally accepted definition is very difficult. Once again, thanks to the importance it acquires during the years, the same International Organisations mentioned above, tried to give a definition to a so broad discipline. The ISO 31000, simply defines RM as "coordinated activities to direct and control an organization with regard to risk". According to the IRM "It is the process whereby organisations methodically address the risks attaching to their activities with the goal of achieving sustained benefit within each activity and across the portfolio of all activities". Generally speaking, the definitions of RM are numerous but all of them want to emphasize the fact that RM is a process that a firm should perform in order to avoid or minimize his exposure to any type of threat. For this reason it plays a central role in the strategic management of any organization and in particular in the corporate security[10].

The RM can be applied to each type of organization (public, private or community enterprise, association or group of individual), at its all areas and levels, at any time, as well as to specific functions, projects and activities. Since the risk drivers are different from one sector/industry to another, as each organization is different from the others in several aspects, the RM plan and framework has to take into account the varying needs both, of the industry and the organization itself. Over time every organization applies a sort of RM even if unconsciously but in the recent years an increasing number of organizations have been adopting a formal risk management process for particular types of risk or circumstances because of the great advantages this discipline leads to.

As anticipated above, the RM can be applied in almost every area of our work experience. The scientific and managerial literature has identified nine main paths of development in the overall field of RM: Strategic risk management (SRM), Financial risk management (FRM), Insurance risk management (IRM), Project risk management (PRM), Engineering risk management (EnRM), Disaster risk management (DRM), Clinical risk management (CRM), Enterprise risk management (ERM) and Supply chain risk management (ScRM).

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[10] approach aimed at the identification and effectively mitigation, at an early stage, any developments that may threaten the resilience and continued survival of a corporation

Strategic risk management – SRM

SRM is defined as "the implementation of an integrated and continuous process of identification and assessment of strategic risks that are considered to be obstacles to reaching the financial and operational goals of an organization."[11] [12] Strategic risk management is applied in particular in presence of opportunity risks, with speculative nature, that can provoke a loss (downside risk) or a profit (upside risk). Usually the top management of the firm has the responsibility over them, and they depend both on external and internal variables. Slywotzky and Drzik (2005) state that every organisation has a unique set of the strategic risks (industry, technology, brand, competitor, customer, project and stagnation) strictly related to the characteristics of the organization itself.

Financial risk management – FRM

The application of RM in finance concerns all those practices that, from one hand lead to create economic value by using financial techniques and and at the opposite it studies methodologies to manage exposure to risk. Financial risks are commonly driven by firm's choices regarding debt and investments, and more in general by the trend of financial markets and transactions with third parties. More in detail, financial risks are represented by *credit risk* caused by the creditor default risk and to the credit spread risk, by *market risk* characterised the loss of value of an investment due to changes in market factors as currency, inflation, interest rate, commodity and liquidity.

[11] Chatterjee, S., R.M. Wiseman, A. Fiegenbaum, and C.E. Devers. 2003. Integrating behav- ioural and economic concepts of risk into strategic management: The twain shall meet. Long Range Planning 36: 61–79.

[12] Miller, K.D. 1992. A framework for integrated risk management in international business. Journal of International Business Studies 23, no. 2: 311–31

Insurance risk management – IRM

As mentioned above, the IRM is the process to manage pure risks in a firm, in particular *property risks* related to losses due to destruction or theft of property, *liability* due to the possibility of being held liable for bodily injury, death or property damage to someone else, or, more in general, *personnel risks*, associated with the loss of or reduction in income, extra expenses or depletion of financial assets. IRM implies a partial transfer of part or all of its specific loss exposure to another party (the insurer) from one party (the insured) through a legally binding contract in change of a front-loaded cost.

Project risk management – PRM

In developing a new product, an organization has to face with several risks caused by three distinctive factors: external, internal and operational. External are strictly related to factors concerning the external environment as political and institutional norms, competitive pressure, etc. The internal factors are determined by changes in business objectives and insufficient definition of how the project is to be carried out. The main risks during a *NPD* relate to *technical or operational* aspects concerning technology, materials, equipments, *organizational* (linked to project teams and human factors), *contractual* in failure of the parties involved, *financial and economic* as inflation, financing risk, market-share volatility and *political* relating to environmental authorizations, land acquisition, permission from governing authorities.

Engineering risk management – EnRM

EnRM is the process engaged in planning and designing an engineering system with the intent to develop the ability to identify and select the appropriate responses to the eventual problems that may subsist related to different risk factors through the adoption of a systemic and proactive approach. The main two branches of EnRM regards the *Programme risk management* and *Environmental risk management.* The first is appropriate to manage technical risks associated with systems engineering in order to meet the performance, cost and schedule objectives, while the second is focused on managing the production, operation and disposal of systems to minimize adverse impacts and assure the sustainability of these systems.

Disaster risk management – DRM

The DRM is an approach aimed at reducing disaster risks in regions at risk and mitigating the spread of disasters, maintaining the processes, structures of RM. Disaster risks are considered systemic risks, in the sense they affect the systems on which society depends: health, transport, environment, telecommunications. With "disaster" we refer to technological (explosions, fires, transportation accidents, etc.) or related to health (infectious diseases). In order to be managed by DRM, with the existence of a disaster risks have to occur two more conditions: the vulnerability and the exposure.

Clinical risk management – CRM

With CRM we define all the guidelines, steps, protocols and clinical procedures adopted by an hospital in order to minimise the probability that an unforeseen event might potentially produce negative or unexpected effects on the health of patients. Clinical risks regard errors in the use of pharmaceuticals, surgical errors, errors in the use of equipment, diagnostic exams or procedures and timing errors.

Enterprise risk management – ERM

COSO[13] defines the ERM as follows:

"A process, effected by an entity's board of directors, management and other personnel, applied in a strategy setting and across the enterprise, designed to identify potential events that may affect the entity, and manage risk to be within its risk appetite, to provide reasonable assurance regarding the achievement of entity objectives."

ERM represents a real integrated process, essentially it is not based on a multitude of disaggregate activities in different fields. It implies the adoption of a structured methodology that takes into account all the aspects related to firm management to understand and assess the risks: strategies, market, processes, financial, recourses, human resources and technologies[14]. It is also defined as "holistic and enterprise" approach thanks to its aim to protect the value of the organization in the short and long terms, for all the stakeholders.

The Table 1 below proposed by Verbano and Venturini shows the main difference between the standard approach of RM and the Enterprise RM.

Traditional risk management	Enterprise risk management
• Fragmented • Reactive • Discontinuous and not frequent • Cost-based • Functional	• Integrated • Proactive • Continuous and frequent • Value-based • Carried out with a process logic

Table 1 Compared features of traditional and enterprise RM

[13] Committee of Sponsoring Organizations of the Treadway Commission. A group formed to help businesses develop their control systems

[14] C. Verbano, K. Venturini, *Development paths of risk management: Approaches, methods and fields of application*, Journal of Risk Research, 2011, pp. 527-528

Supply chain risk management – ScRM

The theory about the supply chain risk management and its relative process and procedures will be deeply analysed in the following section.

1.1.2 ISO 31000: Principles, Framework and Process

The ISO 31 000 outlines the fundamentals and principles on which RM is based on and the framework to develop and implement in order to create an integrate process to manage risks in the multitude of layers involved. In order to provide a complete explanation of how the RM process is articulated, is essential to define the relationship between the principles for managing risk and the framework in which it occurs as well as to understand the differences among the framework, that represents the static side, the pillars of RM, and the process that represents the consequential stages to follow in order to limit the effect of uncertainty. These three elements have to be in accordance between them to develop an efficient strategy of RM.

The Figure 2 in the following page shows the parts they are composed and their relationships.

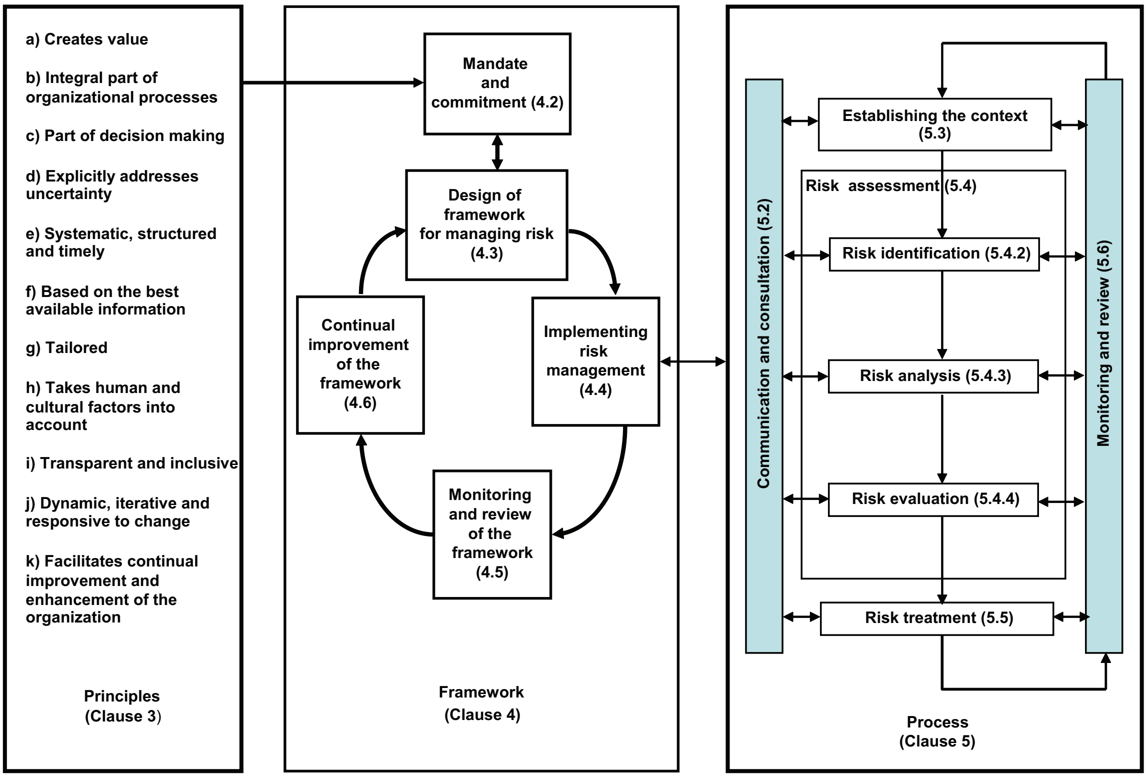

Figure 2 Relationships among Principles, Framework and Process of RM

The Risk Management contributes to demonstrate the value creation through the achievement of objectives and the improvement in the performance in different aspects: human health and safety, security, legal and regulatory compliance, public acceptance, environmental protection, product quality, project management, efficiency in operations, governance and reputation.

As said above, RM is not a stand-alone activity; It is part of the responsibility of the management and as consequence, an integral part of all the organisational processes.

Thanks to its objectivity, it represents an essential tool to manage the uncertainty in an impartial way, since it supports the management in taking decisions, prioritising actions to be taken and distinguishing among alternative courses of action in the attempt to limit the uncertainty. It permits also to compare the different outcomes achieved in order to improve the performance. The results obtained are totally impartial but they depend on the different sources of information the analysis is based on (e.g. historical data, expert judgment, experience, stakeholder feedback, observation, forecasts). Due to this restriction, the decision makers should inform the stakeholders and take into account any limitations in terms of data, modelling used or divergence among experts' opinions.

As mentioned above, since the process is influenced by the organisation's external and internal context and risk profile, the RM has to be aligned with them. Because of the many actors involved, Risk Management has the ability to recognize the different perceptions, capabilities and intentions of internal and external agents which may promote or hinder the objectives' fulfilment.

The framework permits that the information regarding the risk acquired thought the RM process are adequately reported and used as basis for decision making and accountability at all organizational levels.

The principles on which RM is characterised by, define the basis of the mandate and commitment, the initial focus of the framework.

The application of RM and its ongoing effectiveness require a strong commitment by management and at any level of the organization because all the actors involved has to be aware of their role inside the mechanism.

The design of RM framework represents the fundamentals of the discipline and it varies from an organization to another since the elements of which it is composed by are strictly related to the external environment and the internal aspects. Indeed, the external context, like social and cultural, political, legal, regulatory, technological, economic, natural and competitive environment, as the internal one (e.g. the governance, structure, accountability of the organization, his information flows and decision making process, his culture and values) strongly influence the configuration of the organization, and as consequence, its RM pillars and practices.

RM policy and the commitment of each level are other aspects to define. While the *policy* represents all the basic aspects to manage risk, like organization's rationale, how to deal with conflict interests, how to measure and and report the performance, the *accountability* defines who is in charge of any type of activity involved during the whole process, so the risk owners to manage risks, who is accountable for the development, implementation and maintenance of the framework and the responsibilities of people at all levels.

Once the context has been analysed and policy and commitment established, RM has to be embedded in all the organisation's practices and processes, so into the policy development, business and strategic planning review and change management processes.

After that has to be established which types of resources are necessary (human, economic, etc) and in which ratio they will be allocated in the process.

Finally, it is essential to set up the internal communication, in order to support and encourage accountability and ownership of risk, and the external communication, in order to communicate with the stakeholders. Both the practices require reporting procedures.

Defined the design, the framework and the process have to be implemented.

Implementing the framework means define his timing and strategy, applying RM policy and process to organizational processes, complying with legal and regulatory requirements, communicating and consulting with stakeholders to ensure that its RM framework remains appropriate. In the second instance, the implementation of the process provides his application through a risk management plan at all relevant levels and functions of the organization as part of its practices and processes.

In order to ensure that RM is effective and provides a support for organisational performance, the management has to monitor the outcomes, measuring RM performance against indicators, evaluating progresses and deviations from the plans, aligning policy wether not still in line with organisation's external and internal context and reviewing the effectiveness of RM framework.

Furthermore, according to what has been analysed, decisions should be made on how RM framework, policy and plan would be improved.

As mentioned above, the process consists of a series of consequential stages to follow in order to try to limit the damages a risk can impose to an organization.

During the whole process, it is essential to maintain a continuous communication and consultation with internal and external stakeholders to permit them to understand the basis on which a decision has been made and who are the actors accountable for the implementation of RM processes.

The first "real" stage involves the establishment of the context: the external, the internal and the RM processes itself.

Establishing the external context[15] permits to ensure that the objectives of the external stakeholders are considered in developing risk criteria. Furthermore, since anything within the organization influences the way in which it manages the risk, it should focus also on the internal context[16] in such a way that the RM process is aligned with the organization's culture, values and processes. In addition to the external and internal context, the management should establishing the context of the RM process[17] too, in order to evaluate and justify the resources needed performing this type of analysis.

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[15] e.g. defining legal and regulatory requirements, understanding the stakeholders' perceptions, individuating the specific risks that undermine the scope of the RM processes

[16] e.g. the governance, organizational structure, roles and accountabilities; policies, objectives, and the strategies adopted to achieve them; the information systems, information flows and decision making processes

[17] the objectives, strategies, scope and parameters of those activities where RM is being applied. They varies according to the needs of an organization.

Before to focus on the most practical side of the analysis, the organization has to define the risk criteria[18] according to its values, objectives and although, in the respect of his RM policy. The main factors to evaluate are strictly related to the likelihood, in particular how it will be defined, the consequence, in terms of nature and type of causes, and how determining the level of risk.

The second step is the real practical analysis. It is defined Risk Assessment and it includes three different stages: Risk Identification[19], Risk Analysis[20], Risk Evaluation[21].

The Risk Identification determines the sources of risk, the areas to which the risk could impact. The Risk identification implies to create a comprehensive list of all those risk that prevent, degrade or delay the achievement of the organization's objectives. It includes further analysis regarding the knock-on[22] and cascade[23] effects.

The management and decision makers have to be aware that, in case a risk is not identified during the Risk Identification, it would not be analysed in the next stages and could be cause of objectives failures.

The Risk Analysis is aimed at analyse the specific risk. It is focused on the considerations of his causes and sources, the positive or negative consequences that can lead to the organization and his likelihood of occurrence, tangible and intangible. The management can opt for a quantitative, qualitative or mixed analysis. The accuracy of the analysis depends on the level of the risk, the purpose of the

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[18] terms of reference against which the significance of a risk is evaluated

[19] process to identify, recognise and describe risks

[20] process to comprehend the nature of risk and to determine the level of risk

[21] process to compare the results of the risk analysis with risk criteria. The outcomes define wether the risk is tolerable or not

[22] when an event or situation has a knock-on effect, it causes other events or situations, but not directly

[23] an inevitable and sometimes unforeseen chain of events due to an act affecting a system

analysis and the information and data available, considering obviously the resources needed and accessible. According to De Oliveira, Silva Marins, Rocha, Salomon (2017), the most of the studies and researches related to Risk Management and Supply Chain Risk Management reduce the RM process on the stage of Risk Analysis. As mentioned above and according to me it is surely a central stage, so much that it is an input to Risk Evaluation and it provides suggestions to strategies and methods of Risk Treatment, but the whole process can not be shortened in this unique step.

Thanks to the outcomes obtained first from the Risk Identification and then from the Risk Analysis, the Risk Evaluation supports the decision maker in defining which of the risks analysed have the priority of being treated, by comparing the risk levels[24] against the risk criteria established. In accordance with the results, the management can decide to treat the risk, to proceed with further analysis or maintaining existing controls.

The Risk Treatment[25] involves the selection of one or more options to modify the risk by removing the risk source and/or changing the likelihood and/or the consequences. It is a cyclical process, since it has to be applied until the residual risk[26] is tolerable for the organization's risk attitude[27]. Anyway, management and stakeholders, should be aware of the nature and extent of the residual risk after the risk treatment and of the importance to continuously monitor and review it and in case acting with further treatments. The Risk Treatment is articulated into two consequential phases. The first phase is aimed at define the risk treatments options and the relative priorities balancing the resources and efforts needed against the benefits derived by its adoption, considering the legal, regulatory and other

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[24] magnitude of a risk or combination of risks, expressed in terms of the combination of consequences and their likelihood

[25] process to modify risk

[26] part of risk remaining after risk treatment

[27] approach to assess and eventually pursue, retain, take or turn away from risk

requirements. The comparison with the stakeholders is again important, in particular in case the risk treatment impacts on other areas of the organization. Once the risk treatment option has been established, the risk treatment plan has to be prepared or implemented. The more significative information usually relates to the selection of these particular risk treatment option comprehensive of the expected benefits, the proposed actions, the resources needed, the performance measures and the timing and schedule.

The continual Communication and Consultation with the stakeholders during the whole process, as well the simultaneous and regular Monitoring and Reviewing of the procedure is a precondition for an efficient application of the mechanism. Indeed, the Monitoring and Review has to be a planned part of RM process since it provides the controls over the efficiency and, at the same time, it permits to obtain additional information to implement risk assessment. Furthermore, through a periodic check, the management can analyse and learn lessons from events, evaluate change in the external or internal environment and identify emergent risks. Not only monitoring and reviewing, but the outcomes derived by the progress measurements should be, first of all, used as input for framework improvement, and, secondly, recorded and externally and internally reported.

1.2 Fundamentals of Supply Chain Management

As anticipated above, the discipline of supply chain risk management takes his basis from two broader subjects: Risk Management and Supply Chain Management. Since the concept of RM has been deeply analysed, the elaborate carries on with the second main notion: Supply Chain Management[28].

According to Chopra and Meindl, "A *supply chain* consists of all parties involved, directly or indirectly, in fulfilling a customer request", so it includes not only suppliers and customers of a given firm, but all the agents involved along the process of product/service creation, from the acquisition of raw materials until the delivery of the value to the end-consumers. In other terms, it is the sequence of events and processes that take the product from the original supplier or source to the ultimate customer.

The goal of the SCM consists of maximising the overall value generated. The *value* an efficient SCM generates, technically defined *supply chain surplus,* lies in the difference between the value delivered to the end-consumers[29] and the costs the supply chain incurs in filling the customer's request[30].

It should be clear now the reason why an increasing number of firm are continuously investing and improving their SCM. Indeed, an efficient supply chain management can create a competitive advantage over other competitors permitting them to become market leaders of their industry.

The term SCM dates back to the 1980s thanks to the interview of the consultant Keith Oliver for the Financial Times even if his meaning was conceptually different from how we consider it now. Until recently indeed, consultants and academics had

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[28] from now also defined SCM

[29] the maximum amount the customer is willing to pay for the product or service.

[30] the difference between the selling price and the value represents the classic *consumer surplus*, while, the difference between the revenue generated by the transaction and the overall cost across the supply chain is defined *supply chain profitability.*

considered SCM not appreciably different from the contemporary understanding of *logistic management.* The confusion derived because the logistic, as the SCM, deals with the management of materials and information flows across the supply chain, but, oppositely to the SCM, it is a functional discipline within companies.

More than ten years later, the Council of Logistic Management re-conceptualize the definition of SCM, formally distinguishing the two concepts, emphasising that logistic management is only a part of SCM[31].

Now that supply chain and logistic have been defined, the meaning of SCM should be easy to explain, in spite of the various definition. In my opinion, one of the most significative and complete definition is attributed to Mentzer, DeWitt, Deebler, Min, Nix, Smith, and Zacharia that define SCM as "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole"[32]. Less formally, the Supply chain management is the coordination of production, inventory, location, and transportation among the participants in a supply chain to achieve the best mix of responsiveness and efficiency for the market being served.

In the next sections we will analyse in more details its patterns, framework and the way to manage it.

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[31] According to the CLM (Council of Logistic Management), logistics is that part of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from the point-of-origin to the point-of-consumption in order to meet customers' requirements.

[32] Mentzer, John T.,William DeWitt, James S. Keebler, Soonhong Min, Nancy W. Nix, Carlo D. Smith, and Zach G. Zacharia, 2001, "Defining Supply Chain Management", Journal of Business Logistics, Vol. 22, No. 2, p. 18

1.2.1 The basic pattern of SCM

Even if each firm is different from the others in terms of its internal structure and external environment in which it operates, there is a basic pattern that characterises the supply chain of each company. The configuration of this pattern leads the enterprises to take decisions regarding their actions in five areas: production, inventory, location, transportation, information.

All the decisions taken regarding the five areas are characterised by the common trade off between *responsiveness and efficiency*.

Production

Production refers to SC capacity to manufacture and store goods. The decisions regarding the production is focused on the trade-off between responsiveness and efficiency. An excess of capacity in the factories and warehousing consists in a flexible and quick response in case of wide swings in the product demand but, on the other hand, capacity costs money. In other words, the more excess capacity that exists, the less efficient the operation becomes.

The production implies taking decisions within two main facilities: factories and warehousing. Companies organize their factories according with two approaches. The *product focus* implies that a specific productive unit will perform a range of different operations required to make a given product line (from the manufacturing of different product parts until the assembling of them to create the finished goods). Otherwise, the *functional focus* leads the productive unit to executive just a few operations. As with factories, warehouses too can be built to accommodate three different approaches: *SKU*[33] *storage*, *job lot storage*, *crossdocking*[34]. According to the SKU storage, all of a given type of product is stored together; the Job lot

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[33] Stock keeping unit. Distinct type of item for sale

[34] approach pioneered by Wal-Mart

storage differently stores products according to the needs of certain customer or to the needs of a particular job resulting more practice the picking and packing operation; through the crossdocking, the facility is used to house a process where trucks from suppliers unload large quantities of different products, then broken down into small lots recombined of different products according to the needs of the day and quickly loaded onto outbound trucks to be delivered to their final destination.

Inventory

Inventory includes everything from the raw materials, to work-in-process and semi-finished goods, to finished goods held by manufacturers, distributors, retailers in a supply chain. Again thus implies the compromise between efficiency and responsiveness. Holding large amount of inventory permits to be ready in case of demand fluctuations but conversely the creation and storage of inventory is costly.

There are three main approaches to manage the inventory. The first, named *Cycle Inventory*, suggests to define the inventory level required to meet the product demand over the time period between placing orders for the customers, permitting to take economic benefits deriving by the economies of scales, manufacturing large quantities in fewer orders rather than continues orders of small quantities. Otherwise, the *Seasonal Inventory* recommends to produce and stockpile products in anticipation of future demand getting the best economies of scale exploiting the capacity and the cost structure of all the others companies in the supply chain. The last approach is defined *Safety Inventory* since it is able to maintain an inventory level able to satisfy in any time retailers, distributors or end-customers. This approach, even if more costly in terms of procurement and management, permits to compensate the uncertainty that exists in the supply chain.

Location

Location refers to the geographical siting of SC facilities and as consequence to which activities will be performed in each of them. The responsiveness versus efficiency trade-off appears in decisions about centralization/decentralization. The centralisation of facilities in few and concentrated areas looks at the efficiency through the exploitation of the scale economies but, conversely, the decentralisation of the activities located close to customers and suppliers allows to be more reactive with them. The location decisions depends on other numerous factors that relate to a given location, like the cost of facilities, the cost of labor, skills available in the workforce, infrastructure conditions, taxes and tariffs, etc.

Transportation

Transportation denotes the physical movements of everything (from the raw materials to the finished goods) among the facilities. The responsiveness-efficiency trade-off relates to the decisions about the transport modes. The slower ones (like rail and ship) are cost-efficient but not responsive, on the contrary, the fast modes (such airplanes and pipelines) are usually very expensive but they permit to maintain an high level of responsiveness. The key of a performant transportation plan consists on designing the roots[35] and the networks[36] for moving products.

Information

Information is the basis upon which to make decisions regarding the four drivers described above. The information flow represents the connection between the activities and the operations within the supply chain.

In any supply chain the information flow has two main purposes:

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[35] the paths through which the products will move within the SC

[36] are composed of the collection of the paths and facilities connected by those paths

- *coordinating daily activities* in terms of production schedules, inventory levels, transportation routes and stocking locations thanks to available data on supply and demand
- *Forecasting and planning* according an approach of mid-long term, in order to try to anticipate and meet the future demand and scheduling the production according to those data.

Within the specific organization the trade-off between efficiency and responsiveness involves weighing the benefits that good information can provide against the cost of acquiring that information.

1.2.2 The conceptual framework: Network structure, Business processes and Management components

D. M. Lambert and M. C. Cooper have structured a conceptual framework able to emphasise the interrelated nature of SCM in order to support the firms to successfully manage they supply chain.

The framework is composed by three closely interrelated elements: the supply chain network structure, the supply chain business processes and the supply chain management components.

The details of each dimension of this framework will be described right now below.

The Supply Chain Network Structure

The supply chain network structure consists of the member firms involved in the process and the links between them. It depends on several variables, as the complexity of the product, the number of available suppliers and the availability of raw materials and intermediate process. Obviously, the more the network is complex, the more the management has to pay attention on managing its supply chain.

As shown in the **Figure 3** below, the supply chain looks like to an uprooted three, where the branches and roots are the extensive networks of customers and supplier. It means that each firm cannot participate in only one supply chain but actually it is totally incorporated into these of its customers and suppliers.

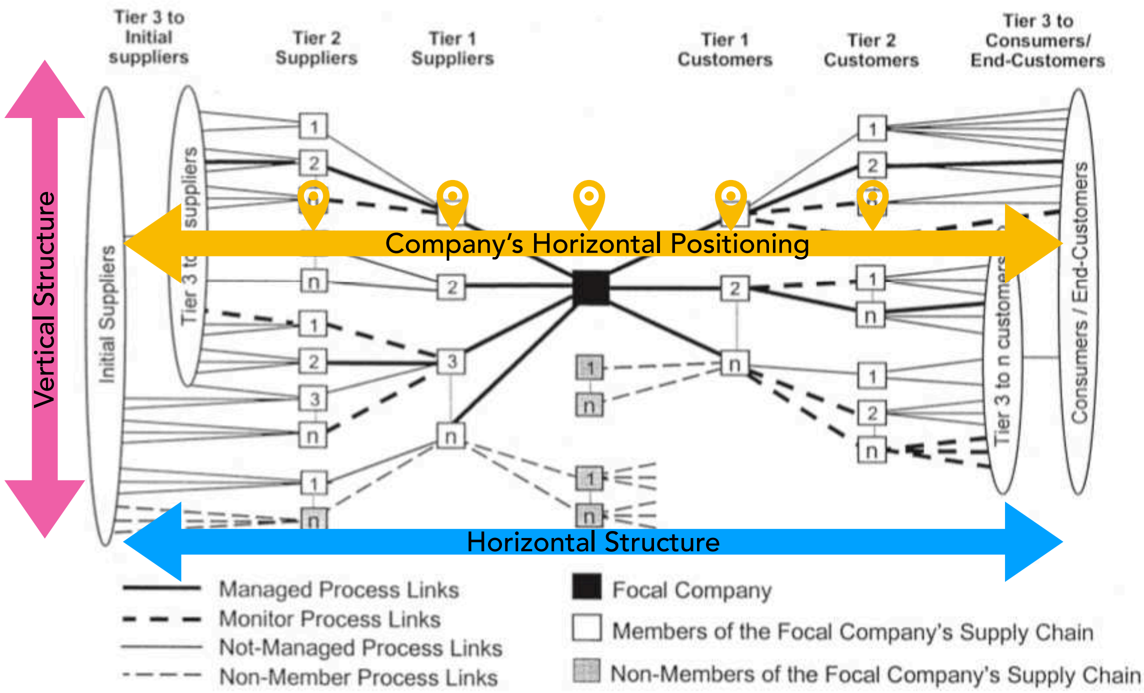

Figure 3 The supply chain network structure

The management defines the appropriate level of partnership for particular supply chain links identifying the one that best fits the specific set of circumstances according to the firm capabilities and the importance to the firm.

There are three primary aspects involved to the company's network structure: the member of the supply chain, the structural dimension of the network and the types of process links across the supply chain.

The authors define member of a supply chain "*each company or organization with whom the focal company interacts directly or indirectly through its suppliers or customers, from point of origin to point of consumption*"[37]. As illustrated above, the agents involved are in the most of the case many so, can be counterproductive (if not impossible) trying to manage all processes link with all members.

The key is indeed to sort out the basis to determine which of those agents are critical to the success of the company in order to allocate over them the right degree of managerial attention and resources. The common, and usually the more practical and efficient, sorting solution is distinguishing the primary from the supporting members. While the first are all those autonomous companies or SBU who carry out value-adding activities in the business processes designed to produce a specific output for a particular customer or market, the supporting members are companies that simply provide resources, knowledge, utilities, or assets for the primary members of the supply chain[38]. Distinguishing from primary and supporting activities allows us to identify the *point of origin* of the supply chain that occurs where no previous primary suppliers exist, rather only supporting members, and the *point of consumption*, where no further value is added, so where the product or service is delivered to the end customer to be consumed.

Another important aspect related to the company network structure concerns its supply chain structural dimension that can be analysed into three directions: the horizontal structure, the vertical one and the horizontal position of the focal company within the end points of the supply chain. Please, note **Figure 3** above.

[37] Lambert, D. M., & Cooper, M. C. (2000). Issues in Supply Chain Management. Industrial Marketing Management, 29(1), 65–83.

[38] similarity with Porter's Value Chain framework, where are distinguished from members performing primary activities to members performing secondary activities

The *horizontal structure* individuates the numbers of tiers across the supply chain, defining a long SC in case of several tiers or short with few ones. The *vertical structure* identifies how many customers or suppliers each tier is composed by, distinguishing from companies with narrow vertical structure, in which each tier is composed by few actors to companies with wide vertical structure, characterised by many actors for each tier. The last structural dimension is focused on identifying the position of the focal company across its supply chain, so close to the initial source of supply, or near to the end customers or somewhere between the point of origin and the point of consumption.

According to the Lamber and Cooper, the supply chain characterised by many tier-1 customers and suppliers leads to an intensive use of the resources in order to try to manage all the link within and between them, sometimes forcing the company to actively manage only a few tiers of their customers and suppliers[39].

The author distinguish four main types of links: Managed Process Links, Monitored Process Links and Not-Managed Process Links and Non-Member Links. The first one are the most critical so the focal company has to integrate and manage (usually represented by tier-1 customers and suppliers). The second are not critical so the focal company should, if necessary, monitor them and in case taking action to face them (in the most cases distinguished by tier-2 or 3 customers and suppliers). The Not-Managed Process Links are those where the focal company is not directly involved in since the use of resources to control them is unjustifiable (those links the focal company fully trusts the other members to manage the process links appropriately). As reported above, the supply chain of a specific company is influenced by decisions made in other connected supply chain, defining Non-Member Process Links. Those are not considered as properly links of the focal company's supply chain structure but they can anyway affect its performance.

[39] principle of functional spin-off. For further information consult Appendix 1

Since each firm is member of other companies' supply chain, and they are strictly integrated between them, in order to manage in the best possible way its supply chain, each management should understand their interrelated roles and perspectives. The integration and management of business process across company boundaries will successful only if it makes sense from each company's perspective[40].

The Supply Chain Business Processes

The supply chain business processes concern all the activities performed by a firm in order to generate a specific output value to deliver to their customers.

In the traditional firms, upstream and downstream portions of the supply chain are not considered as part of a unique system, rather as disconnected entities receiving sporadic information flows over time. To build a successful SCM, the company has to translate the individual functions to integrating activities into key supply chain processes. The information flows play a key role managing the supply chain processes in order to create an efficient product flows. Since the focus of the customer remains on the product, a firm should acquire information, both accurately and in a timely manner for quick response, from the fluctuations in customer demand. This ability would help the firm to create an efficient customer-focused system, although considering that controlling the uncertainty in customer demand represents one of the key aspect to perform an efficient SCM[41].

The Figure 4 below shows the main processes involved in the supply chain of each firm.

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[40] Cooper, M. C., and Gardner, J. T.: Good Business Relationships: More Than Just Partnerships or Strategic Alliances. *International Journal of Physical Distribution and Logistics Management* 23(6), 14–20 (1993)

[41] According to the author, controlling the uncertainty in customer demand, managing in an effective way the manufacturing processes and analysing the suppliers performance are the three fundamental starting point to manage the supply chain in a productive way

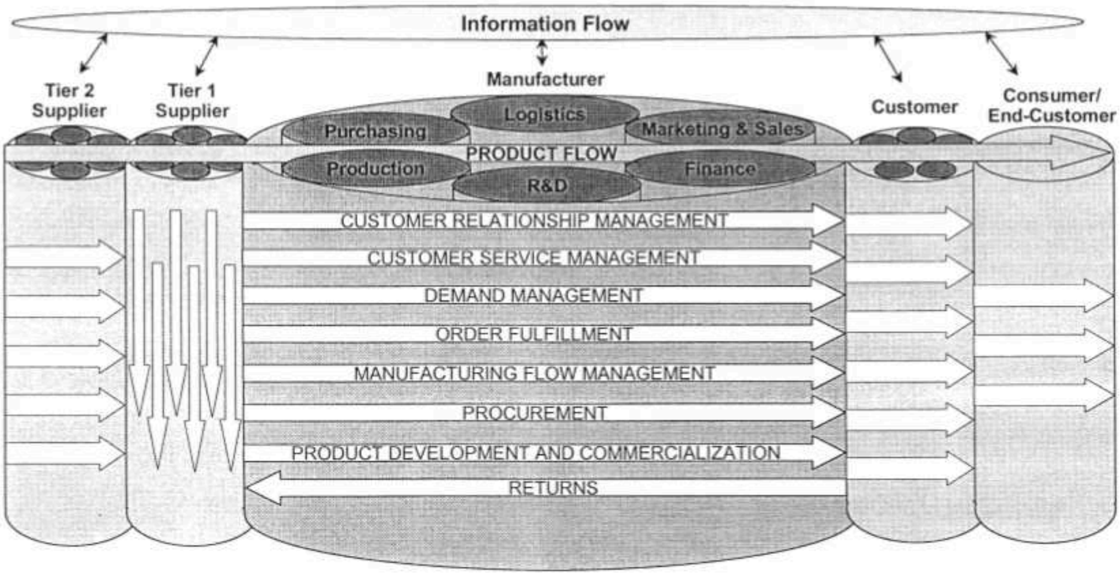

Figure 4 The supply chain management components

The first step towards integrated SCM consists in the identification of the key the critical customers or customer groups for the organisation's business mission. The contact with the customers is created thanks to the customer service that represents a single source of customer information for administering the product/service agreement.

The demand management involves activities like planning and forecasting with the aim to organised a structured inventory availability. All the forecasts deal with four main variables that determine the market conditions: demand, supply, product characteristics and competitive environment. The most adopted methods among firms to forecast the demands are qualitative, casual and time-series.

An effective inventory management means being able to balance the customer's requirements with the firm's supply capabilities. The aim is to reduce the inventory costs but, at the same time, maintain the service required by the customers.

The key to effective SCM is meeting the customer need dates and so the firm's manufacturing, distribution and transportation plans is essential to satisfy them and the alliances between the key supply chain members are the requirements, first of all to meet customer requirements but also to reduce the total cost. The aim is to develop a seamless process from the supplier to the organization and on to its various customer segments.

In the past, most of the manufacturing processes were organised in make-to-stock formula, so producing and supplying products to the distribution channels based in historical forecast. This approach can be suitable for some types of industries or companies but for others it caused only a wrong mix of products manufactured and a useless economic and human expenditures to handle it.
Thanks to SCM orders can be processed just-in-time, so product is pulled through the plant according to customer needs letting to avoid unneeded inventories in terms of quantities and carrying costs and transhipment of product.

Even if traditionally the role of the Procurement Department was based only on betting up on price and buying from the lower cost suppliers, now it manages several functions. The primary activity consists on creating purchase orders for needed products, direct or strategic materials, so needed to produce the product to sell to the end-consumers as well as indirect or RMO (maintenance, repair, and operations) products that a company consumes as part of daily operations. In order to manage efficiently the Purchasing activities, the Procurement Department has to monitor and handle the consumptions frequently. Indeed, the levels of expected consumes have to be established ex ante and they have periodically be compared with the effective consumptions. In such way the substantial incongruity are exposed to the head border in order to investigate the causes and undertake the needed actions. Another important activities attributed to the Procurement Department is the Vendors Selection. This practice is not only based on price but other factors are considered, as their capacity, the quality of their products, the service level offered, the technical support provided. Suppliers are usually categorised according to their power and dimension, permitting the firm to define their contribution and, oppositely their criticality against the organization. Furthermore, most of the companies create long-term strategic alliances with a small group of suppliers to benefit from the win-win relationships[42].

The Product Development Process requires a strong integration between customers and suppliers in order to fully meet the consumer's requirements and to reduce the product's time-to-market. During this phase it is essential considering that the design of a product and its components selection influence first of all the supply chain construction and, as consequence, the finished product's cost structure and availability. The aim of product design in the supply chain perspective is defined by an implicit rule: developing a product with few component, if possible with a simple design, and modular construction from generic sub-assemblies. In this way, the stock can be kept in form of generic sub-assemblies in specific locations along the SC and at the same time, the inventories of finished-good would be minimum since the demand is satisfied rapidly by assembling the components when the orders arrive.

The Delivery Process regards the physical transfer of a good from one point to another and, even if it seems to be natural operation, the firms has to control several aspects. The starting point of an efficient Delivery Process is the effective Order Management that is the process of passing order information from customers back through the supply chain. If the supplier fills the order from its inventory, the purchasing order is turned into a pick ticket, a packing list and an invoice, while, if the inventory is not able to satisfied the customer's needs, the supplier turns its purchasing order into another purchasing order for its supplier and so on. Each customer-supplier order transmission will be turned into a pick ticket, a packing list and an invoice. The delivery scheduling is the second aspect to consider in Delivery Process. The delivery scheduling depends on the constraints imposed by the transport decisions. The main two options are the direct delivery and milk run delivery. The direct delivery is the delivery from an originating location to the receiving location, eliminating each intermediate operations and moving directly the

[42] agreement so much convenient for both the parties

products from where they are stored to where they will be used; it is considered the best solution only when the receiving location generates an EOQ[43] of the same sizes of the truck load[44]. On the contrary, the milk run delivery involves the shipping of a product (or more) from a single originating location to multiple receiving locations and viceversa (from multiple originating locations to a single receiving location). The adoption of this method implies computations about the product quantities and frequency to deliver and to pick up, taking into account the available truck load and priority in terms of shipments. This approach is suitable in case of the need to frequent shipments (usually daily) of relative small quantities for each customer/supplier that combined would result in a full track load.

The last but same important process deals with Returns. Managing returns as a process offers the opportunity to achieve the competitive advantage since the effective management of returns enables identification of productivity improvement and breakthrough projects.

The Supply Chain Management Component

The management components represent the managerial variables by which the business processes are integrated and managed across the supply chain. The level of integration and management of a business process link depends on the number and level of the components added to the link. Hence, adding management component and increasing the level of each component can increase the level of integration of the business process link.

According to D. M. Lambert and M. C. Cooper there are nine management components for a successful SCM that can be divided into two main groups. The

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[43] *Economic Order* Quantities. The order quantity that is the most cost effective amount to purchase at a time

[44] also defined TL or FTL to refer to a full truckload, so the situation in which the item or items shipped take up the entire available space on a truck

first represents the "Physical and Technical" group including all the visible, tangible and measurable components, that, thanks to its features, are the more easy-to-change. The second, "Managerial and Behavioural" group, made of the intangible and less visible components, more difficult to assess and alter. Even if those two group seem to be totally disconnected, the managerial behaviour components define the organisational behaviour defining how the physical and technical management components can be implemented. In order to establish a successful SCM, each of these components and the relationships among them have to been understood and monitored.

The Physical and Technical management components are:

- *Planning and Control* of operations
- The w*ork structure* indicates how the firm performs its tasks and activities and it can be measured by analysing level of integration of processes across the supply chain
- The *organisational structure*
- *Product flow facility structure* defined by the network structure for sourcing, manufacturing and distributing across the supply chain
- *Information flow facility structure* refers to the kind and frequency of information exchanged between the channel members involved in the supply chain

The Managerial and Behavioural management components are:

- *Management methods* include the corporate philosophy and techniques
- The *power and leadership structure* across the supply chain influence its form
- The anticipation of sharing of *risks and rewards* across the chain affects long-term commitment of channel members
- Corporate *Culture and attitude* have to be in line with channel members.

1.2.3 Strategic Supply Chain Management

Thanks to some pioneering firm in several industries the paradigm of supply chain management is radically changing, leading the firms to consider their supply chain as a strategic asset. This new approach is defined *Strategic Supply Chain Management.* The paradigm of this new approach leads the expert to consider the SC as strategic differentiator to reach a competitive advantage allowing the firm to stay one step ahead of the competition. Applying a strategic supply chain management implies creating the best configuration of your SC able to drive your strategic objectives forward.

S. Cohen and J. Roussel describe five key components on which a firm takes decisions defining their supply chain strategy. Obviously, the decisions taken in this five areas have to be in accordance between them to provide a successful strategic supply chain management. The five key configuration components are:

- Operations strategy
- Outsourcing strategy
- Channel strategy
- Customer service strategy
- Asset network

The *Operations strategy* involves decisions about how to produce your good/ service. As introduced above, it depends on several aspects: the characteristics and function of the product, the market and demand structure, the policy of the firm to satisfy the customers' needs. For example, in terms of inventory management, for the the large production of standardised goods is preferable a *make-to-stock* approach, characterised by an high inventories the allow to meet the demand quickly. On the contrary, for a customised goods production may be better opting for a *make-to-order* approach with relative low inventories and less responsiveness in meeting demand. An hybrid strategy is the *configure-to-order*, approach in which the product is partially completed and then finished according to the order received, permitting many variations of the end product (low finished goods inventories and shorter lead times); the *engineer-to-order* approach implies the creation of a product/service according to unique customer specifications. Sometimes, the best option would be applying different operations strategies in line with product or market segments and with the specific requirements of the firm and the market in which it operates. Like the other configuration components, operations strategy is dynamic depending in particular by the PLC and by the number of product variants.

The *Channel strategy* regards how to deliver your product or service to buyers and end-users. The key drivers are the market segments and the geographies since each segment requires different supply chain processes, assets, channels and supplier relationships. Even if sometimes those aspects are undervalued, the decisions about the channel strategy have a strong impact over profit margins of a firm that varies widely depending on which channels are used.

The starting point of the *Outsourcing strategy* implies the ability to recognise the company's supply chain skills and expertise and as well their core competencies. Basing on them, a company defines which activities should be performed in-house distinguishing from those that should be outsourced because of their low strategic importance for the firm according to what a third party could do better, faster or more cheaply. Distinguishing in-house from outsourced activities adds the firms flexibility and agility, permitting them to focus on their core competences and enhancing their competitive position. The support of third party company can provide two types of advantages: in terms of *scale* and in terms of *scope.* Rather than producing a component in-house, the third party provider has a larger production that permits to keep the utilisation rates high and unit costs low. At the same time, outsourcing partners can provide access to operations in new locations and of *technology expertise,* considering, in addition, that in most cases mastering a product or process technology requires a sizeable investment to develop internally. In turning the activity to external providers, a firm should take into account first its source of differentiation (to be kept in-house), its operating scale (comparing the internal operations against the requirements), its power position and the uniqueness of the operations to avoid to loose market share in favour of their providers.

To develop an efficient *Customer service strategy* a company should focus on two main aspects: the overall volume and profitability of each customer account and an understanding of what the customers really want. Usually different customer segments have different interests and needs, because of this a proper way to manage the customer service would be tailoring it in order to deliver the best cost-service trade-off according to the potential revenues could be acquired from them and to their strategic relationship value.

The *Asset Network* configurational components involves all the decisions about the location and the system regarding factories, warehouses, production equipments, order desks and service centres the business owns. Location, size and mission of these assets strongly influence the supply chain management and its performance. Companies usually mix different models. According to the *Global model* a given line is manufactured in one location for the global market (…). The *Regional model* implies the manufacturing is done directly in the region in which the product will be sold because of the need to adapt the product to specific regional requirements. The last model is the *Country* one, in which manufacturing is done primarily in the country where the market generally because of expensive transport costs, excessive duties and tariffs and high barriers to enter the market.

1.3 The Supply chain Risk Management

Even if the concept of supply chain risk management dates back to the 1970s it took notoriety in the last decade when even more researchers and practitioners started to study the way to improve the robustness of the supply chain for some companies. The main event that leads organisations and their managements to focus on risks affected the supply chain is considered the financial crisis of 2008, in which most of all customer orders were canceled, suppliers entered bankruptcy and commodity markets became increasingly volatile.

Many were the companies hit by supply chain disruptions as Boeing, Cisco and Pfizer, which suffered losses of US$ 2 billion, US$ 2.25 billion and US$ 2.8 billion, respectively. According to Blanchard D[45]., the economic consequences of a supply chain glitches involve a drop of the average operating income about 107 percent, a fall in return on sales of 114 percent and the return on asset decreases by 93 percent. Furthermore, sales declines and oppositely costs and inventories increase. Singhal states that the supply chain disruptions not only lower the level of operating performance for a company but it causes bad consequences on the performance for the next couple of years.

Because of the crisis and learning from the experiences of competitors, even more companies started to note the increase in the volume and possibility of supply chain break-downs and, because of this, to focus on the risks that mostly influence their supply chain in order to avoid or reduce the possibility to disruptions.

As anticipated in the previous sections, the Supply Chain is not a stand-alone topic since it takes distinguishing marks from the two main field on which it is based: Risk Management and Supply Chain Management.

The starting point to define ScRM is the notion of *supply chain risk.* The supply chain risks is defined as the "divergence in the distribution of potential outcome of supply

[45] Blanchard D., (2010), *Supply Chain Management Best Practices*, John Wiley & Sons, Inc., Hoboken, New Jersey, pp. 7-29.

chain"[46]. Thanks to the definition of SCR is easier to extract the notion of *supply chain risk management*. The supply chain risk management is considered as a process to control over those factors that can have negative effects on the normal functioning of the supply chain, in order to improve its reliability. The process consists to identify the sources of risk and implement the appropriate actions and measures to avoid or restrict the vulnerability of the SC, controlling the factors that could cause damages of its normal functioning, improving its reliability[47] [48].

The primary aim of the ScRM is to increase the resilience of the supply chain through the identification of the potential sources of risks suggesting also the more suitable measures to mitigate them. More practically the discipline define how to minimise the occurrence of interruptions, to mitigate their impact on performance and at the same time to hasten the restoration of the supply chain to its standard state.

1.3.1 Supply Chain risks classification

As already mentioned supply chain risks is considered the exposure to an event that causes disturbances, affecting the efficient management of the SC. So, the expositions of uncertain and unexpected events in supply chain are the vulnerability for achieving objectives. All supply chain risks, independent from their nature and source, present a set of common characteristics. The concept is based on three main pillars: the objective, the risk exposition and the risk attitude. An efficient planning, monitoring and controlling of organisation's capital resources are the aim of "objective driven risk" that should be reach balancing the efficiency with the effectiveness. While the efficiency involves achieving the objective limiting as much

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[46] J.G. March, Z. Shapira, (1987), *Managerial perspectives on risk and risk taking*, Manag. Sci. 33, 1404-1418.

[47] Guo, Y., (2011), *Research on knowledge-oriented supply chain risk management system model*, J. Manag. Strategy 2 (2), 72-77.

[48] Singhal, P., Agarwal, G., Mittal, M.L., (2011). *Supply chain risk management: review, classification and future research directions*, Int. J. Bus. Sci. Appl. Manag. 6 (3), 15-42.

as possible the resources needed, the effectiveness focuses only on the achievement of the desired result whatever the conditions and circumstances.

The risk exposure depends on two main factors, the appearance of a triggering event, measured in terms of the impact caused by the event and by its probability of occurrence, and the vulnerability[49] or resilience[50] of the supply chain. The risk exposure is also influenced by a time component.

The last pillars is represented by the risk attitude of the decision makers toward risk. The three main approaches are *risk-aversion*, typical of who prefers to avoid any type of risks even if the possibility of a reward, *risk-seeking*, who prefers taking risks to obtain for sure the expected value and *risk-neutrality*, the agents indifferent to bet or obtaining an established amount. Abdel-Basset M., Gunasekaran M., Mohamed M. And Chilmamkurti N. show graphically the three pillars and the underlying connexions in Figure 5.

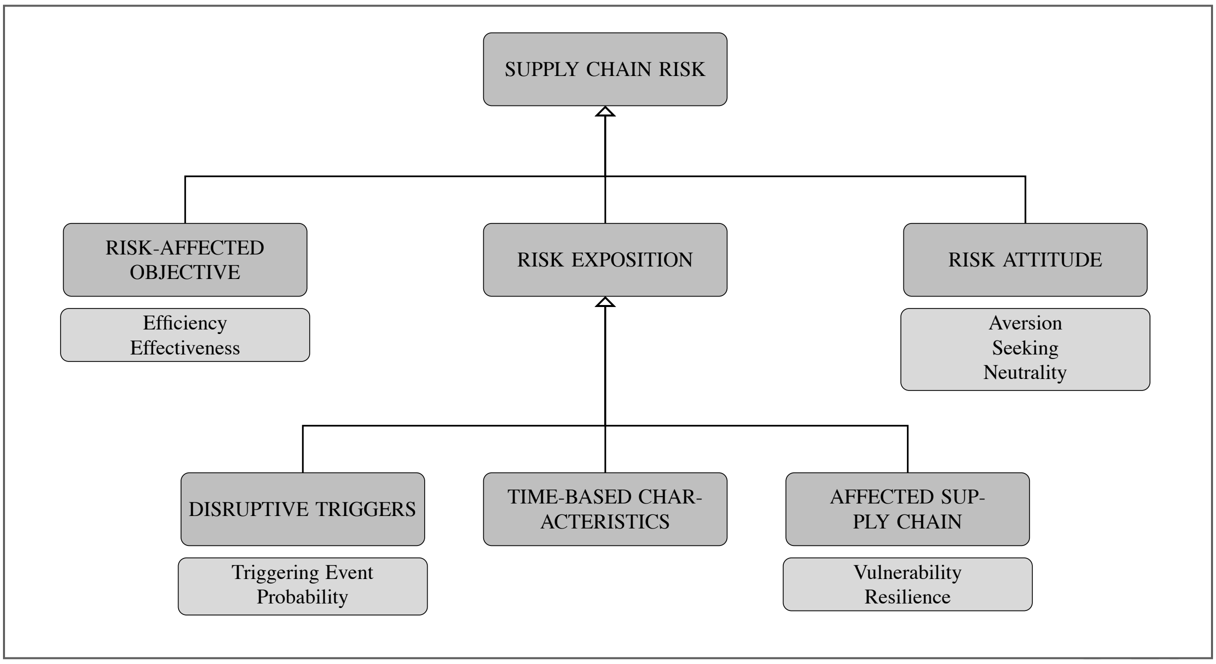

Figure 5 The main characteristics of supply chain risks

[49] in ScRM field represents the scope in which the supply chain is volatile to a risk event

[50] in ScRM filed represents the ability to conquer vulnerability

According to G. Svensson[51], two are the primordial distinctions to consider analysing a risk source: atomistic versus holistic and quantitative versus qualitative.

The *atomistic vulnerability approach* stresses that the perspective is limited to one (or more) selected part of the supply chain as much that it's preferable in case of low value, non-complex and generally available components. Oppositely, the *holistic vulnerability approach* implies an analysis that consider all the components of the SC in order to asses risk. This approach is more suitable for high value, complex and rare components whose lack would create disruptions with wide spread impacts upon the supply chain operations.

The *quantitative perspective* implies the occurrence of events that create a lack of materials and components necessary for the activities of downstream of the supply chain, for example the breakdowns or delays in the transports. While, measurement errors in components regards the *qualitative perspective*, caused by events that lead to the absence of components and materials required in the supply chain.

Since the definition is very broad researchers suggest many classification in order to provide the organization with a guideline in particular in the phase of Risk Identification. Indeed, sources of risks can be sorted on the basis of different parameters and variables in accordance with the type of analysis the management is performing.

The intent of this section would be to describe the major classification, starting from the more generic until the more detailed and fragmented. Please note that each of this classification is not exclusive, they can coexist since they analyse the risk in different respects.

Abdel-Basset M., Gunasekaran M., Mohamed M. and Chilmamkurti N. propose a classification of risk source distinguishing the *external-driven* from the *internal-driven.* The first one, also defined uncontrolled because of their inability to control them, can be driven by events either upstream or downstream in the supply chain,

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[51] Svensson G., (1999), *A conceptual framework for the analysis of vulnerability in supply chains*, International Journal of Physical Distribution & Logistics Management, Vol. 30 No. 9, 2000, 731-749.

while the second, called also controlled, and, thanks of this, provide better opportunities for mitigation them.

The classification between external and internal define five sub-categories for both of them.

The external ones are:

- Demand risks: originated by the downstream side (deeply analysed beyond)
- Supply risks: derived by the upstream side (deeply analysed beyond)
- Environmental risks: relate to economic, social, governmental, and climate factors, including the threat of terrorism.
- Business risks: caused by factors such as a supplier's financial or management stability, or purchase and sale of supplier companies.
- Physical plant risks: linked to the condition of a supplier's physical facility and regulatory compliance

The internal subcategories are:

- Manufacturing risks: attributable to disruptions of internal processes and operations.
- Business risks: due to internal events that disturb the normal equilibrium of the company such as alteration in key structures, management, reporting structures or business processes.
- Mitigation and Contingency risks: due to incidents because of a mitigation plan has not been applied in when the initial symptoms had have been reported.
- Cultural risks: due to the cultural tendency of the organization to hide or delay the negative informations.

Another main classification proposed distinguishes the risks according to their nature: strategic, hazard, financial and operational.

Strategic are defined all those risks potentially able to affected the integrated whole so able to undermine the entire business and its continuity because they are consequential to the organization's ability to carry out its business strategy, achieve

its corporate objectives and protect assets and brands. In the most of cases indeed, strategic risks lead to destroy the business' growth trajectory and its shareholder value. Those risks are strictly related to seven factors internal and specific to each organization: industry, technology, brand, competitor, customer, project, and stagnation.
According to many researchers, the best way to reduce strategic risk lies in an efficient new product development. In that sense, organisations should consider product development as a core process aiming in supporting global innovation and competitiveness.

Hazards are those all risks caused by random disruptions such as natural phenomena, fires or malicious behaviour such as accidents and acts of terrorism.
Due to the direction of the most of companies towards a global supply chain, their exposures to hazard risks increase so, even more of them, are entering into indemnity and other types of partner agreements in order to mitigate risk through technique such as risk pooling[52], sharing risk[53] and disruption insurance.
Insurance coverages are considered the most suitable option to minimise the hazard risk exposure hence several new variants of risk transfer packages have been created in the last decade. Each of those new alternatives are different in terms of their coverage conditions. Here below the most common options.
The First-Party Commercial Property Insurance is the typical reimburses the insured for profits that it would have had earned if it would not have suffered a business interruption. The Cargo Insurance covers damage or theft of the goods during the transport. According to Zurich Insurance, Contingent Business Interruption (CBI) insurance "reimburses a company for lost profits and other possible transferred risks, such as necessary continuing expenses, due to an insurable loss suffered by one or

[52] risk response strategy aimed at spreading the financial risks evenly among a large number of contributors to the program

[53] risk response strategy aimed at maximising the probability of opportunity occurrence by cooperating with third parties

more of its suppliers or customers." The Trade Disruption Insurance protects against lost profits caused by disruptions in the supply chain where there is no physical loss or damage to the insured's or its suppliers' assets. Lastly, the Global Logistics Insurance is considered a derivative of the Cargo Insurance since it expands the coverage including additional elements and activities within a worldwide supply chain.

Virtually, all events occurring to a company have financial implications, visible on its income statement, balance sheet and cash flow statement. Assuming this, it should be defined which events have a primary financial impact and which ones are only consequential of other events. Here below we will discuss about only those whose effect impacts directly over the financial side.

The two major areas that comprise financial risk include supplier financial viability and supply market volatility.

Thanks to the powerful tools and the great availability of data about suppliers and customers, even more companies start their Supply Chain Risk Analysis investigating on their suppliers and customers financial situation. This way to proceed could be an ideal point of departure in the selection of customers and suppliers according to the intent to minimise risk but, at the same time, financial risk is not the only kind of risk present in supply chains. Analysing the financial side is surely important and necessary but it is not sufficient enough part of supply chain risk management to be the only thing being assessed.

The second source of financial risk is driven by the supply market volatility. When demand exceeds the supply, the power of the buyers shifts to the sellers that raise up the prices originating financial risk. Indeed, the price volatility is a direct cause of the increase of financial risk. In the last decades, price volatility has not be determined by war or depression as during the Ist and IInd World War, rather by the structure of the world economy. In the actual economy, only eight Countries control and produce the majority of commodities needed, so the the volatility appears to be a structural change in the way the global economy has organised itself.

There are several approaches to assess financial risk across the supply chain. The more adopted is the Supplier Financial Health Assessment through Ratio Analysis[54] that implies the computation of the ratio starting from two financial data and its comparison against the industry benchmark, internal historical performance or to other companies belonging to the same industries. This approach permits the CFO to compare the financial strength of more suppliers and to predict the potencial bankruptcy of the suppliers. According to the literature, the ratios fall into six main categories. The *liquidity ratio* measures the performance in meeting short-time obligations, the *activity ratio* looks at the efficiency of the supplier in managing its assets, the *leverage ratio* tryouts the ability of the supplier to meet the debt obligations, the *profitability ratio* provides insight into the rate of return a supplier is earning, the *market ratio* compares results with market indicators like price, earning and shareholders returns and the *growth ratio* detects the rate of growth over time of the suppliers. Usually the quantitative analysis through the financial performance metrics is performed taking into consideration a Qualitative Supplier Financial Risk Indicators in order to consider some variables and implications that can not be expressed by a numerical indicator. At the opposite side of the chain is essential assessing the customer creditworthiness. From a risk perspective is much the same for customers except with different objectives: from the suppliers side the organisation evaluates the financial integrity of its suppliers in order to avoid future supply disruptions due to financial issues, while it evaluates the financial integrity of its customers to ensure the invoices are paid.

Others techniques to minimise the financial risks are the hedging and Currency Risk Management. The *hedging* is a strategy in risk management implemented to reduce or offset the probability of loss due to fluctuations of the price of commodities,

[54] also defined financial performance metrics

currencies and securities[55]. Practically it implies the transfer of the risk without the support of an insurance policies taking equal and opposite positions in two different markets. When a company deals with the international market it has to deal with the possibility of currency fluctuations that present financial risk. Also in this last case there are several method in order to minimise as much as possible the financial risks that may disrupt the supply chain of the organisation.

External and internal quality problems, late deliveries along the supply chain, service failures due to poorly managed inventory and problem derived by poor forecasting are only few examples of Operational Risks. Indeed the majority of the risks that each organisation has to face daily fall into this category. Those risks can cause operational failures through the prism of the four pillars of the SCR: supply risk, demand risk, process risk and environmental risk.

The Supply Risk is generally associated to logistic and transportation impediments that lead to the obstruction of product flow intended as raw materials or semi-finished goods within the supply chain.

In the traditional approach, in order to reach advantages in terms of raw materials prices and delivery times, many companies tend to build a relationship with the minor number of suppliers that offered to their customers a higher service level so as not to risk to loose orders and volumes. If this approach could be suitable in a stable environment, because of the globalisation and the supply market volatility, now the companies tend to find out the right mix of multiple suppliers in order not to be totally dependent from an unique source of procurement in case of its disruption.

Furthermore, the concept of Business Process Outsourcing has emerged also in the logistic field thanks to the 3PLs[56], that are able to develop tools and technique to

[55] Financing or investment instruments (some negotiable, others not) bought and sold in financial markets, such as bonds, debentures, notes, options, shares (stocks), and warrants. See also security http://www.businessdictionary.com/definition/securities.html

[56] Third parties logistic

manage risks during the transportation for their customers and, at the same time, managing a better, faster and cheaper delivery.

Risks affecting the Demand side relate to the customers of the organization, the product the organization produce and the way in which it delivers the product to its customers. Estimating the demand means predict what, when and how much the customers will purchase. Taking this, forecast errors represent the key risk in demand side indeed the only way to mitigate this risk source implies to develop an accurate computation and management of the company's safety stock, managing a buffer stock of the choke points throughout the supply chain.

Another source of risk is strictly related to the product in case of failure or warranty issues. In particular in NPD[57], because of the unavailability of historical data and benchmarking, measuring the demand and defining the purchase requirement is even more difficult.

As in the supply side, also in demand one the logistic risks are present and it relates to outbound materials (in particular finished goods) to assembly or packaging partners, distribution or warehouse and end customers. Once again the 3PLs represent a way to mitigate risks thanks to their better performance and the risk sharing or pooling.

Process risks are inherently positioned within an organisation and, because of this, the organisation has better control over them since they occur within their own domain. Process risks are distinguished into *Known, Unknown* and *Chronic risks.* The first, also called hard risks, are measurable and note, and derive from the management's attitude or by the lack of investment in terms of time and resources. When they are ignored and permanent the solutions are not taken, hence they tend to recur daily becoming chronic, symbol of an higher level of risk. The second, also defined soft risks, are impossible to foresee and, because of this, the only way to try to mitigate them is the development of a response scenario[58] in order to take

[57] new product development

[58] also called Business continuity planning (BCP)

reactive remedies. As anticipated above, non-managed known risks may become chronic risks. Usually organisations don't take any corrective actions as known risks cause only tolerable internal disruptions so their impact is absorbed and work-arounds are developed.

The last pillars is the more immature due to the continual emerging of new policies and regulations, in particular for those companies which have organised their supply chain in the global scale. As the process, also the environmental risks can be known or unknown, so the first implies the adoption of a proactive behaviour to handle, while the second a reactive one, again through the use of scenario-based BCP.

Since the next sections, as well the case study, are totally focused on the operational risks that may breakdown the supply chain of the firm, **Appendix 2** propose a list of risks with the relative remedies.

CHAPTER 2. MATHEMATICAL TOOLS TO MEASURE RISKS AFFECTING THE SUPPLY CHAIN

2.1 Introduction to Multi-Criteria Decision Making

As suggested by the ISO 31000, the Risk Analysis and Risk Evaluation represent the two steps more tricky during the RM process. To evaluate the sources and causes of a possible event and to measure its impact over the robustness of the supply chain, can be applied both, quantitative and qualitative analysis. In the majority of cases it is preferable opting for mixed procedures, in order to prove mathematically the result and, at the same time, basing on the experiences and evaluating factors that could not be considered adopting uniquely mathematical or statistical model.

As mentioned in the several researches about the topic, the most common quantitative methods to measure risks falls into the Multiple-Criteria Decision-Making (MDCM) technique[59].

The MCDM techniques are a sub-discipline of the Operation Research (OR) that deals with the application of advanced analytical methods to help make better decisions[60] evaluating multiple conflicting criteria in decision making.

In most of cases the optimal solution exists only when one single criterion is taken into consideration, indeed in real decision situation any decision involves conflicts or dissatisfaction. The main aim of MCDM technique consists in supporting the decision maker to find the optimal choice among the alternatives when the choice is influenced by more than one conflicting criterion. The role of the decision maker implies not only the selection the best alternative but also to prioritise all the alternatives for resource allocation.

[59] also defined Multiple-Criteria Decision Analysis (MCDA)

[60] https://en.wikipedia.org/wiki/Operations_research

The **Figure 6** below shows the general structure of the MCDM process.

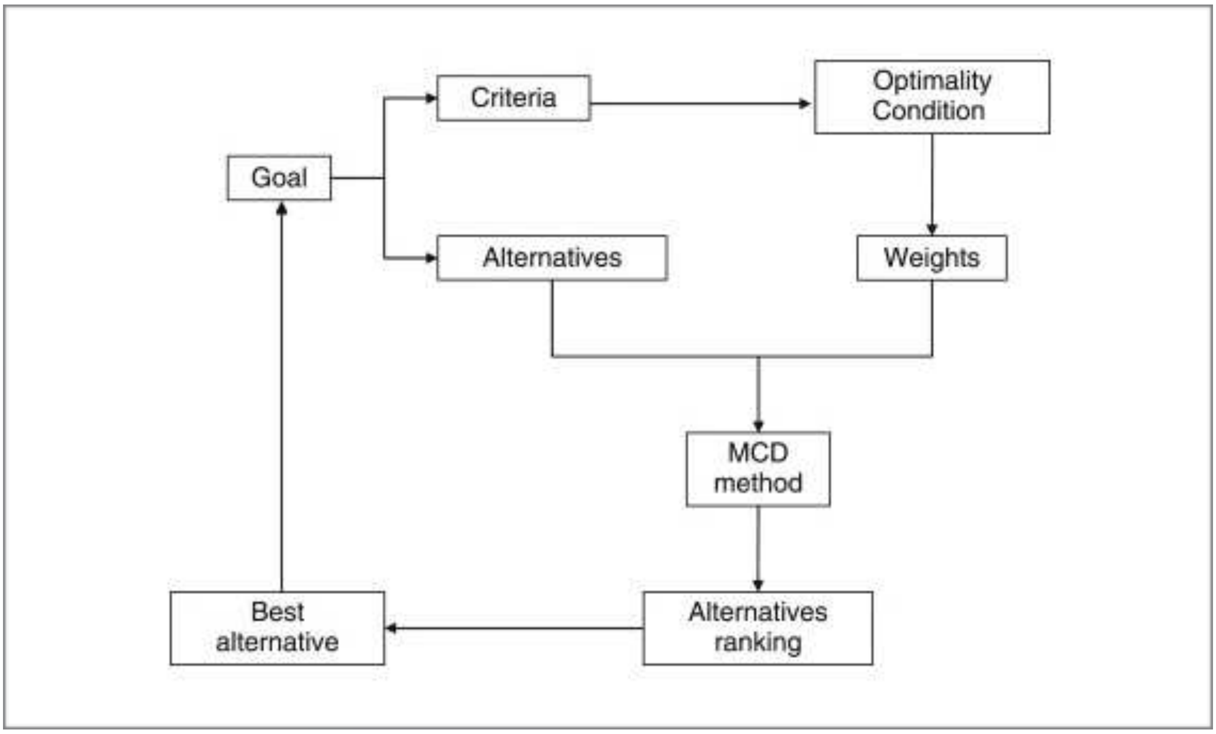

Figure 6 General structure of MCDM process

The common way to structure a MCDM process starts representing the intangible goals in terms of number of individual criterion. At first instance, this first step implies at least three shared problems: how to measure what we define “intangibles”, secondly, how to combine the measurements in order to obtain an overall preference or ranking, and third, how to use this output to make a decision with the best available mathematics.

The second step involves, jointly, the identification of the set of alternatives and the criteria[61] by which these alternative are to be compared. The set of alternatives can be both, defined explicitly by a finite list of alternatives, called *multi attribute decision making*, or defined implicitly by a mathematical programming structure, called *multi-objective optimisation* theory.

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61 According to Bouyssou, criterion is a tool allowing the comparison of alternatives according to a particular axis or point of view

The criteria have to be organised in a hierarchical way, from the more generic goals, refining into the more detailed subgoals. In identifying the criteria, some considerations are to be taken into account: their *value relevance*, so the link with the DM concept of their goals; the *understandability* and their *measurability*, that implies their inherent ability to measure the performance against the criteria; their *non-rendundancy*, in order to avoid the concept they represent is attributed excessive importance; their *judgement independence*, so the preferences respecting a single criterion should be independent of the level of another; and their *balancing between completeness and conciseness.*

Once defined both, the criteria and, as result, the optimality condition and, at the other hand, the criteria and their relative weights, the MCD technique can be applied permitting to obtain an alternative ranking as output. The first-ranked alternative will represent the best alternative, following the others according to the classification.

The MCDM can be distinguished into *Generating Technique* and *Preference Technique*. The first are executed without considering any type of prior judgment in the definition of the importance of the criteria, oppositely, the second are based one prior information or according to a defined preference function. Taking this into consideration, an analysis carries out with a preference technique permits to obtain a more complete ordering of the total set of alternatives.

In analysing the result obtained performing a MCDM technique, we should consider that subjectivity is intrinsic in all decision making particularly in the choice of the criteria on which the analysis is based on and in their relative weight. Indeed, MCDM process does not dissolve subjectivity but it conveys the need for subjectivity judgements explicit and it allows to make transparent the whole process by which these judgments are considered.

Over the years, the adoption of MCDM techniques has increased its uses and they begun to widen their borders. Now it can be applied in different areas, with different theoretical background and, facing different kind of demand and offering different types of results. Its application permits to solve specific problem as well as general ones. For each problems can be applied many MCDM techniques but one is preferred against another according with the nature of the model, the needed information and how the model is performed. If, in an hand, one model is more suitable than others, they all permit to create a more formalised and better informed decision making process, to accomplish the need to define alternatives to be considered, the criteria guiding the evaluation and the relative importance of each criteria.

The different methods developed to solve multi-criteria decision problems can be divided into several groups:

- Pareto optimality;
- Outranking method based on ordinal comparison of concordance and discordance;
- Partial order ranking (POR) theory;
- Utility and multi-attribute value theory based on the use of lottery comparisons;
- Goal programming (GP);
- Priority theory; and
- Bayesian theory.

The analytic hierarchy process (AHP), regime method, convex cone theory, hierarchical interactive method, visual reference direction approach, aspiration level interactive method, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and fuzzy set theory belongs to the discipline of the Priority theory, the most used in the ScRM.

Before we move to a deep analysis of some of the discipline previously cited, this elaborate would introduce the topic to the reader through a rapid explanation of the notation at the basis of each methodology.

Considering A the finite set of n alternatives that has to be ranked, then, the consequences of these alternatives are described by a set F of p criteria, so: $A = \{a_1, a_2, \ldots, a_n\}$, also defined $A = \{a, b, c, \ldots\}$ and $F = \{f_1, f_2, \ldots, f_p\}$.

So alternatives a and b are defined p-dimensional vectors as follow

$$\mathbf{a} = \{a_1, a_2, \ldots, a_n\}, \qquad \mathbf{b} = \{b_1, b_2, \ldots, b_n\}$$

where p is the number of selected criteria.
Each ith alternative $(i = 1,2,\ldots,n)$ assumes for the jth criterion $(j = 1,2,\ldots,p)$ the actual value f_{ij}, and, as consequence, the value of the jth criterion for the n alternatives can be re-written in a n-dimensional vector

$$\mathbf{f}_j = \{a_{1j}, a_{2j}, \ldots, a_{nj}\}$$

To take into account the different relevance associated to the criteria in the decision rule, each criterion can be weighted

$$\mathbf{w} = \{w_1, w_2, \ldots, w_p\}$$

considering the following constraints:

$$0 \leq w \leq 1, \qquad \sum_{j=1}^{p} w_j = 1, \qquad j = 1,2,\ldots,p$$

The ranking function R associates the rank to each n alternatives; the rank represents its position within the n-dimensional set of alternatives.
Considering a vector **x** of n values, the ranking function can be expressed as follow

$$R(\mathrm{x}) : R^n \rightarrow r \in R, \qquad 0 \leq r \leq n$$

Therefore, the ranking function associates to the ith object value x_i a ranking value r_i according with the n values, so

$$R(x_i | x) = r_i, \qquad 0 \leq r_i \leq n$$

In the further sections, the AHP and TOPSIS techniques will be deeply analysed in theoretical and practical way, performing a supply chain risk management analysis following the theories suggested by the models.

2.2 The Analytic Hierarchy Process (AHP) Technique

The AHP is a MCDM techniques developed in the 70s by the mathematician Thomas L. Saaty. The primordial elaboration processing dated back to the 1971 and formally realised in the 1973 when It has been adopted to identify the alternative action plans for the development of the Sudan.
The acronym *AHP* defines perfectly what the technique consists in. The term *Analytic* suggests the breakdown of any complex problem into its constitutive elements; *Hierarchy* involves the predisposition of a pyramidal structure that presents the goal on the top and below it the criteria and sub-criteria; the notion *Process* implies the succession of actions and functions to follow in order to achieve the desirable purpose.

Through the utilisation of the AHP methodology the DMs are able to take decision despite of the high number of linked factors and the multiple information to consider. The main features of the methodology are, from one side the ability to frame the problem in a simple hierarchy that permit to decompose the problem, analysing its single component and, only at the end, obtaining a single result; from the other the ability to link together quantitative-qualitative and tangible-intangible elements of the DM in assigning the priorities.

Thanks to its great potentiality and adaptability, over the years, the AHP model becomes a popular tool to support the DM in taking decisions in several fields and types of decisional problems. According with Vaidya and Kumar[62] the applications of the AHP models can be classified into three groups: applications based on a theme, specific applications and applications combined with some other methodology.

According to their theme, can be individuated the following categories of purpose:

- Selection: the adoption of the AHP technique to detect the best warehouse site[63], to select the best software product among various alternatives[64] or to find out the bet contractor in the field of project manager[65];

[62] Vaidya, O. S, & Kumar, S., *Analytic hierarchy process: An overview of applications*, European Journal of Operational Research (2006) 1-29.

[63] Korpela J., Tuominen M., A decision aid in warehouse site selection, International Journal of Production Economics 45 (1–3) (1996) 169–180.

[64] Lai V., Trueblood R.P., Wong B.K., *Software selection: A case study of the application of the analytical hierarchical process to the selection of a multimedia authoring system*, Information and Management 36 (4) (1999) 221–232.

[65] Lai V., Wong B.K., Cheung W., *Group decision making in a multiple criteria environment: A case using the AHP in the software selection*, European Journal of Operational Research 137 (1) (2002) 134–144.

- Evaluation: the acceptance of the model to evaluate the best casting supplier[66] or to assess the quality of a group of journal according to some established criteria[67];
- Benefit-cost analysis: the application of the theory to analyse the feasibility about the implementation of a concurrent engineering in the organization[68] or to analyse multiple investment decisions to activity based costing[69];
- Allocations: the AHP methodology as tool to formulate the location strategies in a volatile complex decision environment[70] and, more generally, for all resource allocation problems;
- Planning and Development: the AHP adoption to plan the information resource in a health care system[71] or to assist development planners in formulating development plans in line with national objectives[72];
- Priority and Ranking: application of the model to rank a list of enterprises according to their achieved level of business efficiency[73];

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[66] Akarte M.M., et al., *Web based casting supplier evaluation using analytic hierarchy process*, Journal of the Operational Research Society 52 (5) (2001) 511–522.

[67] Forgionne G.A., Kohli, R., *A multi-criteria assessment of decision technology system and journal quality*, Information and Management 38 (7) (2001) 421–435.

[68] Tummala V.M.R., Chin K.S., Ho S.H., *Assessing success factors for implementing CE: A case-study in Hong Kong electronics industry by AHP*, International Journal of Production Economics 49 (3) (1997) 265–283.

[69] Angels D.I., Lee C.Y., *Strategic investment analysis using activity based costing concepts and analytic hierarchy process techniques*, International Journal of Production Research 34 (5) (1996) 1331–1345.

[70] Badri M., *Combining the AHP and GP for global facility location–allocation problem*, International Journal of Production Economics 62 (3) (1999) 237–248.

[71] Lee C.W., Kwak N.K., *Information resource planning for a health-care system using an AHP-based goal programming method*, Journal of Operational Research Society 50 (1999) 1191–1198.

[72] Ehie I.C., et al., *Prioritizing development goals in low-income developing countries*, Omega 18 (2) (1990) 185–194.

[73] Babic Z., Plazibat N., *Ranking of enterprises based on multi-criteria analysis*, International Journal of Production Economics 56–57 (1–3) (1998) 29–35.

- Decision making: adoption of the model for identifying the most appropriate entry mode alternative for foreign direct investments (FDIs)[74] or to develop a decision support model to identify successful new ventures[75]; and
- Forecasting: the AHP adoption in demand forecasting for inventory[76] or to anticipate the fluctuation of US Dollar/DM exchange rates[77].

As reported in the non-exhaustive list above, the application of the AHP methodology is very broad. Furthermore, in the recent years, it has became a real tool to support the organization in evaluate risks that may disrupt their supply chain in order to assess its robustness.

2.2.1 Model's principles, axioms and characteristics

In most cases, people who takes decisions in rational way adopts the so called *rationale deductive reasoning*. Even if it may look the most preferable method, it implies both, the rational thinking and considerations driven by the past experiences or the emotive side.

The AHP is considered an improvement of this technique thanks to its ability to combine two methods: the *deductive approach (*or *systematic*) and the *inductive* one. Through the deductive method, the DM analyses a system focusing on the

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[74] Levary R.R., Wan K., *An analytic hierarchy process based simulation model for entry mode decision regarding foreign direct investment*, Omega 27 (6) (1999) 661– 677.

[75] Jain B.A., Nag B.N., *A decision support model for investment decision in new ventures*, European Journal of Operational Research 90 (3) (1996) 473–486.

[76] Korpela J., Tuominen M., *Inventory forecasting with a multiple criteria decision tool*, International Journal of Production Economics 45 (1–3) (1997) 159–168.

[77] Ulengin F., Ulengin B., *Forecasting foreign exchange rates: A comparative evaluation of AHP*, Omega 22 (5) (1994) 505–519.

generic perspective, without focusing in any specific detail; conversely, the inductive approach permits the DM to analyse each part of the system individually[78].

Furthermore, independently from the field of application and its complexity, every application of the AHP methodology implies the presence of three basic principles: the *decomposition*, the *comparative judgements* and the *synthesising of priorities*.

The decomposition principles involves the particular way to structure the problem, deriving element in a level that are totally independent from those in the succeeding ones, working downward from the focus in the top level, to criteria relevant in second levels. Followed by sub-criteria in the third levels and so on, from the general to the more particular and concrete.

The principle of comparative judgments is considered the fundamental on which the *pairwise comparison* is based. It involves the comparison of the relative importance of elements in some given level with respect to a shared criterion or property in the level above.

"In the AHP priorities are synthesised from the second level down by multiplying local priorities by the priority of their corresponding criterion in the level above and adding, for each element in a level according to the criteria it affects. This gives the composite or global priority of that element, which in turn is used to weight the local priorities of the elements in the level below compared to each other with it as the criterion, and so on to the bottom level". The process already described, defines the principle of synthesising of priorities.

Moreover, the AHP methodology lies on four axioms:

I. Reciprocal judgments (details will be provided in next section).
II. Homogeneous element. According to it, can be compared only element not too much different between them[79].

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[78] please note that, in the inductive approach may result complex considering the link between the elements of the system and the surrounding environment.

[79] as suggested by T. Saaty, cannot be compared a grain of sand against a mountain. In order to be compared the DM needs to lay them into different hierarchic levels.

III. **Hierarchic or feedback dependent structure.** It implies that the judgements about an element belonging to a defined hierarchic level has not to depend on other elements of underlying levels.

IV. **Rank order expectations.** The DM has to be informed and has to know the problem under study.

2.2.2 AHP mathematical derivation

The AHP technique involves a set of consequential steps to follow in order to achieve the desirable results. Those steps can be summarised in:

1. Definition of the problem and identification of the knowledge sought
2. Design of the hierarchy structure
3. Construction of a set of pairwise comparison matrices
4. Derivation of the priority vectors
5. Check of consistency
6. Obtaining the overall ranking

1. Definition of the problem and identification of the knowledge sought

The definition of the problem and, as consequence the identification of the knowledge sought merely depend on the analysis the DM are providing. So, there is no a universal way to proceed. The reasonings and implications to take into account vary from case to case.

2. Design of the hierarchy structure

Designing the hierarchy structure of the model represents the most creative part and, at the same time, an important step since it has a significant effect on the outcome of the whole analysis. The basic question the DM should ask himself during this phase is "*Can I compare the elements on a lower elements using some or all of the elements on the next higher level as criteria or attributes of the lower level* *elements?*". The most suitable way to structure the hierarchy is, first of all, defining the overall goal to be after decomposed into the most general and the most easily controlled factors. Once the goal and factors have been established, the alternatives should be defined from the simplest criteria they must satisfy and aggregating the sub-criteria until the level of the two processes are linked to render possible the comparison.

The consequential steps to follow are: (1) identifying the overall goal; (2) identifying the potential sub-goals of the overall goals; (3) identifying the criteria that must be satisfied to achieve the sub-goals and the overall goal; and (4) identifying the sub-criteria of each criterion.

Other key points concern the actors involved and their goals and policies and the possible options or outcomes.

It can be useful represent graphically the hierarchy structure in order to check if each element is in line with the others, so that the logic process is correct. The Figure 7 below shows a generic representation of a hierarchic structure.

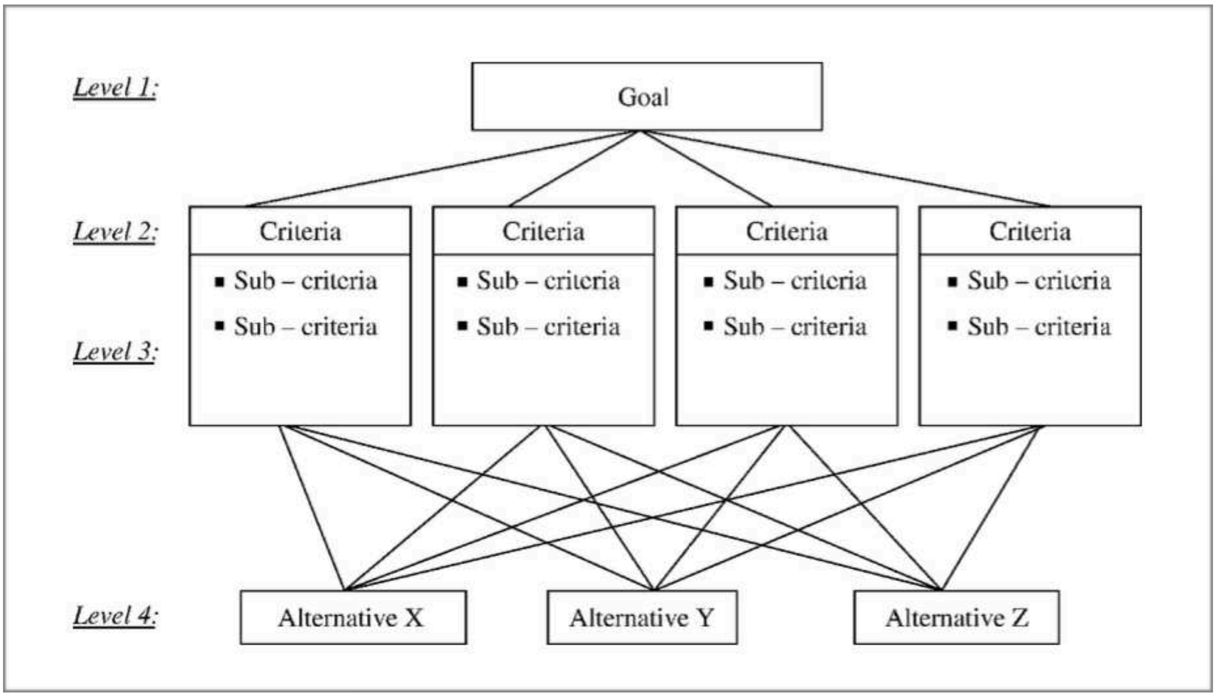

Figure 7 Generic hierarchy structure

Each box is called "hub", if they are in the same line are defined "peers"[80]. Each hub depend directly from an hub below it, defined "children", and from an hub above, from whose it descends, called "father".

3. Construction of a set of pairwise comparison matrices

Humans presents a cognitive limits in effectively comparing several alternatives at the same time. The pairwise comparison permits to overcome this limit, allowing the DM to consider two alternatives at the same time through the decomposition of the original problems into many smaller sub-problems to deal with.

We can define the terms "judgement" or "comparison" the numerical representation of a relationship between two elements that share a common parent. The set of those judgements can be arranged in a square matrix , defined *pairwise comparison matrix* $\mathbf{A} = (a_{ij})_{n\times m}$, in which the set of elements is compared with itself.

The matrix takes the following structure:

$$\text{A} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \tag{1}$$

where $a_{ij} > 0$ to indicate the degree of preference of x_i to x_j.

Each entry represents indeed the dominance of an element in the column on the left over an element in the row on top.

Morevore Saaty, in order to support the DM in collecting the various preferences, proposed The Fundamental Scale for Pairwise Comparison reported in the Table 2 below.

In order to fill the matrix to the right entries, each agent involved in the analysis should ask himself: "Which of the two elements is more important in accordance

[80] it means they are equivalent in terms of logic meaning

with to the higher level criterion? How much/less strong is the preference for the element on the row against the element at the column of the matrix?". In case the element on the row is less important than that on the top of the matrix, we enter the reciprocal values in the corresponding position of the matrix. This properties is defined condition of multiplicative reciprocity[81] and it can be mathematically expressed as $a_{ij} = \frac{1}{a_{ij}} \forall i, j$ holds.

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Table 2 The Fundamental Scale for Pairwise Comparison

[81] it implies that, if for example, x_1 is 2 times better than x_2, then we can deduce that x_2 is 1/2 as preferable as x_1

So, the matrix can be re-written as follow:

$$\mathbf{A} = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \dots & 1 \end{bmatrix} \tag{2}$$

Please, note the following implications:

- the number of comparison depends on the number of factors to compare, and it is expressed by the relation: $\frac{n(n-1)}{2}$;
- $a_{ii} = 1$, since the comparison between one element against itself cannot be different from "the element is as much important as the element itself". Because of this, a unit *diagonal* is created.

Another essential basic consistency requirement (in addition to the condition of reciprocity) is the transitivity-related consistency[82], so $\mathrm{A}_{ij}\mathrm{A}_{jk} = \mathrm{A}_{ik}$.

4. Derivation of the priority vectors

Once the comparison matrix has been filled, the analysis moves on deriving the priority vectors. There are many methods to derive the priority vectors; they consist on a rule for synthesising the pairwise comparison into a rank.

The most popular method to extract the priority vector is proposed by Saaty that, according with the Perron-Frobenius theorem, individuates the priority vector in the dominant eigenvector of $\mathbf{A}$.

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[82] it implies that, if for example, x_1 is 2 times better than x_2 and x_2 is 3 times better than x_3, then we can deduce that x_1 is 2×3 times better than x_3, that is 6 times better.

Considering the matrix $\mathbf{A}$ whose entries are obtained by the ratios between weights, and multiplying it by w:

$$\mathbf{Aw} = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = n\mathbf{w} \tag{3}$$

The formulation $\mathbf{Aw} = n\mathbf{w}$ identifies respectively the *eigenvalue* n and the *eigenvector* $\mathbf{w}$ of the matrix $\mathbf{A}$.

Furthermore, considering the matrix $\mathbf{A}$ would be perfectly consistent, since it presents the symmetry, reciprocity and the consistency of DM, it has an unit rank so n is the largest eigenvalue of $\mathbf{A}$ and its corresponding eigenvector represents the priority vector that once normalised provides the weight of the compared elements.

Saaty extends this result to all pairwise comparisons matrix by replacing n with the more generic maximum eigenvalue of $\mathbf{A}$, defined by the value $\lambda_{\max}$.

So, the eq (3) can be re-written as follow:

$$\mathbf{Aw} = \lambda_{max}\mathbf{w} \tag{4}$$

where, as anticipated above, $\lambda_{\max}$ represents the maximum eigenvalue of $\mathbf{A}$ and $\mathbf{w}$ the relative eigenvector which corresponds to the vector of the weighs. A more detailed explanation about eigenvalues, eigenvector and the Perron-Frobenius theorem statement can be find in Appendix 3.

Another widely adopted technique to estimate the priority vectors is based on the concept of *geometric mean*[83]. According to this method, each component of the eigenvector w is derived through the geometric mean of the entries on the respective row, divided by a normalisation term.

$$w_i = \frac{(\prod_{j=1}^{n} a_{ij})^{\frac{1}{n}}}{\sum_{i=1}^{n} (\prod_{j=1}^{n} a_{ij})^{\frac{1}{n}}} \tag{5}$$

This method enables the DMs to take decisions without using specific tools indeed a simple spreadsheet permits to solve complex decisions problems.

5. Check of the consistency

Once extracted the priority vectors (one for each matrix analysed), the consistency of the matrix should be verified in order to evaluate the reliability of the priorities associated by the DM. Rarely the judgments of the DM are perfectly consistent because of a mix of factors such as, the lack of accurate informations, the possiblilty of errors in the data entering or, worse, because of a real inconsistency of the models due to an inadequate structure of the problem, in terms of wrong choice of criteria or wrong links between hubs.

Before to move forward with the analysis it is opportune reflecting on the possible errors that the analysis presents in order to correct them and adjust the sight, if possible.

Once again the concept of eigenvalue comes in handy to verify the consistency of the matrix through the *Consistency Index:*

$$CI(A) = \frac{\lambda_{max} - n}{n - 1} \tag{6}$$

[83] The geometric mean method has been elaborated by the mathematicians Crawford and Williams in 1985

The more the index presents value close to zero, the more the matrix is consistent, oppositely, the more the value raises up, the more the matrix is inconsistent.
As reported above, is almost impossible that an AHP analysis presents a null consistency index and indeed the methodology accepts a low degree of inconsistency since it doesn't prejudice the validity of the result obtained. The *Consistency Ratio* is a rescaled version of *CI* obtained dividing the *CI* by the real number RI_n, the *Random Consistency Index*[84]*:*

$$CR(A) = \frac{CI(A)}{RI_n} \tag{7}$$

According to Saaty, the DM should accept matrices that present $CR \leq 0.1$ and reject values greater than 0.1.

The Table 3 below has been proposed through the Monte Carlo simulations; it shows that a random DM would get the following CI:

n	3	4	5	6	7	8	9	10
RI_n	0.5247	0.8816	1.1086	1.2479	1.3417	1.4057	1.4499	1.4854

Table 3 Values of RI_n

6. Weighing and adding the priorities

This step involves the extraction of the weights associated to the vectors. The underlying principle recommends to associate the weight to a vector proportionally to the importance of the criterion associated with it. There is not a unique way to

[84] derived taking the average of several consistency index estimated by an elevate number of positive, square, reciprocal and causal matrix.

proceed, but the authors suggests to adopt the same technique used for determining the priority vector (and all the previous and consequent steps).

The pairwise comparison matrix which compares the importance of the criteria for the achievement of the goals would be $\hat{A} = (\hat{a}_{ij})_{n \times n}$.

Then, we derive the vector whose components represent the weights to associate to each criterion, so $\hat{w} = (\hat{w}_1, \hat{w}_2, \ldots, \hat{w}_n)$.

By proceeding through the linear combination[85], we sum the weights (importance) of each criterion with its relative priority vector:

$$\mathrm{w} = \hat{w}_1 \mathrm{w}_1 + \hat{w}_2 \mathrm{w}_2 + \ldots + \hat{w}_n \mathrm{w}_n \tag{8}$$

In this way we obtain a final ranking to choose the best alternative, the one that presents the highest rank, formally described through the relation $\{x_i \,|\, w_i \geq w_j, \forall i, j\}$.

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[85] an expression constructed from a set of terms by multiplying each term by a constant and adding the results (e.g. a linear combination of *x* and *y* would be any expression of the form *ax* + *by*, where *a* and *b* are constants).
https://en.wikipedia.org/wiki/Linear_combination

CHAPTER 3. AHP APPLICATION TO MEASURE RISKS AFFECTING ROSSIMODA'S SUPPLY CHAIN

Before to move on directly on the arguments reported in this chapter I would like to spend some words on its roots and about the motivations that lead me to compose this dissertation.

The growing interest about risk management applied to supply chain discipline raises during my internship period at the Purchasing Office of Rossimoda Spa. Before that, my knowledge about the subject was limited since I have had dealt only partially with the topic during the teaching of some courses. Rossimoda provides me the chance to be involved in all the risk evaluations regarding the operational side. After six months I felt my self confident enough to analyse the stock and requirement to satisfy the production, to estimate lead times typical of particular components, to maintain and manage the relationships with different type of suppliers. Thanks to these acquired knowledge I have developed a increasing awareness about risk affected the upstream of the supply chain (the closer to my field of application, the Procurement area) and I have started to consider and evaluate some typical implication about the Operations discipline.

Recently, Rossimoda has given me the opportunity to start a new experience as production planner and scheduler that I consider the chance to continually improve my knowledge about the topic. This possibility is extremely important because I can experience situations, no longer from the upstream side of the supply chain (as it was from the procurement) but from a "central side", slightly unbalanced towards the downstream of the process, the production.

Thanks to this opportunity I decided to focus my master thesis on this topic trying to develop an AHP analysis that could support manager in evaluate risks affecting the supply chain of the firm in an objective and methodic way. I would like to point out that this work does not suggest to substitute the experience and knowledge of managers about their way to work and awareness regard supply chain risks, rather I hope it may be useful to confirm their suppositions to maintain the robustness of the supply chain of Rossimoda.

The chapter reports an introduction about the firm in terms of its historical background, its values and its processes in order to understand how it is structured and which are the operations and flows it has to manage.
After that, there would be a section where would be presented the AHP analysis to individuate the risks that mostly affect the supply chain of the firm.

3.1 Rossimoda Spa: A leading company in luxury shoes industry

Rossimoda Spa is an historic firm engaged in the creation of luxury shoes born in 1947 in the heart of the footwear district of Venice, the Riviera del Brenta[86] district. The location in which the firm has set the stages is not casual, indeed, the economy of the Riviera del Brenta rotated around the footwear industries because of the agrarian crisis at the end of nineteenth century.
Today Rossimoda is one of the most famous reality of the area indeed it is synonymous with the excellence in the development and production of luxury footwear thanks to its ability to mix the tradition typical of craftsmanship realisations with the technological innovations in terms of processes to deliver the highest quality and best service to our customers. The notoriety of the firm increases as result of its acquisition by one of the most well known groups of the Fashion industries and strong-drink industries: LVMH Fashion Group[87].

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[86] is an area of the Metropolitan City of Venice that extends along the *Naviglio* of Brenta river, between Padua and Venice.

[87] literally *Louis Vuitton Moët Hennessy*, is a French multinational luxury goods conglomerate headquartered in Paris.

Despite of the entry of the Group, Rossimoda has been able to keep its mission, vision and core values on which it has been based on since its birth.

3.1.2 Historical background

The art of shoemaking dates back to the late 13th century in the Venice region thanks to the foundation of a corporation of shoemakers and cobblers called the Calegheri School, successively relocated to Campo S. Tomà, in the central position of the Island.

The effective beginning of a real entrepreneurial activity has to be attributed to Giovanni Luigi Voltan that, on the basis of the experience acquired in the most important footwear industry in USA, in 1898 promotes the first industrialised footwear manufacturing complex in Italy. This event changed radically the whole area since it encourages the flourishing of companies specialised in the footwear production, giving impetus to the economic growth of the Riviera del Brenta district, which lasted throughout and into the aftermath of World War II.

Exploiting this moment of economic progress, in 1947 Narciso Rossi, a self-made expert in shoe production, opened his small business specialised in handcraft traditional shoe-making settling its small workshop for women's shoes in Capriccio di Vigonza, which initially was limited to the production of one or two pairs a day.

The first real turning point is dated 1956 when Narciso lets the reins of the business to his son Luigino, supported by the brothers Diego and Dino. The aim of Luigino, in accordance with the will of his father was to enhance the family tradition but, at the same time, broaden the horizons of the company. Indeed, thanks to his cosmopolitan spirit, travelling between France, Italy and England, decide to produce only luxury shoes signed by great designers. In the 60s, the volumes required by its customers raised up and Luigino casted off the old production unit created by his father to build a new structure for about 150 employees, and contextually setting up other four facilities for the production of semi-finished goods (lasts, insoles, soles and heels) in order to asses the integration of the entire production chain and permitting a more efficient flow of materials and information.

The increasing value associated to the brand and the continuously improvements to maintain an efficient and stable value chain permits Rossimoda to acquire notoriety between the big brand of the Fashion and Luxury industry. In the same years the company acquired the license to produce women shoes for Yves Saint Laurent, whose collaboration will last for 38 years. Rossimoda created also others collaborations with the most prestigious fashion houses of that time such as created over the years as: Christian Dior, Givenchy, Emanuel Ungaro, Vera Wang, Christian Lacroix, Fendi, Calvin Klein, Marc by Marc Jacobs, Donna Karan, Kenzo and Porsche Design.

In 1975 the actual headquarter has been erected and formally named Rossimoda.

The 2001 represents for the company another important transformation due to the acquisition of principal global luxury group, LVMH, interested in the development potential and the renowned technical know-how of Rossimoda.

From 2011 and 2014, when, through a re-organization of the company structure, Rossimoda becomes part of the LVMH Fashion & Leather Goods Division obtaining the licensing conditions for the development and production of luxury shoes for some brands like Celine, Givenchy, Emilio Pucci and Nicholas Kirkwood. As we will see in further section, the acquisition does not only provoke a variation in the structure but in the whole organization without loosing the traditional characters to which it was based on when it was created by Narciso.

Nowadays Rossimoda counts almost 300 employees, 190 directs and 110 indirects. Only in the headquarter in Vigonza there are 220 employees equally distributed between white and blue collars. Indeed the headquarter presents all the staff offices, (as HR, IT, Finance, Planning and Procurement), the area engaged in product development and the production side. In the head office there are indeed all the technical production departments for the creation of the footwear that create the four brands collections.

Today Rossimoda represents the excellence in the industrial production of high quality footwear for elegant woman all over the world and in the last year, is watching the world of the men's fashion with an increasing interest.

Rossimoda has great expectations for the future. The company wants to keep up with the constant tendency to innovation and the search for novelties that distinguish the actual fashion system, as well as, facing with the LVMH Group the several challenges that characterise our contextual socio-economic situation: the digital transformation, the technological innovation, the orientation towards the product customization, the sustainability of the materials and processes adopted and the will to be the best-in-class on each product developed.

3.2.1 Organization and Processes

In order to well understand how the supply chain is organised in my opinion it is essential to understand how the organization is structured and which processes are involved in the value chain.

The main feature below the company consists of the will and the ability to be simultaneously a laboratory dedicated to research, development and innovation and, on the other hand, has a soul deeply rooted in production. This two aspects coexist, contaminate and influence each others but they strongly influence the production process.

Ideally the manufacturing process seems to be simple. It starts from the Style departments, specifically one for each Maisons in order to accurately understand the requests coming from the Brand. Technicals and product managers, after the periodic debate with the designers, create the prototype, that, once evaluated, modified and approved would become the same sample that would be exposed during commercial campaigns. Once the orders are received, they are elaborated by each Maison for each model presented. Only after the process department has assured the feasibility and has created the sizes, the production can start.

The **Figure 8** below shows the steps from the designer's idea to the delivery of the end-product.

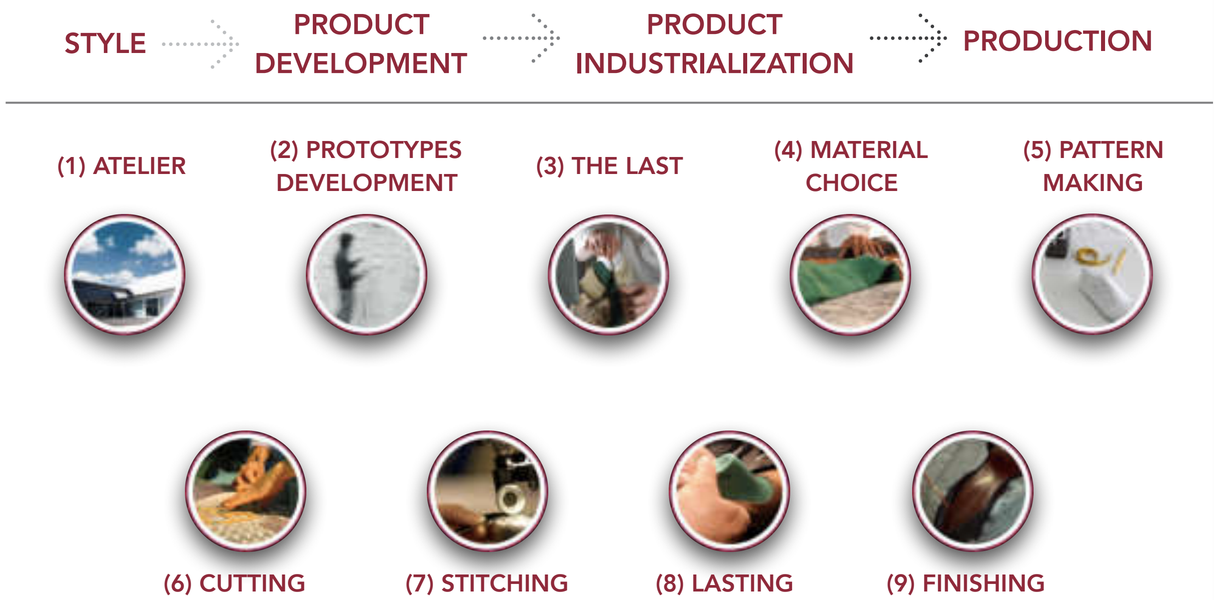

Figure 8 From the idea development to the end product

The production process starts from the Atelier, newly created in 2012 in the headquarter Rossimoda, where specialised people are in charge to translate the designers' ideas into real prototypes and samples that would be proposed in the future fashion collections by each brand.

Through a constant collaboration with the fashion house's designers to understand the essence of the new collection, the Rossimoda Product Managers begin the creative process to individuate the appropriate materials, colours and accessories. From the stylist's design, the first prototype is launched, starting from the lasts, that are specific for each shoe, followed by all the other structural components. The product developers transfers the style lines into the lasts so the pattern-makers can transform the new model into a CAD[88].

A whole department of Rossimoda is in charge of the creation of the shoe lasts essential to give shape to the shoe. The first model is hand-crafted in wood, then, the others, through the utilisation of numerically-controlled automated equipment that precisely re-produce the lasts in larger volumes to realise the massive production of that type of shoe.

The material choice follows the lasts production. The accuracy plays a key role during this phase indeed Rossimoda selectors' have to single out several different materials, as kid, calf, lambskin, suede, exotic skins, etc, with the highest quality but, at the same time, respecting the indications of the Product Managers. The satisfaction of the customers (meant as the Maisons) is the primary goal of each organization. Respecting their will means realising the shoe as they require, in terms of structure but also of materials and accessories. Can happen indeed that, in order to accomplish the brand, Rossimoda's suppliers have to create specific skins or accessories for the realisation of the shoe.

Thanks to the technological innovation, the pattern-makers can digitalize the style lines in order to process a 2D shoe samples to be displayed on the computer. Then all the components are extracted from the digitized shoe to proceed to the cutting stage.

In the meanwhile, the Planning Department, according to the indications in terms of volumes required by the Maisons, communicates to the Purchasing Department the requirements for each model in order to start with the procurement process, once confront with the Process Department. Note that, each time a sub-unit, meant as structural part of shoe (insoles, soles and heels), leathers or skims and accessories, is delivered, it has to pass meticulous quality controls[89]. Only after the Quality

[88] Computer-Aided Design. It implies the use of computers (or workstations) to aid in the creation, modification, analysis, or optimization of a design.

[89] the Quality Department is responsible for the conformity of SKU and single components and, later in the process production, for the quality of the end-product.

Department assures the conformity of the components, each SKU and semi finished good can be stocked to be withdrawn by the production line.

The cutting stage can take place in three different way: manual cutting, stamp cutting and automatic cutting. *Manual* implies the cutting of each single element through the ability of a skilled hand and a fibreboard as template; s*tamp* cutting involves the using a heavy press and a metal “cookie-cutter” of the pattern pieces; a*utomatic* cutting is an innovative system that through the support of cams, it cuts the skins with a laser.

The stitching is the step before the lasting stage. It involves the creation of the upper, assembling and applying the accessories, the decorative stitching and the lining and the insertion of reinforcements (toe-tip and heel) to provide greater support to the shoe.

The lasting is the stage in which all the disaggregate elements of the shoe, after have been entered in the assembly line, come out as end-product. This step involves the combination of expert hands and machine-assisted operations.

The whole production process ends with the finishing stage, in which the shoe is accurately cleaned inside and outside and given its finishing touches. The shoe is now ready to be packaged and then delivered to the boutique.

3.1.3 Rossimoda's supply chain structure: Pros and Limits

Developing and implementing a robust supply chain able to face with all the possible breakdown events that may occur all days is possible only through a continuous supervision. Over the years Rossimoda has demonstrated to have created and implemented its supply chain efficiently and efficaciously, developing a process that produce more than five hundreds pairs of hand-made shoes per day.

In the recent years, due to an inefficient waste of resources and raw materials, the firm has established to embrace a procurement technique based on the *make-to-order* approach. As discussed in the previous section, the make-to-order technique implies economic savings from one hand, and lack in responsiveness from the other.

The decision to move from a make-to-stock approach to a make-to-order approach has been deeply analyzed considering some essential aspects. The lack of responsiveness is partially contained because, first of all, Rossimoda has no more to forecast demand after the Group entry since it works over maisons' orders. In addition, the closeness to Riviera del Brenta District, permits to reduce considerably the lead-times to obtain materials in case of imminent requirements thanks also to the four controlled firms by Rossimoda. The Riviera del Brenta represents indeed the primary source of procurement of the firm concerning raw materials, semi-finished goods (as upper). Regarding the finished goods, the larger volumes is attributed to elegant woman shoes whose production takes place in Italy, between the Riviera del Brenta, Tuscany, Marche and Naples. Rossimoda collaborates also with foreign suppliers, specifically with Spanish and Portugal ones for the production of sneakers, vulcanised rubber product or espadrilles and Romanian ones for plastic components and sneakers production.

An important limits to consider over the procurement process is the technical lead-times which some components intrinsically have. Some skins for example are subject to non-variable lead-time due to their living nature. Lacquered and chromed heels, after been shaped, require a specific timing for the painting and drying.

The warehousing and production plant has been organised in order to promote efficiently goods and information exchange. Once raw materials and semi-finished goods are entered and asserted their quality, they are stocked according the SKU storage approach. In particular, leathers and accessories are stored close the cutting and stitching areas[90], while structure components, as heels, insoles, and soles are stored close to lasting lines. This structure permits to shorten the time and the distance to the relative process, permitting at the same time to follow a well established process.

Packaging and lasts are the only components not stored in the Rossimoda's headquarter. Indeed boxes and lasts requires huge amount of space to be stocked. They are located in a supporting warehouse and transferred when required through the using of daily milk run delivery solutions.

As well as the warehouse, also the production lines are organised to facilitate the flow of materials from an area to another with an efficient management of space and information exchange. The manufacturing process is developed through two lasting lines and consequently two finishing lines. Each lasting line is strictly linked to the relative finishing line, please note that where the lasting stage runs out the finishing stage starts that, in turn, ends on the packaging tables.

The Figure 9 in the next pages illustrates how the warehouse and the production plant is arranged.

[90] the cutting of leathers and the realisation of the upper (leathers with accessories) through the stitching

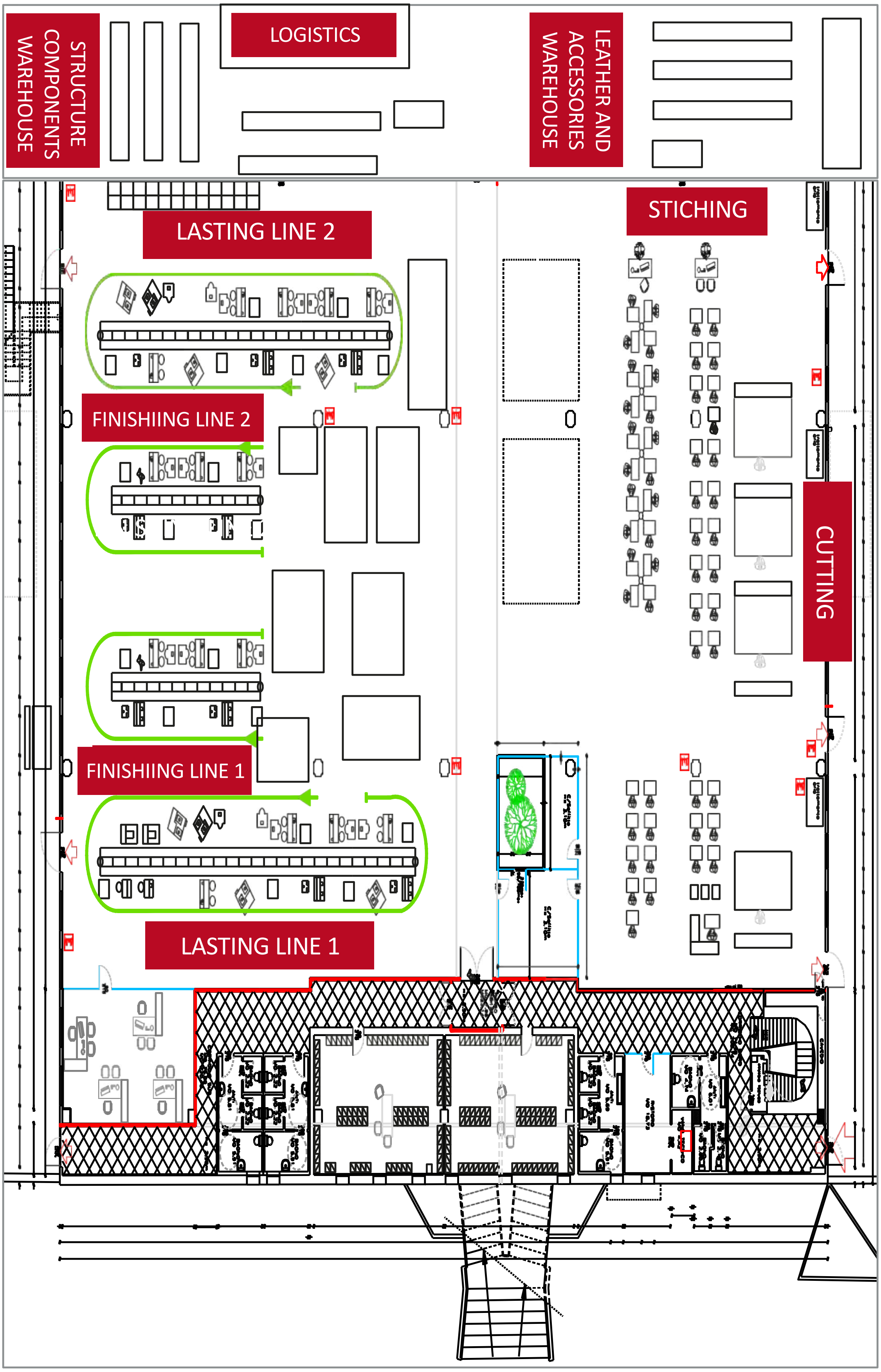

Figure 9 Warehouse and Production plant arrangement

In my opinion two are the key point on which the stability of the supply chain of the firm is based.
The first is strictly related to the ecosystem in which Rossimoda operates: Riviera del Brenta. Thanks to the presence of more the 130 shoe factories and 400 companies engaged in accessories production, technicians and sales agent in the shoe industry belonging to the Riviera del Brenta cluster offers to the firm the presence of a complete and integrated supply chain that provides a very rapid response to market needs and, at the same time, the sensitivity to style, taste, design, craftsmanship and rigorous attention to the detail. In addition, the Politecnico Calzaturiero, institution representative of Distretto della Calzatura della Riviera del Brenta, supports shoe makers training young employees that want to enter in the shoe industry and offering service to the firms. Rossimoda has always been able to exploit the synergies and the scale economies of the District and as well, with Luigino Rossi has broaden this ecosystem through the establishment of four new factories for the production of lasts, insoles, soles and heels. The positive results are demonstrated by the data of suppliers[91] that stock up the firm indeed more than 60% of them belongs to the District.
The second key point regards the acquisition by the multinational Group LVMH. Indeed, its entry not only had impact over the organisational structure but also in the configuration of the firm's supply chain. From one side the licensee agreements have facilitated the way to work of Rossimoda by avoiding them to spend time in forecasting the demand and to save money dictated by non accurate estimated procurement process. At the opposite side, the entry of the Groups has raised the complexity of the management of the other components of the supply chain due to the fact to deal with four different brands. Managing four brands involves respecting their will in terms of structures and materials and respecting their deadline. To make even more complex the production process are the capsules collections that the firm usually provides. They imply a specific process from the product development until

[91] meant as raw materials, semi-finished goods and end-products

the production stage, usually looking for extremely refined materials and very complex processes. Furthermore, as anticipated in the previous section, the ability to combine simultaneously the production and the product development

3.2 AHP Analysis on risks affected Rossimoda's supply chain

As suggested by the AHP technique the starting point of the analysis is aimed at defining the problem that implicitly identifies the purpose of the analysis.

As anticipated in the previous chapter the scope of the analysis consists in defining which are the risks, from an operational perspective, that mostly influence the supply chain of Rossimoda. The decision to focus entirely on operational risks lies on the activities and the application fields I have conducted during and after my internship period within the firm.

The support of firm's managers has been essential in designing the hierarchy structure and construct the pairwise comparison.

The business model of Rossimoda is not developed to satisfied directly the end-customers[92] but it works thanks to Maisons orders; in this sense meeting the brands requests represent the primary objective for the firm. So, the overall goal is defined by "*meeting the maisons' needs in order to achieve the customers value*". It does not only imply to produce and deliver finished goods but it involves several factors more or less important as: quality standards, deadlines, mix of products, ability to meet the intrinsic values each brand wants to deliver selling its products.

To construct the real cognitive map of the problem, we invited all managers involved in the supply chain management to define the criteria and the preferred classification of the risks. Three experts, logistics and warehousing manager, production and planning manager and procurement manager were interviewed.

[92] as described above Rossimoda does not have flagship stores neither it sells to wholesalers

According to Abdel M. et al[93] and confirmed by the managers experience, meeting the maisons' needs implies to identify the "perfect order" made of those factors which permit to achieve the customer value. The author identifies those factors as follow:

A. On-time delivery;
B. Order completion;
C. Free delivery of damage/defect.

Once identified the key criteria to achieve the goal, we have focused on determining all probable risks which affect the goal.

In accordance with the author and through managers' interviews, we have detected the risks that may cause disruption in the supply chain of the firm. The risks identified are:

- unplanned machine stoppages (R1_1)
- Warehousing and production interruption (R1_2)
- Lack of skilled people/low personnel polyvalence (R1_3)
- No transport solution alternatives (R2_1)
- Damages in transport (R2_2)
- Wrong transport reservation (R2_3)
- Serious forecasting errors (R3_1)
- Low integration/Miscommunication with final-product supplier (maisons) (R3_2)
- Low integration between intermediate suppliers (R4_1)
- Low quality of materials ordered (R4_2)

Those reported above are the most relevant risks on which the firm every day has to face with. Through a simple elaboration, we opt to classifying the risks suggested in four macro-categories: Manufacturing risks (R1_1, R1_2, R1_3), Transport and

[93] Abdel-Basset M., Gunasekaran M., Mohamed M., Chilamkurti N., *A framework for risk assessment, management and evaluatio: Economic tool for quantifying risks in supply chain*, Future Generation Computer System 90, (2019) 489-502

Logistics risks (R2_1, R2_2, R2_3), Planning and Control risks (R3_1, R3_2) and Supply risks (R4_1, R4_2).

The decision to organise the problem in such way derives by the need of synthesise the information. Filling pairwise comparison made of several lines, from one hand permits to obtain very detailed results, but at the opposite side, it leads to loose the general purpose of the analysis focusing on each specific single part.

The **Figure 10** here below illustrates the hierarchy structure of the analysis.

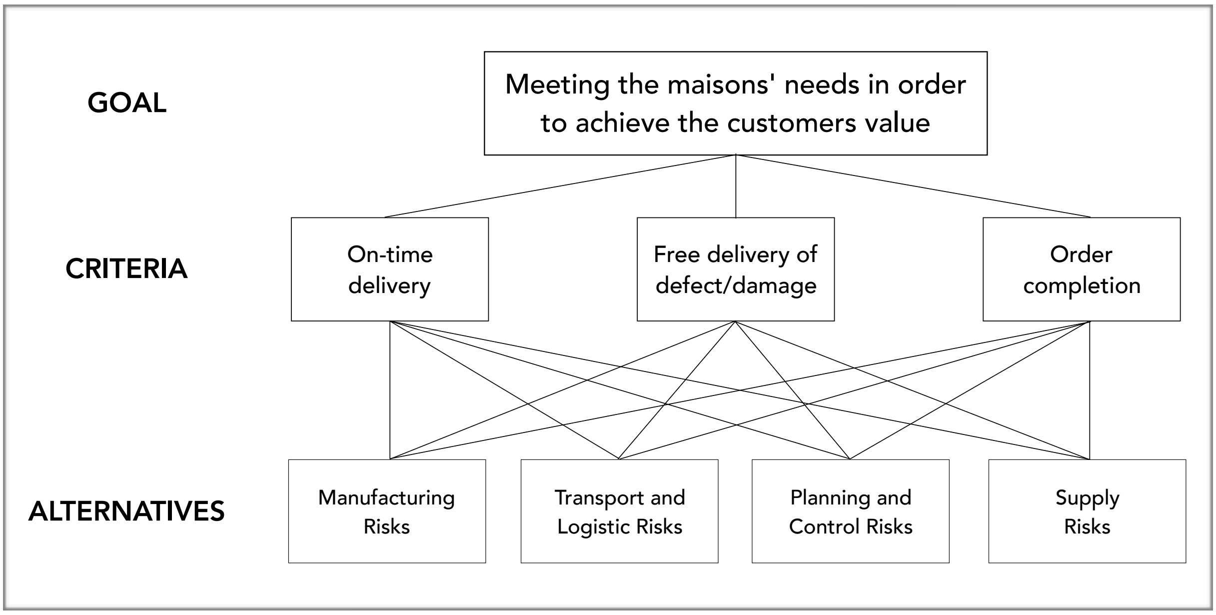

Figure 10 Analysis Hierarchy Structure

The next step involves to collect the data through the pairwise technique. A sample questionnaire to gather information about the perfect order and the sensitivity regard the risks identified is reported in **Appendix 4**.

The survey is organised in four parts. The first, "Instructions", illustrates the directives to follow to fill the it. The second, "Section A", represents the classification of the objectives in terms of their importance, with the aim to define the perfect order. The third, "Section B", reports all the risks individuated during the previous stage classified into their macro-categories. The four, "Section C" is composed by three under sub-sections since it contains the pairwise comparison of each macro-category risks with regard of the three objective.

In section A and C, in order to collect data through the pairwise comparison technique, it has been utilised the Likert Scale with a range from -7 to +7, evaluating the objectives in terms of their importance and the risks in terms of their riskiness. The adoption of this methodology permits to collect data without the formal utilisation of the Fundamental Scale of Pairwise Comparison. The Section C requires the manager arranges each specific risk in a table considering its degree of likelihood of occurrence against its impact over the supply chain of the firm. Organising a specific section not basing on pairwise comparison permits to obtain a more precise indication about which risks are potentially more dangerous for the supply chain of the firm, in order to not develop too complex and detailed pairwise comparisons analysis.

Once collected the data about objective importance and riskiness through the interviews and the questionnaire to each manager involved, we organised their relative pairwise matrixes (see **Eq. (2)**). As introduced above, the pairwise matrices have been structured thanks to the Likert Scale. For example, considering the case on the **Figure 11** below, the "Option A" is extremely more important than "Option B", in this sense, the entry "Option A against Option B" would be 7 and conversely, according to the condition of multiplicative reciprocity, its opposite "Option B agains Option A" would be 1/7[94].

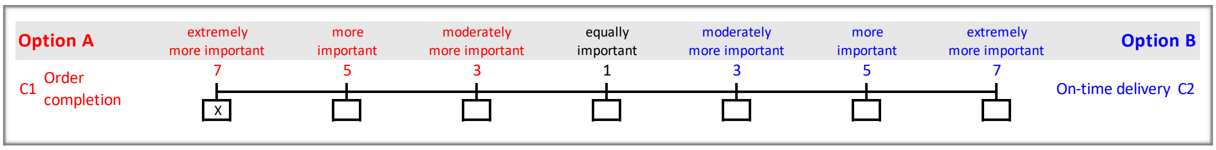

Figure 11 From the Likert Scale to the Pairwise Comparison matrix

[94] obviously the comparison of a Option agains itself has a value of 1

The following step involves the computation of the priority vectors thanks to the eigenvector methodology by using Eq. (4) or through the geometric mean technique Eq. (5), deriving the value associated to each risk category (alternatives) and the weight of each objective (criteria) relative to each alternative.
The whole process implies a continuous check of the consistency of decision maker's judgements through Eq. (6) and Eq. (7), to investigate the causes of the possible misalignment against the security range offered by the Monte Carlo scale.
The last step involves compounding in linear combination, Eq. (8), the weight associated to the vectors in order to obtain a rank that expresses the risk categories in terms of their importance over the impact on the supply chain of the firm.

The next pages contain the whole derivation for each one of the three managers with whom I have collaborated.

3.2.1 *Purchasing Manager risks' perceptions*

MATIRX COMPARISON

	R1	R2	R3	R4
R1	1	0,2	0,2	0,1
R2	5	1	1	1
R3	5	1	1	0,3
R4	7	1	3	1

RANK

GEOMETRIC MEANS		RANK
0,27494162	0,054474036	4
1,495348781	0,296272651	2
1,136219366	0,225118533	3
2,140695143	0,42413478	1
5,047204911		

CI COMPUTATION

EIGENVALUES ESTIM.	
0,219342955	4,026559676
1,217896143	4,110727524
0,935139623	4,153987721
1,77708128	4,189897565
CI	4,010%

Table 4 Risks pairwise comparison relating to "On-time delivery"

The idea underlying the entries provided by the purchasing manager lies on the fact that all risks that imply a new procurement section are the most relevant. In this sense, she defines thefts and damages during transportation and even more low quality of materials and problems in purchasing area the most critical situations for the supply chain of Rossimoda. She suggests that risks regarding manufacturing process are more manageable through recurring service on the machinery.

MATIRX COMPARISON

	R1	R2	R3	R4
R1	1	7	5	3
R2	0,14	1	0,33	0,2
R3	0,2	3	1	0,3
R4	0,33	5	3	1

RANK

GEOMETRIC MEANS		RANK
3,201085873	0,563812769	1
0,312393994	0,055022492	4
0,668740305	0,117786382	3
1,495348781	0,263378357	2
5,677568953		

CI COMPUTATION

EIGENVALUES ESTIM.	
2,328037195	4,129096257
0,227504972	4,134763129
0,483409198	4,104117897
1,079787553	4,099758107
CI	3,898%

Table 5 Risks pairwise comparison relating to "Free delivery of defect/ damage"

The purchasing manager considers null Transport and Logistic risks for a delivery free of defect and damage since the physic characteristics of the product. The impact of risk on the objective increases considering risks typical of planning process and more again in case of threat regarding the manufacturing process. The most critical category remains the supply risks due to the complexity and the highest quality standards of raw materials and semi-finished goods the firm requires.

MATIRX COMPARISON

	R1	R2	R3	R4
R1	1	3	0,14	0,3
R2	0,33	1	0,14	0,2
R3	7	7	1	1
R4	3	5	1	1

RANK

GEOMETRIC MEANS		RANK
0,614788153	0,110954103	3
0,312393994	0,056379413	4
2,645751311	0,477492874	1
1,967989671	0,35517361	2
5,540923129		

CI COMPUTATION

EIGENVALUES ESTIM.	
0,466696813	4,206215022
0,232612104	4,125834079
2,004001093	4,196923559
1,447425857	4,075262958
CI	5,035%

Table 6 Risks pairwise comparison relating to "Order completion"

According to the procurement manager, the order completion strictly depends on the planning process. In this sense, serious forecasting errors in terms of internal or external capacity have strong impact over the achievement of the goal although because incurring in those risks, in most cases, does not permit the firm to redress the balance.

Now that we have attributed a score to each alternative relative to the criteria considered, we compute the weight to associate to each risk category.

MATIRX COMPARISON

	C1	C2	C3
C1	1	5	5
C2	0,2	1	0,33
C3	0,2	3	1

RANK

GEOMETRIC MEANS		RANK
2,924017738	0,700710858	1
0,405480133	0,097169155	3
0,843432665	0,202119987	2
4,172930537		

CI COMPUTATION

EIGENVALUES ESTIM.	
2,197156566	3,135610845
0,304684655	3,135610845
0,633769623	3,135610845
CI	6,781%

Table 7 Objectives pairwise comparison

As shown on Table 8, the purchasing manager identifies the perfect order to meet the customers' needs according the following rank:

I. On time delivery
II. Order completion
III. Free delivery of defect/damage

The reason why the free delivery of defect/damage is placed as third factor is not due to importance Rossimoda associates to the quality indeed the respect of quality standards are mandatory for launching the product to the market. It implies that, once the product can be sold it means that the quality standards have been respected. The punctuality of the delivery is considered also more important than the order completion. According to the purchasing manager the punctual even if partial delivery is preferable since permits the brands to provide goods for wholesalers and retailers.

The last step is aimed at defining the total rank concerning riskiness of the categories analysed. By multiplying the normalised priorities to each alternative for the relative criterion as shown in Table 8 and blending the value obtained through a linear combination as in Table 9 we extract the priority vector.

OBJECTIVES		WEIGHT		RISKS		PRIORITIES		
C1	On-time delivery	0,700710858	x	R1	Manufacturing/Operational Risks	0,054474036	=	0,038170548
			x	R2	Transport and Logistic Risks	0,296272651	=	0,207601464
			x	R3	Planning and Control Risks	0,225118533	=	0,157743001
			x	R4	Supply Risks	0,42413478	=	0,297195846
C2	Free delivery of defect/damage	0,097169155	x	R1	Manufacturing/Operational Risks	0,563812769	=	0,05478521
			x	R2	Transport and Logistic Risks	0,055022492	=	0,005346489
			x	R3	Planning and Control Risks	0,117786382	=	0,011445203
			x	R4	Supply Risks	0,263378357	=	0,025592252
C3	Order completion	0,202119987	x	R1	Manufacturing/Operational Risks	0,110954103	=	0,022426042
			x	R2	Transport and Logistic Risks	0,056379413	=	0,011395406
			x	R3	Planning and Control Risks	0,477492874	=	0,096510853
			x	R4	Supply Risks	0,35517361	=	0,071787685

Table 8 Linear combination of alternatives with relative weights

		On-time delivery C1	Free delivery of defect/damage C2	Order completion C3	TOTAL	FINAL RANK
Manufacturing/Production Risks	R1	0,038170548	0,05478521	0,022426042	0,1153818	4
Transport and Logistic Risks	R2	0,207601464	0,005346489	0,011395406	0,224343359	3
Planning and Control Risks	R3	0,157743001	0,011445203	0,096510853	0,265699057	2
Supply Risks	R4	0,297195846	0,025592252	0,071787685	0,394575783	1

Table 9 Final rank perceptions

According to the purchasing manager perceptions over the most critical risks affected the supply chain of Rossimoda, the Supply risks represent the primary threat, followed by Planning and Transport risks. Risks relating to manufacturing and production are considered the less dangerous for a possible supply chain breakdown.

The accuracy of the results obtained are proved in first instance by the low inconsistency indices obtained from the information transferred and confirmed by the heat-map filled during her interview (**Figure 12**). Despite several controls over the quality of the materials ordered it remains a risks with a likely probability of occurrence that may implicate critical consequences over the supply chain in particular in case of capsules or special orders. Serious forecasting errors is another critical risks particularly in case of decisions taken with an imminent cancel date.

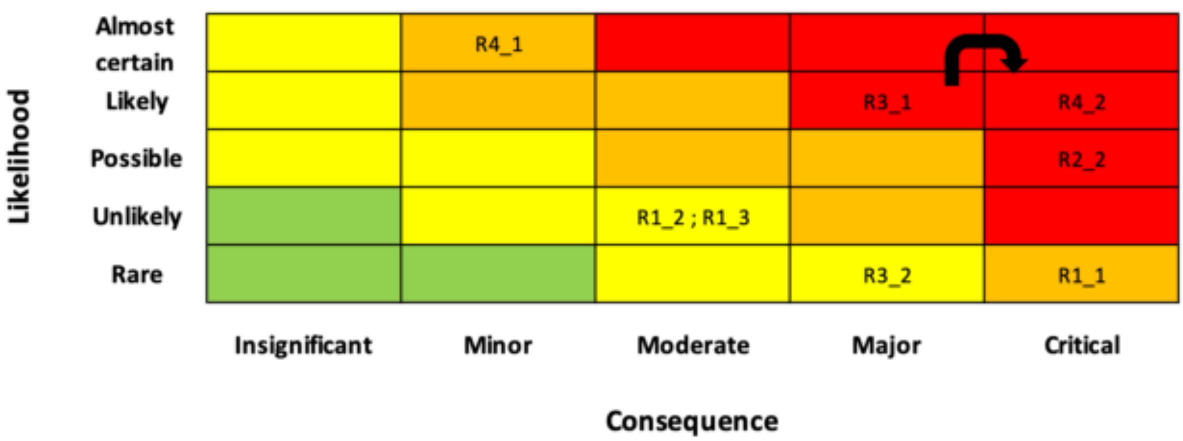

Figure 12 Purchasing manager's risks heat-map

3.2.2 Logistic and Warehouse Manager risks' perceptions

As far as "On-time delivery" is concerned the Logistic and Warehouse manager considers supply risks the more impacting over the supply chain of Rossimoda. Supply risks are particularly threatening in case of capsules rather than with carryover[95] orders. The production of special orders implies a continuous change of raw materials and consequently suppliers and as well in terms of particular manufacturing techniques. Thus has a strongly impact over the warehousing management especially if it is organised according the Make-to-Order approach. Table 10 reports the the normalised priorities according to the criteria analysed.

MATIRX COMPARISON

	R1	R2	R3	R4
R1	1	3	0,33	0,1
R2	0,33	1	0,33	0,1
R3	3	3	1	0,3
R4	7	7	3	1

RANK

GEOMETRIC MEANS		RANK
0,614788153	0,10658944	3
0,354948106	0,061539442	4
1,316074013	0,228175497	2
3,482004545	0,603695621	1
5,767814817		

CI COMPUTATION

EIGENVALUES ESTIM.	
0,453508497	4,254722567
0,259369986	4,214695119
0,933794018	4,092437748
2,465124288	4,083389384
CI	5,377%

Table 10 Risks pairwise comparison relating to "On-time delivery"

According to the Warehouse and Logistic Manager Supply risks and Manufaturing/ Production risks are the most dangerous in terms of the quality of the product delivered. The several stages to produce the premium quality shoes and the defects caused by non compliant raw materials and semi-finished goods are the most frequent reasons that lead the firm to generate wastes of end-product. He agrees with the Purchasing Manager considering Transport and Logistic risks almost irrelevant. since when the product is delivered it has already passed numerous controls that certificate its conformity to enter in the market. The only defect it may

[95] production of the same product year after year

exhibit concerns the packaging considered unnecessary to the eyes of the consumers.

Table 11 illustrates the manager's perceptions of risk against the objective.

MATIRX COMPARISON

	R1	R2	R3	R4
R1	1	7	5	1
R2	0,14	1	3	0,2
R3	0,2	0,33	1	0,1
R4	1	5	7	1

RANK

GEOMETRIC MEANS		RANK
2,432299279	0,425370313	1
0,541082269	0,094626651	2
0,312393994	0,054632722	3
2,432299279	0,425370313	1
5,718074821		

CI COMPUTATION

EIGENVALUES ESTIM.	
1,786290794	4,199378135
0,404366068	4,273278878
0,23201619	4,246835593
1,706302937	4,011335259
CI	6,090%

Table 11 Risks pairwise comparison relating to "Free delivery of defect/ damage"

According to the last criteria, "Order completion", the manager locates Supply risks and Planning and Control risks "at the summit" of the priority vector. If the planners are unable to transmit the right priorities to the procurement department the production would be unable to respect the deadline meeting the order mix required by the brand particularly in case of materials that require long production time. Once again risks associated to Transport and Logistic side are almost negligible except in the case of wrong transport reservation that in most cases is easily resolvable save imminent cancel date. **Table 12** below reports the normalised priorities.

MATIRX COMPARISON

	R1	R2	R3	R4
R1	1	5	1	1
R2	0,2	1	0,14	0,1
R3	1	7	1	1
R4	1	7	1	1

RANK

GEOMETRIC MEANS		RANK
1,495348781	0,298994291	2
0,252760077	0,050539259	3
1,626576562	0,325233225	1
1,626576562	0,325233225	1
5,001261982		

CI COMPUTATION

EIGENVALUES ESTIM.	
1,202157038	4,020668867
0,203261896	4,021861387
1,303235557	4,007080021
1,303235557	4,007080021
CI	0,472%

Table 12 Risks pairwise comparison relating to "Order completion"

The attitude towards the perfect order to meet customers' needs is totally aligned to the purchasing manager one.

According to him, the way in which a firm organises its warehousing and logistic management defines the correct perfect order to follow. Adopting a Make-to-Stock approach implies that the timely delivery and the order completion acquires the same importance. Following a Make-to-Order approach is the preferential way for the Lean Production but it increases the complexity on the warehousing management leading defect over both, the On-time delivery and Order completion. **Table 13** reports the priority vector of the criteria.

MATIRX COMPARISON				RANK			CI COMPUTATION	
	C1	C2	C3	GEOMETRIC MEANS		RANK	EIGENVALUES ESTIM.	
C1	1	7	5	3,27106631	0,730644671	1	2,239343779	3,06488758
C2	0,14	1	0,33	0,362460124	0,080961232	3	0,248137074	3,06488758
C3	0,2	3	1	0,843432665	0,188394097	2	0,577406727	3,06488758
				4,4769591				
							CI	3,244%

Table 13 Objectives pairwise comparison

To conclude **Table 14** and **Table 15** illustrates the rankings relative to the different criteria that once combined linearly define the total decision.

OBJECTIVES		WEIGHT		RISKS		PRIORITIES		
C1	On-time delivery	0,730644671	x	R1	Manufacturing/Production Risks	0,10658944	=	0,077879007
			x	R2	Transport and Logistic Risks	0,061539442	=	0,044963465
			x	R3	Planning and Control Risks	0,228175497	=	0,166715211
			x	R4	Supply Risks	0,603695621	=	0,441086988
C2	Free delivery of defect/damage	0,080961232	x	R1	Manufacturing/Production Risks	0,425370313	=	0,034438505
			x	R2	Transport and Logistic Risks	0,094626651	=	0,00766109
			x	R3	Planning and Control Risks	0,054632722	=	0,004423133
			x	R4	Supply Risks	0,425370313	=	0,034438505
C3	Order completion	0,188394097	x	R1	Manufacturing/Production Risks	0,298994291	=	0,056328759
			x	R2	Transport and Logistic Risks	0,050539259	=	0,009521298
			x	R3	Planning and Control Risks	0,325233225	=	0,06127202
			x	R4	Supply Risks	0,325233225	=	0,06127202

Table 14 Linear Combination of alternatives with relative weights

		On-time delivery C1	Free delivery of defect/damage C2	Order completion C3	TOTAL	FINAL RANK
Manufacturing/Production Risks	R1	0,077879007	0,034438505	0,056328759	0,168646271	3
Transport and Logistic Risks	R2	0,044963465	0,00766109	0,009521298	0,062145854	4
Planning and Control Risks	R3	0,166715211	0,004423133	0,06127202	0,232410363	2
Supply Risks	R4	0,441086988	0,034438505	0,06127202	0,536797513	1

Table 15 Final rank perceptions

As shown in the table above, the manager perception's about risk is almost in line with the Procurement manager ones with a greater unbalance towards the Supply Risks. It means that the Warehouse and Logistic manager considers supply risks as extremely more dangerous for supply chain disruptions than risks belonging to other categories. The manager places Transport and Logistic Risks at the last position of the rank. Indeed, according to him, the risks that affect the initial side of the supply chain are more hazardous than the ones affecting the end of the chain. Once a non-perishable good has been manufactured and packaged the risks to not meet the customers' needs is very low.

The Figure 13 below displays the manager's perceptions over supply chain risks.

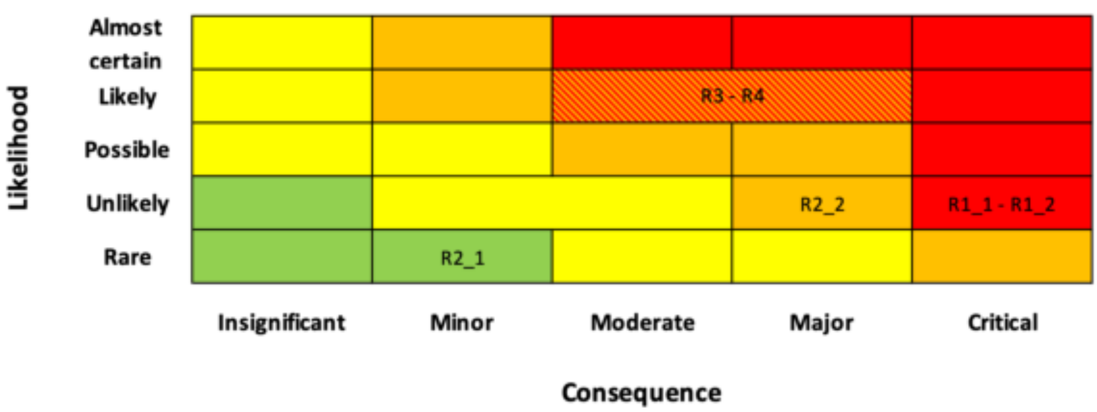

Figure 13 Warehouse and Logistic manager's risk heat map

3.2.3 Production Planner Manager risks' perceptions

The aim of the planning department consists on offering continuity to the production set up looking at the effectiveness in the short term and at the efficiency in the middle and long term. In this sense the purpose of the planning department is meeting the goal in the first instance and developing over time an efficient process.

MATIRX COMPARISON

	R1	R2	R3	R4
R1	1	3	1	0,3
R2	0,33	1	0,33	0,2
R3	1	3	1	0,3
R4	3	5	3	1

RANK

GEOMETRIC MEANS		RANK
1	0,200959887	2
0,386097395	0,077590089	3
1	0,200959887	2
2,590020064	0,520490138	1
4,976117459		

CI COMPUTATION

EIGENVALUES ESTIM.	
0,808186752	4,021632207
0,315661374	4,068320829
0,808186752	4,021632207
2,114199901	4,061940363
CI	1,446%

Table 16 Risks pairwise comparison relating to "On-time delivery"

As shown in **Table 17** Supply risks once again represents the more significant factors for possible breakdowns of the supply chain of the firm. According to the production planner manager, low quality of materials ordered and delays on the procurement process implies that the production can not start forcing the other departments, particularly the planning, to take immediate decisions to try to control the problem. These decisions regards changes about the production mix and priorities, support by external suppliers and decisions and forecasts about internal and external capacity. A more precise focus should take into consideration dealing with low quality of materials that may cause delays on the delivery. Three distinct situations can occur: the first concerns the low quality of skins, accessories and shoes structure components, the second looks at the semi-finished goods and the third focuses on the end-products. The low quality of skins, accessories or components has an high impact over the process since the process cannot start[96] but a limited impact over the cost. The low quality of semi-finished goods has an high impact over the process since the process has already started, and due to the flaw, it has to restart while a medium impact over the cost depending on whether the shoes structure can be re-used. The worst situation consist of the low quality of the end-product; it implies restart the procurement process of upper and shoes structure materials and it has a great impact both, over the process and the cost.

Manufacturing/Production risks are considered as dangerous as Planning and Control ones. The first are almost rare in terms of likelihood but at the opposite their occurrence may cause great dissatisfaction over the customers' needs, oppositely, Planning and Control risks are more common in terms of frequency but, in most cases have less impact on the stability of the supply chain.

The idea below the Free delivery of defect/damage is common to the other managers. The more relevant risks to the satisfaction of the objective are the Manufacturing/Production. The difficulty is associated with the operator who has to create completely new products able to meet the highest quality standards required by the Brands. The considerations about Supply, Transport and Logistic and Planning and Control risks are similar to the one of the previous managers. **Table 17** shows in detailed the results obtained.

MATIRX COMPARISON

	R1	R2	R3	R4
R1	1	5	5	3
R2	0,2	1	0,33	0,2
R3	0,2	3	1	0,3
R4	0,33	5	3	1

RANK

GEOMETRIC MEANS		RANK
2,942830956	0,540293269	1
0,339808849	0,062387693	4
0,668740305	0,122778335	3
1,495348781	0,274540703	2
5,446728892		

CI COMPUTATION

EIGENVALUES ESTIM.	
2,289745518	4,23796788
0,266280599	4,268159101
0,509513635	4,149865974
1,134911929	4,13385671
CI	6,582%

Table 17 Risks pairwise comparison relating to "Free delivery of defect/damage"

[96] the upper cannot be produced

As far as the order completion is concerned the planning department is the primary responsible for the achievement of this objective even if its realisation depends on factors associated to others unit-centres as procurement and industrialisation divisions. Whether the timings of the Procurement unit and Industrialisation unit are aligned the Planning department has been able to schedule the production respecting the deadline imposed by the brands forecasting the possible problems that may arise during the process in order to be able to overcome them. During the whole manufacturing process, the production planning division collaborates with the quality control divisions to assure the conformity of the end-product.

Table 18 illustrates the implications described above.

MATIRX COMPARISON

	R1	R2	R3	R4
R1	1	3	0,33	0,2
R2	0,33	1	0,2	0,1
R3	3	5	1	0,3
R4	5	7	3	1

RANK

GEOMETRIC MEANS		RANK
0,668740305	0,117786382	3
0,312393994	0,055022492	4
1,495348781	0,263378357	2
3,201085873	0,563812769	1
5,677568953		

CI COMPUTATION

EIGENVALUES ESTIM.	
0,483409198	4,104117897
0,227504972	4,134763129
1,079787553	4,099758107
2,328037195	4,129096257
CI	3,898%

Table 18 Risks pairwise comparison relating to “Order completion”

Generally the planning division considers the three objectives equally important to meet the customers’ satisfaction. For this, theoretically, it has to have a central sight with the aim collect the information, process them and push the other actors involved to the stages to perform according the deadline considering the timing needed to the whole process. In reality some unexpected events make one objective prevail over another. Whenever the company takes charge of a new order, the timing, its evasion and the quality of the product are agreed beforehand with the customer.So, the production planning manager considers the punctuality of the delivery and the order completion equally important. The quality is not a secondary purpose for the firm but, as anticipated above, it can be considered as a precondition and an intrinsic features in the way in which Rossimoda works.

Table 19 shows this relation.

MATIRX COMPARISON				RANK			CI COMPUTATION	
	C1	C2	C3	GEOMETRIC MEANS		RANK	EIGENVALUES ESTIM.	
C1	1	3	1	1,44224957	0,428571429	1	1,285714286	3
C2	0,33	1	0,33	0,480749857	0,142857143	2	0,428571429	3
C3	1	3	1	1,44224957	0,428571429	1	1,285714286	3
				3,365248997				
							CI	0,000%

Table 19 Objectives pairwise comparison

By combining the judgements with the relative criteria (Table 20) and summing the results obtained we extract the complete decision of the manager (Table 21).

OBJECTIVES		WEIGHT		RISKS		PRIORITIES		
C1	On-time delivery	0,428571429	x	R1	Manufacturing/Production Risks	0,200959887	=	0,086125666
			x	R2	Transport and Logistic Risks	0,077590089	=	0,033252895
			x	R3	Planning and Control Risks	0,200959887	=	0,086125666
			x	R4	Supply Risks	0,520490138	=	0,223067202
C2	Free delivery of defect/damage	0,142857143	x	R1	Manufacturing/Production Risks	0,540293269	=	0,077184753
			x	R2	Transport and Logistic Risks	0,062387693	=	0,008912528
			x	R3	Planning and Control Risks	0,122778335	=	0,017539762
			x	R4	Supply Risks	0,274540703	=	0,0392201
C3	Order completion	0,428571429	x	R1	Manufacturing/Production Risks	0,117786382	=	0,050479878
			x	R2	Transport and Logistic Risks	0,055022492	=	0,023581068
			x	R3	Planning and Control Risks	0,263378357	=	0,112876439
			x	R4	Supply Risks	0,563812769	=	0,241634044

Table 20 Linear Combination of alternatives with relative weights

		On-time delivery C1	Free delivery of defect/damage C2	Order completion C3	TOTAL	FINAL RANK
Manufacturing/Production Risks	R1	0,086125666	0,077184753	0,050479878	0,213790296	3
Transport and Logistic Risks	R2	0,033252895	0,008912528	0,023581068	0,065746491	4
Planning and Control Risks	R3	0,086125666	0,017539762	0,112876439	0,216541866	2
Supply Risks	R4	0,223067202	0,0392201	0,241634044	0,503921346	1

Table 21 Final rank perceptions

The results obtained are not totally different from the one derived from the previous analysis. The supply risks once again are considered the most dangerous for the supply chain maintenance. According to the manager's perception Manufacturing/Production risks and Transport and Logistic risks have almost the same level of risks.

The **Figure 14** below shows the manager's perceptions specifically to each risks taken into consideration. As anticipated above the Manufacturing/Production risks have moderate effects because of the several maintenance of the machine and because the capacity is determined according to the history of the production process of the firm accurately measured and tracked day by day. The Transport and Logistic risks are almost always negligible since, being at the end of the chain a solution can be easily find particularly in a dynamic and flexible industry as the fashion one. Planning and Control risks concerns although errors in forecasting internal and external capacity that are very likely because of the continuous stream of standard orders, capsules and carry-over production, the whole amplified by the Make-to-Order approach applied to the Warehousing Management. The low integration with the brand regards specially the mix of product and the order completion rather than the volume requested. According the production planning manager Supply risks are the most impactful for the continuity of the supply chain and they have a great influence over the planning process. The planning behaviour depends on the lead times provided by the purchasing department in order to schedule the internal and external production. The intermediate suppliers have to be perfectly aligned and have to respect the priorities in order to permit the planners to communicate the right input to the operators to meet the brand's requests.

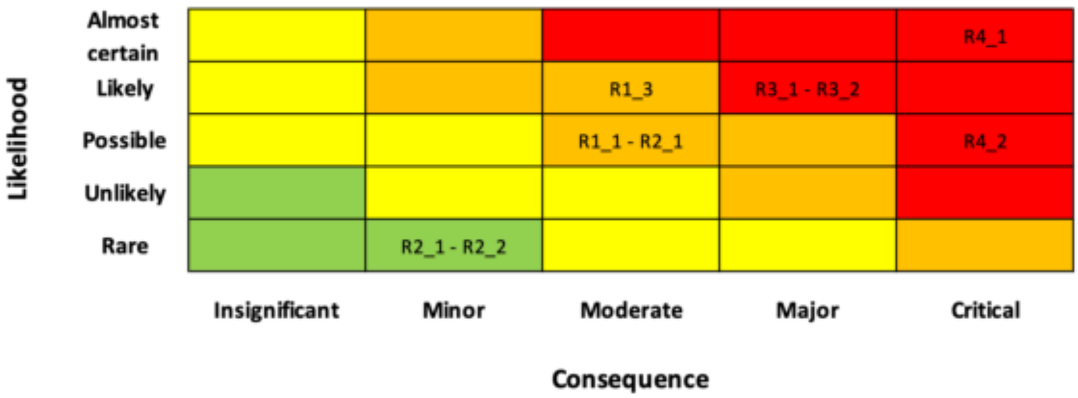

Figure 14 Production planner manager's risk heat map

The **Appendix 5** illustrates the computation of the whole analysis through the use of the software R.

3.2.4 Summing up

In my opinion the analysis carried out some interesting details.

First of all, the priority vector has individuated an aligned vision of all the managers over the perfect order to follow in order to achieve the customers' needs, with acceptable inconsistency rates.

The priority vectors of the managers are:

Pur-Man = (0.70071,0.09716,0.20211)

LogWar-Man = (0.73064,0.08096,0.18839)

ProdPlan-Man = (0.42857,0.14285,0.42857)

Considering these results, the criteria to meet the customers' needs individuates the On-time delivery as the more important factor, followed by the Order completion and, as last, the Free delivery of defect/damage.

From the rank obtained it seems the quality of products created by Rossimoda is not perceive as an important aspect over the managers' perceptions. Managers pointed out to me that the free delivery of defect/damage, placed at the last position, in reality needs a more detailed explanation. Rossimoda does not conceive producing shoes with some damages indeed a milestone of the production of the firm is the highest quality its products are realised with, but, during the multiple production stages may happen that some of them may be ruined. In this sense, the implication to take into account regards the extent of the damage in an end-product. Before to be launched in the market the products have to overcome several quality controls so, it implies that the damage or defect was really imperceptible to the end-customer having the approval of the quality standards.

It demonstrates how the respect of the highest quality standards is an intrinsic objective for the firm. The meaning the managers have wanted transmitting to the reader is that, if the product has the concession to be delivered it means it has overcome several quality controls and any imperceptible defect is less important than a punctual delivery and the order completion.

Despite the perceptions of individual managers regarding the riskiness of the elements analysed and the considerations presented, the final ranks obtained combining the judgments with the relative criteria demonstrates a polarisation on the managers' perceptions over risks that mostly influence the supply chain of Rossimoda. According to two of them, Transport and Logistic risks are those that have the least impact on the supply chain although because they affect the last part of the chain but also because of their reduced frequency. Manufacturing and Production risks are, according to the rank obtained, at an intermediate position in terms of riskiness. Despite the low probability of occurrence deriving from the periodic maintenance of the machinery with the aim to avoid production interruptions and trying to develop a technical polyvalence among the personnel, the risks related to the production can cause serious damages to the maintenance of the supply chain. Manufacturing and Production risks are particularly serious if production is forced to stop because it implies a probable delay of the delivery. Another unfavourable situation occurs when one or more products are damaged during production process due to technical errors of the personnel or due to the incorrect setting of a machine. Being the warehousing organised according to the Make-to-Order logic, damages during the lasting process usually lead to a new procurement of both, the upper (and relative accessories) and the structure components.

Planning risks take second place in the ranking of all managers involved in the analysis. According to them the major issues to consider are internal and external capacity and the management of external semi-finished products suppliers.

The internal and external production scheduling of a well-established company may seem to be a not extremely complex operation thanks to the large availability of historical data on which the planners can rely to create projections but, in reality, planning the production in fashion industry is extremely difficult.

Timing, deadline and operation times are not the only variables to take care. Typically, during standard production, the planner must take into account special orders, capsules and samples that may have imminent urgencies.

Furthermore, the planning work depends strictly on that of the Purchasing department and vice versa. From on side the Planning department schedules the production according to the data timing provided by the Procurement department indeed, the delay in the delivery of some materials obliges the planner to re-evaluates the production plan taking into consideration the new information acquired. On the other hand, the Planning department must be able to transfer the correct information and convey the priorities to the Purchasing department so that it can solicit the materials ordered according to the needs communicated to it in advance.

Precisely because the supply chain process starts with the procurement process, supply risks are perceived by all managers as the riskiest for a possible supply chain failure. The absence of materials to start production invalidates all the objectives necessary to achieve customer satisfaction particularly the on-time delivery and the order completion as well as causing problems in the delivery mix. Furthermore, working according to a Make-to-Order approach, the timing of the ordered components must be in line with the production requirements to favour continuity in the production process. In order to avoid this situations the Purchasing manager and her team work providing visibility to its suppliers. It involves to communicate quantities and technical requirements of the materials to the suppliers in advance, before to formally placing the order, to reserve part of its capacity and favouring them in their procurement process.

The **Figure 15** graphically illustrates the managers' perceptions over risks affecting the supply chain through a radar chart.

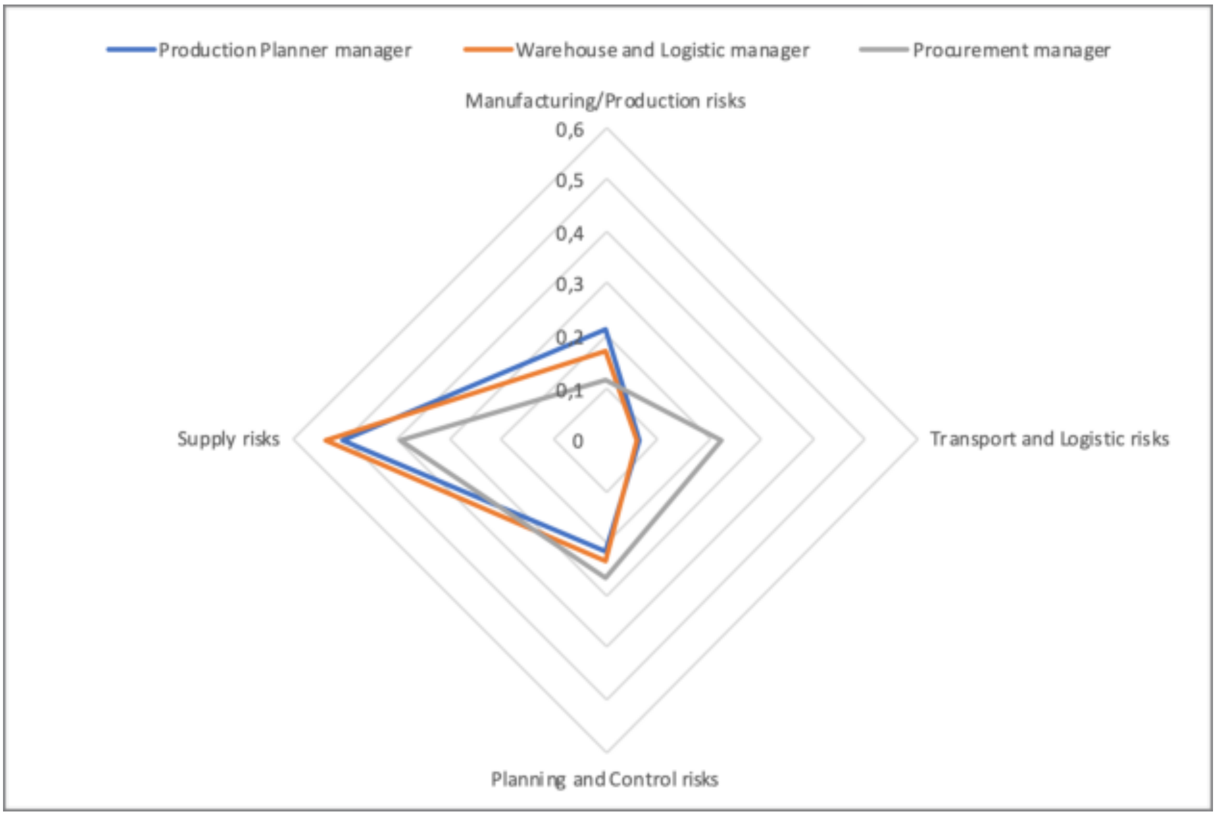

Figure 15 Polarization of managers’ perceptions regard risks

CONCLUSION

As experienced by several firms of any industry, the supply chain disruptions do not only cause enormous economic losses but usually their consequences lead the firms to suffer for long time. Furthermore, in the actual dynamic environment in which companies operate, factors as globalisation, digitalisation, the ebbing of new policies, from one hand offer to the firm new opportunities of doing business or the possibility to extend the one in which the operate but, at the opposite side, the exposition to risks of their supply chain increases.

This dissertation arise with the intent to offer to the reader a brief explanation of the discipline of supply chain risk management (SCRM) providing a mathematical tool to measure risks affecting the supply chain of an industry. Indeed, its main purpose was to outline the risks that mostly influence the supply chain of the firm through the use of basic tools that permit to analyse their impact limiting the degree of the subjectivity of the decision maker.

Establishing an efficient SCRM strategy is a compelling challenge being the supply chain of a given firm strictly related to the supply chain of its primary and secondary suppliers and customers. In this sense, its robustness strongly depends on the performance of those entities involved in the chain and on their ability to manage their relative supply chains.

From this, it borns the need to adopt some initiatives aimed at limiting the risks affecting the supply chain of the firms. The ISO 31000 identifies a framework and a process to manage risk suitable for each discipline, comprised the supply chain management. Even if its theory can be enforced in each field, its practical application may be different from an industry to another because of the different risks and implications at the basis of each sector. Particularly in performing Risk Analysis and Evaluation, even more companies feel the need to combine qualitative techniques, usually characterised by an high degree of subjectivity from the decision maker, with quantitative ones since they permit to limit the subjectivism. Thanks to the great applicability of the AHP technique we opt to adopt this methodology in order to define which are the risks that more influence the supply chain of Rossimoda. The results obtained have showed unexpected details due to a strong polarisation in terms of managers' perceptions about objectives and risks. Despite the difference application fields, they have individuate the same perfect order to follow in order to meet the customers needs that, in terms of importance, it illustrates at the top the punctual delivery, followed by the order completion and, at the bottom, the delivery in quality conformity. In terms of riskiness, at the top they have individuated the Supply risks followed by those related to Planning and Control. Manufacturing/Production and Transport and Logistic risks seems to be less relevant for the supply chain breakdowns.

If from one side the AHP methodology allows us to individuate the risks levels by attributing a numerical value to each risk category analysed reducing the subjectivity of the DM, the research also presents some limits.

Firstly the case study has evaluating operational risks only. Operational risks are not the only that may cause supply chain disruptions; in order to develop a broader study, it has to take into account also the other types of risks that affect the normal functionality of the supply chain: strategic, hazard and financial.

Secondly, the outcomes provided by the investigation should not be considered universally accepted. The results are based on some fundamental implications that managers have considered in filling the questionnaire. Essentially the whole analysis has been carried out assuming the firm in presence of a normal conditions, in absence of particular circumstances as an imminent cancel date, delivery drop or other events that may upset the standard course of production but, especially in the fashion industry, in which the high dynamism and change are characteristic features of the sector. In this sense the assumptions considered in the analysis are limited on few periods of the yearly production of the firm belonging to the industry.

The AHP technique can be considered an efficient methodology to quantify in objective manner the risks but, if performed in the wrong way, it losses important implications and considerations in determining the results. Because of this, the information and the communication are essentials during the development of the analysis. Managers have to discuss explaining which are the factors on which their considerations base on, in order to obtain well reasoned outcomes.

As mentioned by the discipline of ISO 31000 and in accordance with the AHP theory, all the information, assumptions considered and the conclusions acquired have to be reported and documented in order to make the stakeholders accountable and involved in the decision taken.

Despite the different techniques developed over time are useful tools for limiting the risk effects affecting the supply chain, once again the human factor is fundamental for the realization of an efficient SCRM strategy that identifies as compulsory elements the flow of information among the agents involved in the procedure and the creation of a consolidated processes to be followed until they become an integral part of the culture of the company and its employees.

APPENDIX

Appendix 1 - The functional spin-off

The theory of functional spin-off developed by Stigler in 1951 provides a conceptual framework for measuring and anticipating channel structural arrangements. Differently from the usual researches, Stigler identifies the reason why firm subcontract some functions by analysing the average total cost curve of the firm by function rather than evaluating the classical variables such as salaries and interest.

The average total cost curve of a firm is determined by the sum of each function cost curve, whose shapes vary from function to function and according to the specific firm. Some may increase at the raising of the volume other, at the contrary, may decrease with increasing volume. For other functions the average cost curve will assume a U-shaper design, so they decrease as the volume increases up to a given threshold and then decrease despite the volume continues to increase.

Stigler assumes that the average total cost curve assumes the U-shape too, as shown in the Figure 16 below.

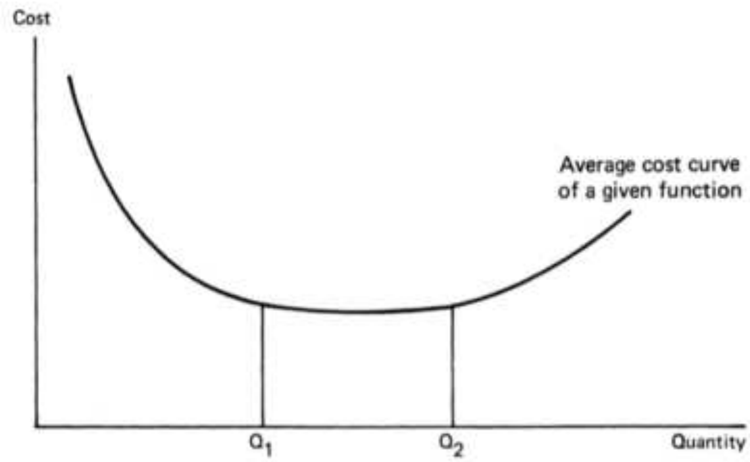

Figure 16 The U-shape of the average cost curve

In order to obtain economic befits Stigler suggests to spin-off those distributive functions that presents a decreasing curve as volume increases when the firm has a relative small volume, so, in most cases, when it enters or creates a new market.
Considering a middleman specialist faces the same cost curve as the producer, each individual producer at this low volume has an higher average cost for performing a function with a decreasing cost curve than the specialist who combines the volumes of several producers. Thus allows the specialist to benefit from its scale that the performance of this specific function generates at higher volumes. Taking that the middleman specialist will transfer all or some of the lower costs, the producer's total average cost declines as result of this spin-off of the distributive function.
At the opposite side, with a rising functional cost curve, may be suitable to spin-off certain functions to small specialists when the firm has reached high volumes. All these small specialists can perform the rising cost function at lower cost in case they stay small and do not combine the volumes of too many producers.

Appendix 1 - Operational Risks and relative remedies

Supply Risks

Supply Risk	Cause	Horizons	Traditional Remedies
Supplier lead times	Material/capacity issues	Both	Buffer stock, larger order quantities
Supplier quality	Manufacturing processes	Both	Contract verbiage, penalty clauses, inbound inspection
Transportation lead time	Breakdowns, acts of God, customs issues	Both	Contract verbiage, penalty clauses
Subcontractor availability	Initial source can't deliver	Both	Contracts for potential capacity reservation
Supplier pricing	Performance issues, contract changes, breach of contract	Tactical	Due diligence, phone-fax, and possible visits
Time delay	Customs, lack of performance	Both	Buffer stock, rescheduling final delivery
Disruption	Labor issues, natural disasters, terror	Both	Buffer stock, safety stock, second source capacity
Import delays	Customs paperwork, port strikes, labor issues	Both	Additional freight forward companies, calls to government contacts
Supplier insolvency	Poor management, acts of God, force majeure	Both	Loans, law suites, litigation, and second sourcing
Fraud/ corruption	Poor government oversight	Both	Fines, penalties, and operating restrictions
Counterfeit material	Poor government oversight	Both	Fines, penalties, and operating restrictions
Supplier delivery	Manufacturing issues, quality issues, customer requirement changes	Both	Buffer stock, warehouse inventory, second source

Demand Risks

Demand Risk	Cause	Horizons	Traditional Remedies
Forecast error	Seasonal issues, lead times, poor information, inadequate systems, poor communications, inadequate skills	Both	Statistically derived safety stock, buffer stock points, excess inventory throughout supply chain
Time delays	Customer changes, systems issues, product issues	Both	Rescheduling, price concessions
Outbound transit times	Carrier issues, acts of God, customers' issues	Both	Carrier discussions, customs calls, freight forwarding follow-ups
Customer pricing	Poor communication, inadequate contract verbiage, poor performance	Operational	Concessions, Rescheduling deliveries

Demand Risk	Cause	Horizons	Traditional Remedies
Customer promotions	Poor communications, poor execution on both sides	Operational	Constant conference calls, rescheduling manufacturing and deliveries, stealing product form other customers
Customer bankruptcy	Poor execution, fraud, corruption, sell out by owner	Both	Possible loans, possible merger or partnership
Product failure	Poor quality control, material issues, incorrect specifications	Both	Rescheduling, modifying the specifications, price concessions
Warranty issues	Poor communications, poor specification management, recall of product, death and more	Both	Law suites, litigation, government involvement, fines and penalties
Customer loss	All of the above issues and more	Both	Sell off material designated for customer, write off if specific and scan for new customers
New product introduction	Poor planning, poor communication throughout organization, poor execution, poor assumptions	Both	Ad hoc meetings, excessive overtime, price modifications, new promotions, rescheduling of manufacturing plans
Fraud and corruption	Poor government oversight	Both	Fines, penalties, and operating restrictions

Process Risks

Process Risk	Cause	Horizons	Traditional Remedies
Manufacturing yield	Equipment failure, material issues, human error	Operational	Reschedule run, cut into existing capacity plan
Capacity	Equipment failure, poor performance, poor communications, poor planning	Both	Reschedule runs, reschedule deliveries, possible use of contractors
Information delays	Poor planning, inadequate systems, outages	Both	Backup systems, ad hoc meetings, extreme overtime
Time delays	All of the above and below	Both	Ad hoc meetings and excessive overtime
Disruption	Labor issues, systems, material, inbound material, natural disaster or act of God	Both	Ad hoc meetings and excessive overtime
Systems	Outages, terror, hackers, internal errors	Both	Backup systems, ad hoc meetings, vendor outreach and excessive overtime
Receivables	Poor execution, poor contract verbiage, poor relationships, customer financial issues	Both	Phone calls, e-mails, faxes, visits and possible collection agencies

Process Risk	Cause	Horizons	Traditional Remedies
Payables	Cash flow issues in-house, cash flow strategy, poor relationships with suppliers, poor supplier performance	Both	Phone calls, e-mails, visits and possible contract renegotiations
Inventory	Forecast error, product life cycles, poor planning systems, poor supply chain management execution	Both	Excessive safety stock, write-downs and write-offs
Intellectual property	Outsourcing, contractors, partnerships, and espionage	Both	Vertical integration, contract verbiage, fines and penalties
Human/ process error	Operator issues, fraud, corruption, systems breach	Both	Process revalidation, employee reeducation, law suites/or discharge
Planning	Inadequate systems, inadequate training, poor supervision, poor management style	Both	Systems upgrades, reeducation, additional collaboration, and metrics of success
Product failure	Poor material, poor quality control, poor communication, poor management oversight	Both	Enhance communications, customer visits, supplier visits, contract renegotiations
Equipment failure	Poor maintenance schedules, operator error, material issues, component failure	Both	Perform assessment, revalidation of alternative equipment/routings, vendor visits in-house
Organizational management	Poor performance, poor communication, inadequate measurements, fraud	Both	Ad hoc meetings, assessment of skill sets and possibly enhancement of roles, goals and measurements
Strategy	Poor planning, poor execution, poor communication, competition	Both	Same as above with possible change in strategy

Environment/Ecosystem Risks

Environment/ Ecosystem Risk	Cause	Horizons	Traditional Remedies
Currency exchange rates	Central banks, country issues, conflicts	Both	Use of financial hedging techniques
Political environment	Conflicts, political upheaval	Both	Calls with country officials, tapping own government contacts
Customs regulations	Improper paperwork, poorly packaged material, terror	Both	Use of 3rd party logistics partners, conversations with customs, enhanced paperwork
Weather/acts of God	Floods, tornados, hurricanes, fires, volcanoes, war	Both	Disaster insurance

Environment/ Ecosystem Risk	Cause	Horizons	Traditional Remedies
Environmental regulations	Lack of discipline, failure of audit, poor management and diligence	Both	Excessive overtime for remedial compliance
Industry regulations	Same as above	Both	Same as above
Country regulations	Same as above	Both	Same as above
Fraud/ corruption	Country policies or lack-thereof, suspect partners, misrepresentation by 3rd party contractors	Both	Fines, penalties, shutdowns and remedial policy enhancements, including discharge
Counterfeiting	Same as above	Both	Same as above, including alternative sourcing and partnerships
Competition	Lack of focus, poor company communication, poor product introduction process, poor execution	Both	Price reductions, marketing promotions, customer visits, enhanced product portfolio and extended warranties

Appendix 3 - Eigenvalues and eigenvectors discipline and Perron-Frobenius theorem

This appendix contains an introduction to eigenvalues and eigenvectors focused on their relevance for the discipline of AHP. Successively it reports the explanation of the Perron-Frobenius theorem.

Definition 1 (Eigenvalues and Eigenvectors). *Considering a $n \times n$ square matrix A and an n-dimensional vector, then $\mathbf{w}$ and λ are respectively the eigenvector and eigenvalue of $\mathbf{A}$, if and only if:*

$$\mathbf{Aw} = \lambda \mathbf{w}$$

Being *w* an eigenvector of *A*, then all vectors $\alpha \mathbf{w}$ for $\alpha \in \mathbb{R}$ are also eigenvectors of $\mathbf{A}$, indeed this set of vectors is called the *eigenspace* of $\mathbf{A}$ associated to that specific eigenvector (and, as consequence, its relative eigenvalues).

As reported in the dissertation, software as R-Cran or Excel are able to extracts the eigenvalues and eigenvectors simply calling a function but can be interesting how to define the two values through the mathematical computation. The demonstration showed below involves the utilisation of the identity matrix $\mathbf{I}$ and the null vector $\mathbf{0} = (0,0,\ldots,0)$. Re-writing the eq. (A.1):

$$\mathbf{Aw} = \lambda \mathbf{w}$$

$$\mathbf{Aw} - \lambda \mathbf{w} = \mathbf{0}$$

$$\mathbf{Aw} - \lambda \mathbf{Iw} = \mathbf{0}$$

$$(\mathbf{A} - \lambda \mathbf{I})\mathbf{w} = \mathbf{0}$$

According to the linear algebra if *det*$(\mathbf{A} - \lambda \mathbf{I}) \neq 0$ then, the eq (A.2) presents only one solution, defined trivial solution $\mathbf{w} = (0,0,\ldots,0)$; oppositely, in case of *det*$(\mathbf{A} - \lambda \mathbf{I}) = 0$ (defined *characteristic polynomial*), then we need to compute the its roots.

As anticipated in chapter two, taking a pairwise comparison matrix $\mathbf{A}$, if and only if $\mathbf{A}$ is consistent, then one eigenvalue, $\lambda_{\max}$ is equal to n while the other to 0. This section would explain the behaviour of $\lambda_{\max}$ in the absence of a consistent matrix. The Perron-Frobenius theorem support us in defining $\lambda_{\max}$ when $\mathbf{A}$ is not consistent.

Theorem 1 (Perron-Frobenius). Giving A a matrix with positive entries, primitive and irreducible, then:

1. there is a positive real eigenvalue $\lambda_{\max}$, with $\lambda_{\max} > |\lambda|$, for all other eigenvalues λ's;
2. the eigenvector associated to $\lambda_{\max}$ has positive components.

The software R-Cran support us to demonstrate the potentiality offered by the Perron-Frobenius theorem. Here below a print-screen of the tool engaged in determining the dominant eigenvalue and its relative dominant eigenvector.

```
> # Considering the 3x3 square matrix A:
> A <- matrix(9:1,3,3,byrow=T)
> A
     [,1] [,2] [,3]
[1,]    9    8    7
[2,]    6    5    4
[3,]    3    2    1
> eigen(A)
eigen() decomposition
$values
[1]  1.611684e+01 -1.116844e+00 -5.038509e-16

$vectors
           [,1]        [,2]       [,3]
[1,] -0.8186735 -0.61232756  0.4082483
[2,] -0.5253221  0.08675134 -0.8164966
[3,] -0.2319707  0.78583024  0.4082483
```

As shown above the function "*eigen(matrix name)*" allows to extract both, the eigenvalue, that in the example is $\lambda_{max} = 16.11684$ (greater than zero), and the relative eigenvector that may seem not positive but, considering the eigenvectors are defined up to constant, changing signs we easily obtain:

$$v_{max} = (0.8186735, 0.5253221, 0.2319707)$$

Università Ca'Foscari Venezia

ECONOMIC TOOLS FOR RANKING AND QUANTIFYING RISKS IN SUPPLY CHAIN

Name: ____________________

Surname: ____________________

Job Position: ____________________

Instructions

Please, read the following table and fill the questionnaire

Explanation	Numeric Values
If Option A is equally important/risky than Option B	1
If Option A is moderately more important/risky than Option B	3
If Option A is more important/risky than Option B	5
If Option A is extremely more important/risky than Option B	7

Example:

Given Options A & B, please judge their relative importance as shown below:

Classifying the objectives in terms of their importance

Option A	extremely more important	more important	moderately more important	equally important	moderately more important	more important	extremely more important	Option B
	7	5	3	1	3	5	7	
C1 Order completion	X							On-time delivery C2

If you consider the option "**Order completion**" in column A extremely more important than the option "**On-time delivery**" in column B, then mark "**7**" on the left side.

Classifying the risks in terms if their riskness

Option A	extremely more risky	more risky	moderately more risky	equally risky	moderately more risky	more risky	extremely more risky	Option B
	7	5	3	1	3	5	7	
R1 Manufacturing/ Production Risks						X		Transport and Logistic Risks R2

If you consider the option "**Transport and Logistic Risks**" in column B **more risky** than option "**Manufacturing/Operational Risks**" in column A, then mark "**5**" on the **right side**.

	7	5	3	1	3	5	7	
R1 Manufacturing/ Production Risks				X				Planning and Control Risks R3

If you consider the option "**Manufactruing/Operational Risks**" in column A **as risky as** the option "**Planning and Control Risks**" in column B, then mark "**1**" in the **middle**.

Additional comments:

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Section A - Objectives importance classification

Please compare the relative importance for the goal

Goal: Meeting the maisons' needs in order to achieve the customers value

C1 On-time delivery
C2 Free delivery of defect/damage
C3 Order completion

Please, classify the objectives in terms of their importance:

	1	6	11	16	21	26	31	
Option A	extremely more important	more important	moderately more important	equally important	moderately more important	more important	extremely more important	**Option B**
C1 On-time delivery	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Free delivery of defect/damage C2
C1 On-time delivery	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Order completion C3
C2 Free delivery of defect/damage	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Order completion C3

Additional comments:

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Section B - Risks classification

According to the classification proposed below, can you suggest other risks that may breakdown the supply chain of the firm?

R1 Manufacturing/Production Risks

A1 Unplanned machine stoppages

A2 Warehousing and production interruption

A3 Lack of skilled people/low personnel polyvalence

A4 ______________________________

R2 Transport and Logistic Risks

A5 No transport solution alternatives

A6 Damages in transport

A7 ______________________________

A8 ______________________________

R3 Planning and Control Risks

A9 Serious forecasting errors

A10 Low integration/Miscommunication with final-product suppliers (maisons)

A11 ______________________________

A12 ______________________________

R4 Supply Risks

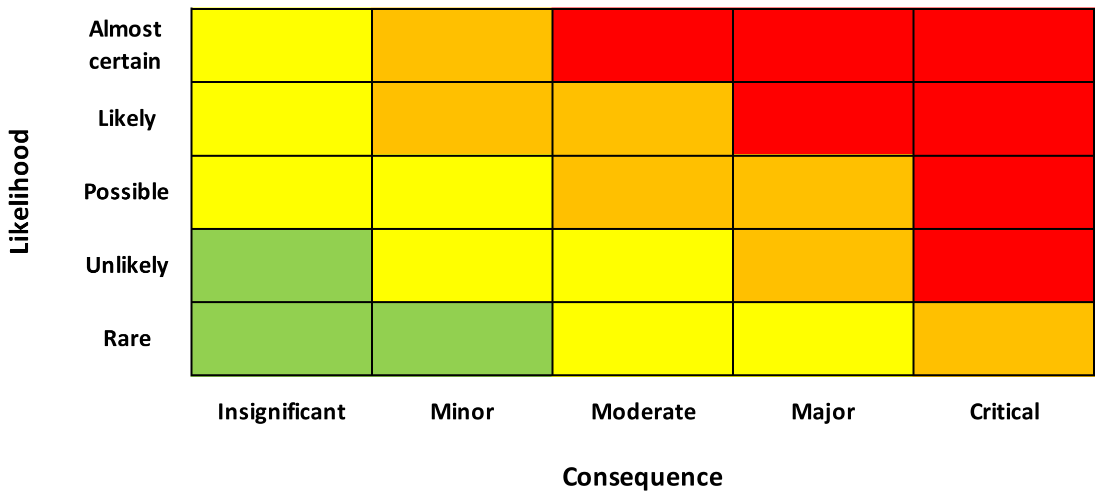
A13 Low integration between intermediate suppliers

A14

A15 ______________________________

A16 ______________________________

Please risks A1, A2, A3, etc in the heat map according to their consequence and likelihood. Each box can contain more than one item.



Additional comments:

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Section C - Risks

Please compare the risks with regard to the objective "C1: On time delivery"

Suggestion:

Ask yourself: "How much riskier is Option A against Option B (or viceversa) in reference to the Objective "On time delivery".

Option A		extremely more risky	more risky	moderately more risky	equally risky	moderately more riky	more risky	extremely more risky	Option B	
R1	Manufacturing/Production Risks	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Transport and Logistic Risks	R2
R1	Manufacturing/Production Risks	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Planning and Control Risks	R3
R1	Manufacturing/Production Risks	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Supply Risks	R4
R2	Transport and Logistic Risks	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Planning and Control Risks	R3
R2	Transport and Logistic Risks	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Supply Risks	R4
R3	Planning and Control Risks	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Supply Risks	R4

Additional comments:

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Section C - Risks

Please compare the risks with regard to the objective "C1: Order completion"

Suggestion:

Ask yourself: "How much riskier is Option A against Option B (or viceversa) in reference to the Objective "Order completion".

Option A		extremely more risky	more risky	moderately more risky	equally risky	moderately more riky	more risky	extremely more risky	**Option B**	
R1	Manufacturing/Production Risks	7	5	3	1	3	5	7	Transport and Logistic Risks	R2
R1	Manufacturing/Production Risks	7	5	3	1	3	5	7	Planning and Control Risks	R3
R1	Manufacturing/Production Risks	7	5	3	1	3	5	7	Supply Risks	R4
R2	Transport and Logistic Risks	7	5	3	1	3	5	7	Planning and Control Risks	R3
R2	Transport and Logistic Risks	7	5	3	1	3	5	7	Supply Risks	R4
R3	Planning and Control Risks	7	5	3	1	3	5	7	Supply Risks	R4

Additional comments:

Section C - Risks

Please compare the risks with regard to the objective "C1: Free delivery of defect/damage"

Suggestion:

Ask yourself: "How much riskier is Option A against Option B (or viceversa) in reference to the Objective "Free delivery of defect/damage".

Option A	extremely more risky	more risky	moderately more risky	equally risky	moderately more riky	more risky	extremely more risky	Option B
R1 Manufacturing/Production Risks	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Transport and Logistic Risks R2
R1 Manufacturing/Production Risks	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Planning and Control Risks R3
R1 Manufacturing/Production Risks	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Supply Risks R4
R2 Transport and Logistic Risks	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Planning and Control Risks R3
R2 Transport and Logistic Risks	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Supply Risks R4
R3 Planning and Control Risks	7 ☐	5 ☐	3 ☐	1 ☐	3 ☐	5 ☐	7 ☐	Supply Risks R4

Additional comments:

Appendix 5 - AHP Risk Analysis Computation with the software R

```
> PurMan_C1<-matrix(c(1,1/5,1/5,1/7,5,1,1,1,5,1,1,1/3,7,1,3,1),4,4,byrow=T)
> colnames(PurMan_C1)<-c("R1","R2","R3","R4")
> rownames(PurMan_C1)<-c("R1","R2","R3","R4")
> PurMan_C1
   R1  R2  R3        R4
R1  1 0.2 0.2 0.1428571
R2  5 1.0 1.0 1.0000000
R3  5 1.0 1.0 0.3333333
R4  7 1.0 3.0 1.0000000
> eigen(PurMan_C1)
eigen() decomposition
$values
[1]  4.121125e+00+0.000000e+00i -6.056238e-02+7.039193e-01i -6.056238e-02-7.039193e-01i -4.014089e-17+0.000000e+00i

$vectors
               [,1]                     [,2]                     [,3]              [,4]
[1,] 0.09293567+0i  0.03479178+0.01508135i  0.03479178-0.01508135i -2.357023e-01+0i
[2,] 0.51693406+0i  0.20192079+0.40040888i  0.20192079-0.40040888i  9.428090e-01+0i
[3,] 0.39500403+0i  0.13667643-0.35792940i  0.13667643+0.35792940i  2.357023e-01+0i
[4,] 0.75373335+0i -0.80664051+0.00000000i -0.80664051+0.00000000i -8.096545e-16+0i

> Re(eigen(PurMan_C1)$values)
[1]  4.121125e+00 -6.056238e-02 -6.056238e-02 -4.014089e-17
> Re(eigen(PurMan_C1)$vectors)
           [,1]        [,2]        [,3]          [,4]
[1,] 0.09293567  0.03479178  0.03479178 -2.357023e-01
[2,] 0.51693406  0.20192079  0.20192079  9.428090e-01
[3,] 0.39500403  0.13667643  0.13667643  2.357023e-01
[4,] 0.75373335 -0.80664051 -0.80664051 -8.096545e-16
> vec_PurMan_C1<-Re(eigen(PurMan_C1)$vectors)[,1]
> vec_PurMan_C1
[1] 0.09293567 0.51693406 0.39500403 0.75373335
> rank_PurMan_C1<-vec_PurMan_C1/sum(vec_PurMan_C1)
> rank_PurMan_C1
[1] 0.05284618 0.29394517 0.22461187 0.42859678
> lambda_PurMan_C1<-Re(eigen(PurMan_C1)$values)[1]
> lambda_PurMan_C1
[1] 4.121125
> n=4
> CI_PurMan_C1<-(lambda_PurMan_C1-n)/(n-1)
> CI_PurMan_C1
[1] 0.04037492
```

```
> PurMan_C2<-matrix(c(1,7,5,3,1/7,1,1/3,1/5,1/5,3,1,1/3,1/3,5,3,1),4,4,byrow=T)
> colnames(PurMan_C2)<-c("R1","R2","R3","R4")
> rownames(PurMan_C2)<-c("R1","R2","R3","R4")
> PurMan_C2
          R1 R2        R3        R4
R1 1.0000000  7 5.0000000 3.0000000
R2 0.1428571  1 0.3333333 0.2000000
R3 0.2000000  3 1.0000000 0.3333333
R4 0.3333333  5 3.0000000 1.0000000
> eigen(PurMan_C2)
eigen() decomposition
$values
[1]  4.1169824+0.0000000i -0.0037480+0.6933829i -0.0037480-0.6933829i -0.1094864+0.0000000i

$vectors
              [,1]                    [,2]                    [,3]           [,4]
[1,] 0.88799225+0i  0.90609394+0.00000000i  0.90609394+0.00000000i -0.82674869+0i
[2,] 0.08688903+0i -0.01028824-0.09126804i -0.01028824+0.09126804i  0.08860316+0i
[3,] 0.18467467+0i -0.17297433+0.02916744i -0.17297433-0.02916744i -0.24094104+0i
[4,] 0.41208656+0i  0.00913311+0.37376971i  0.00913311-0.37376971i  0.50058316+0i

> Re(eigen(PurMan_C2)$values)
[1]  4.116982443 -0.003748027 -0.003748027 -0.109486390
> Re(eigen(PurMan_C2)$vectors)
           [,1]         [,2]         [,3]        [,4]
[1,] 0.88799225  0.906093939  0.906093939 -0.82674869
[2,] 0.08688903 -0.010288241 -0.010288241  0.08860316
[3,] 0.18467467 -0.172974331 -0.172974331 -0.24094104
[4,] 0.41208656  0.009133114  0.009133114  0.50058316
> vec_PurMan_C2<-Re(eigen(PurMan_C2)$vectors)[,1]
> vec_PurMan_C2
[1] 0.88799225 0.08688903 0.18467467 0.41208656
> rank_PurMan_C2<-vec_PurMan_C2/sum(vec_PurMan_C2)
> rank_PurMan_C2
[1] 0.56500905 0.05528549 0.11750425 0.26220121
> lambda_PurMan_C2<-Re(eigen(PurMan_C2)$values)[1]
> lambda_PurMan_C2
[1] 4.116982
> n=4
> CI_PurMan_C2<-(lambda_PurMan_C2-n)/(n-1)
> CI_PurMan_C2
[1] 0.03899415
```

```
> PurMan_C3<-matrix(c(1,3,1/7,1/3,1/3,1,1/7,1/5,7,7,1,1,3,5,1,1),4,4,byrow=T)
> colnames(PurMan_C3)<-c("R1","R2","R3","R4")
> rownames(PurMan_C3)<-c("R1","R2","R3","R4")
> PurMan_C3
          R1 R2        R3        R4
R1 1.0000000  3 0.1428571 0.3333333
R2 0.3333333  1 0.1428571 0.2000000
R3 7.0000000  7 1.0000000 1.0000000
R4 3.0000000  5 1.0000000 1.0000000
> eigen(PurMan_C3)
eigen() decomposition
$values
[1]  4.15165801+0.0000000i -0.03660874+0.7890176i -0.03660874-0.7890176i -0.07844053+0.0000000i

$vectors
             [,1]                    [,2]                    [,3]           [,4]
[1,] 0.1838611+0i -0.05559760+0.19446136i -0.05559760-0.19446136i  0.06709035+0i
[2,] 0.0917524+0i -0.07020008-0.03544597i -0.07020008+0.03544597i -0.07926897+0i
[3,] 0.7937830+0i  0.88182821+0.00000000i  0.88182821+0.00000000i -0.63260670+0i
[4,] 0.5724379+0i -0.03352707-0.41732979i -0.03352707+0.41732979i  0.76747904+0i

> Re(eigen(PurMan_C3)$values)
[1]  4.15165801 -0.03660874 -0.03660874 -0.07844053
> Re(eigen(PurMan_C3)$vectors)
          [,1]        [,2]        [,3]        [,4]
[1,] 0.1838611 -0.05559760 -0.05559760  0.06709035
[2,] 0.0917524 -0.07020008 -0.07020008 -0.07926897
[3,] 0.7937830  0.88182821  0.88182821 -0.63260670
[4,] 0.5724379 -0.03352707 -0.03352707  0.76747904
> vec_PurMan_C3<-Re(eigen(PurMan_C3)$vectors)[,1]
> vec_PurMan_C3
[1] 0.1838611 0.0917524 0.7937830 0.5724379
> rank_PurMan_C3<-vec_PurMan_C3/sum(vec_PurMan_C3)
> rank_PurMan_C3
[1] 0.11198518 0.05588408 0.48347324 0.34865749
> lambda_PurMan_C3<-Re(eigen(PurMan_C3)$values)[1]
> lambda_PurMan_C3
[1] 4.151658
> n=4
> CI_PurMan_C3<-(lambda_PurMan_C3-n)/(n-1)
> CI_PurMan_C3
[1] 0.05055267
```

```
> PurMan_Obj<-matrix(c(1,5,5,1/5,1,1/3,1/5,3,1),3,3,byrow=T)
> colnames(PurMan_Obj)<-c("C1","C2","C3")
> rownames(PurMan_Obj)<-c("C1","C2","C3")
> PurMan_Obj
    C1 C2        C3
C1 1.0  5 5.0000000
C2 0.2  1 0.3333333
C3 0.2  3 1.0000000
> eigen(PurMan_Obj)
eigen() decomposition
$values
[1]  3.1356108+0.0000000i -0.0678054+0.6485563i -0.0678054-0.6485563i

$vectors
             [,1]                  [,2]                  [,3]
[1,] 0.9524097+0i  0.9524097+0.0000000i  0.9524097+0.0000000i
[2,] 0.1320728+0i -0.0660364-0.1143784i -0.0660364+0.1143784i
[3,] 0.2747225+0i -0.1373613+0.2379167i -0.1373613-0.2379167i

> Re(eigen(PurMan_Obj)$values)
[1]  3.13561084 -0.06780542 -0.06780542
> Re(eigen(PurMan_Obj)$vectors)
          [,1]       [,2]       [,3]
[1,] 0.9524097  0.9524097  0.9524097
[2,] 0.1320728 -0.0660364 -0.0660364
[3,] 0.2747225 -0.1373613 -0.1373613
> vec_PurMan_Obj<-Re(eigen(PurMan_Obj)$vectors)[,1]
> vec_PurMan_Obj
[1] 0.9524097 0.1320728 0.2747225
> rank_PurMan_Obj<-vec_PurMan_Obj/sum(vec_PurMan_Obj)
> rank_PurMan_Obj
[1] 0.70071086 0.09716915 0.20211999
> lambda_PurMan_Obj<-Re(eigen(PurMan_Obj)$values)[1]
> lambda_PurMan_Obj
[1] 3.135611
> n=3
> CI_PurMan_Obj<-(lambda_PurMan_Obj-n)/(n-1)
> CI_PurMan_Obj
[1] 0.06780542
```

```
> rank_PurMan_C1
[1] 0.05284618 0.29394517 0.22461187 0.42859678
> rank_PurMan_C2
[1] 0.56500905 0.05528549 0.11750425 0.26220121
> rank_PurMan_C3
[1] 0.11198518 0.05588408 0.48347324 0.34865749
> rank_PurMan_Obj
          [,1]       [,2]    [,3]
[1,] 0.7007109 0.09716915 0.20212
> FinalRank_PurMan<-0.7007109*rank_PurMan_C1+0.05588408*rank_PurMan_C2+0.20212*rank_PurMan_C3
> FinalRank_PurMan
[1] 0.09123935 0.22035545 0.26167421 0.38544596
```

```
> WLMan_C1<-matrix(c(1,3,1/3,1/7,1/3,1,1/3,1/7,3,3,1,1/3,7,7,3,1),4,4,byrow=T)
> colnames(WLMan_C1)<-c("R1","R2","R3","R4")
> rownames(WLMan_C1)<-c("R1","R2","R3","R4")
> WLMan_C1
          R1 R2        R3        R4
R1 1.0000000  3 0.3333333 0.1428571
R2 0.3333333  1 0.3333333 0.1428571
R3 3.0000000  3 1.0000000 0.3333333
R4 7.0000000  7 3.0000000 1.0000000
> eigen(WLMan_C1)
eigen() decomposition
$values
[1]  4.16241691+0.0000000i -0.06607693+0.8171177i -0.06607693-0.8171177i -0.03026305+0.0000000i

$vectors
               [,1]                   [,2]                   [,3]           [,4]
[1,] -0.16914484+0i -0.2330389+0.1495439i -0.2330389-0.1495439i  0.04889707+0i
[2,] -0.09595068+0i -0.0343071-0.1406284i -0.0343071+0.1406284i -0.01730070+0i
[3,] -0.34814192+0i  0.3146994+0.2161196i  0.3146994-0.2161196i -0.38951988+0i
[4,] -0.91705000+0i  0.8698464+0.0000000i  0.8698464+0.0000000i  0.91955643+0i

> Re(eigen(WLMan_C1)$values)
[1]  4.16241691 -0.06607693 -0.06607693 -0.03026305
> Re(eigen(WLMan_C1)$vectors)
            [,1]        [,2]        [,3]        [,4]
[1,] -0.16914484 -0.23303885 -0.23303885  0.04889707
[2,] -0.09595068 -0.03430706 -0.03430706 -0.01730070
[3,] -0.34814192  0.31469940  0.31469940 -0.38951988
[4,] -0.91705000  0.86984642  0.86984642  0.91955643
> vec_WLMan_C1<-Re(eigen(WLMan_C1)$vectors)[,1]
> vec_WLMan_C1
[1] -0.16914484 -0.09595068 -0.34814192 -0.91705000
> rank_WLMan_C1<-vec_WLMan_C1/sum(vec_WLMan_C1)
> rank_WLMan_C1
[1] 0.11053142 0.06270109 0.22750100 0.59926650
> lambda_WLMan_C1<-Re(eigen(WLMan_C1)$values)[1]
> lambda_WLMan_C1
[1] 4.162417
> n=4
> CI_WLMan_C1<-(lambda_WLMan_C1-n)/(n-1)
> CI_WLMan_C1
[1] 0.05413897
```

```
> WLMan_C2<-matrix(c(1,7,5,1,1/7,1,3,1/5,1/5,1/3,1,1/7,1,5,7,1),4,4,byrow=T)
> colnames(WLMan_C2)<-c("R1","R2","R3","R4")
> rownames(WLMan_C2)<-c("R1","R2","R3","R4")
> WLMan_C2
          R1        R2 R3        R4
R1 1.0000000 7.0000000  5 1.0000000
R2 0.1428571 1.0000000  3 0.2000000
R3 0.2000000 0.3333333  1 0.1428571
R4 1.0000000 5.0000000  7 1.0000000
> eigen(WLMan_C2)
eigen() decomposition
$values
[1]  4.18514529+0.0000000i -0.11378896+0.8783899i -0.11378896-0.8783899i  0.04243263+0.0000000i

$vectors
              [,1]                   [,2]                   [,3]           [,4]
[1,] 0.71116412+0i  0.9357393+0.0000000i  0.9357393+0.0000000i -0.44769884+0i
[2,] 0.16105857+0i -0.1299678+0.2024032i -0.1299678-0.2024032i -0.05049598+0i
[3,] 0.09192492+0i -0.0701105-0.1103106i -0.0701105+0.1103106i -0.02206223+0i
[4,] 0.67812649+0i  0.2181110-0.0433253i  0.2181110+0.0433253i  0.89248482+0i

> Re(eigen(WLMan_C2)$values)
[1]  4.18514529 -0.11378896 -0.11378896  0.04243263
> Re(eigen(WLMan_C2)$vectors)
           [,1]        [,2]        [,3]        [,4]
[1,] 0.71116412  0.93573926  0.93573926 -0.44769884
[2,] 0.16105857 -0.12996781 -0.12996781 -0.05049598
[3,] 0.09192492 -0.07011046 -0.07011046 -0.02206223
[4,] 0.67812649  0.21811095  0.21811095  0.89248482
> vec_WLMan_C2<-Re(eigen(WLMan_C2)$vectors)[,1]
> vec_WLMan_C2
[1] 0.71116412 0.16105857 0.09192492 0.67812649
> rank_WLMan_C2<-vec_WLMan_C2/sum(vec_WLMan_C2)
> rank_WLMan_C2
[1] 0.43303619 0.09807045 0.05597416 0.41291919
> lambda_WLMan_C2<-Re(eigen(WLMan_C2)$values)[1]
> lambda_WLMan_C2
[1] 4.185145
> n=4
> CI_WLMan_C2<-(lambda_WLMan_C2-n)/(n-1)
> CI_WLMan_C2
[1] 0.0617151
```

```
> WLMan_C3<-matrix(c(1,5,1,1,1/5,1,1/7,1/7,1,7,1,1,1,7,1,1),4,4,byrow=T)
> colnames(WLMan_C3)<-c("R1","R2","R3","R4")
> rownames(WLMan_C3)<-c("R1","R2","R3","R4")
> WLMan_C3
    R1 R2        R3        R4
R1 1.0  5 1.0000000 1.0000000
R2 0.2  1 0.1428571 0.1428571
R3 1.0  7 1.0000000 1.0000000
R4 1.0  7 1.0000000 1.0000000
> eigen(WLMan_C3)
eigen() decomposition
$values
[1]  4.0141849+0.0000000i -0.0070925+0.2385176i -0.0070925-0.2385176i  0.0000000+0.0000000i

$vectors
              [,1]                   [,2]                   [,3]             [,4]
[1,] 0.54393857+0i  0.7360662+0.0000000i  0.7360662+0.0000000i  6.832950e-17+0i
[2,] 0.09199656+0i -0.0428754-0.1205820i -0.0428754+0.1205820i  1.345401e-17+0i
[3,] 0.58977431+0i -0.2634548+0.3892373i -0.2634548-0.3892373i -7.071068e-01+0i
[4,] 0.58977431+0i -0.2634548+0.3892373i -0.2634548-0.3892373i  7.071068e-01+0i

> Re(eigen(WLMan_C3)$values)
[1]  4.014184930 -0.007092465 -0.007092465  0.000000000
> Re(eigen(WLMan_C3)$vectors)
           [,1]        [,2]        [,3]          [,4]
[1,] 0.54393857  0.73606621  0.73606621  6.832950e-17
[2,] 0.09199656 -0.04287543 -0.04287543  1.345401e-17
[3,] 0.58977431 -0.26345478 -0.26345478 -7.071068e-01
[4,] 0.58977431 -0.26345478 -0.26345478  7.071068e-01
> vec_WLMan_C3<-Re(eigen(WLMan_C3)$vectors)[,1]
> vec_WLMan_C3
[1] 0.54393857 0.09199656 0.58977431 0.58977431
> rank_WLMan_C3<-vec_WLMan_C3/sum(vec_WLMan_C3)
> rank_WLMan_C3
[1] 0.29961082 0.05067331 0.32485794 0.32485794
> lambda_WLMan_C3<-Re(eigen(WLMan_C3)$values)[1]
> lambda_WLMan_C3
[1] 4.014185
> n=4
> CI_WLMan_C3<-(lambda_WLMan_C3-n)/(n-1)
> CI_WLMan_C3
[1] 0.00472831
```

```
> WLMan_Obj<-matrix(c(1,7,5,1/7,1,1/3,1/5,3,1),3,3,byrow=T)
> colnames(WLMan_Obj)<-c("C1","C2","C3")
> rownames(WLMan_Obj)<-c("C1","C2","C3")
> WLMan_Obj
          C1 C2        C3
C1 1.0000000  7 5.0000000
C2 0.1428571  1 0.3333333
C3 0.2000000  3 1.0000000
> eigen(WLMan_Obj)
eigen() decomposition
$values
[1]  3.0648876+0.0000000i -0.0324438+0.4447702i -0.0324438-0.4447702i

$vectors
             [,1]                   [,2]                   [,3]
[1,] 0.9628019+0i  0.96280192+0.00000000i  0.96280192+0.00000000i
[2,] 0.1066861+0i -0.05334305-0.09239287i -0.05334305+0.09239287i
[3,] 0.2482550+0i -0.12412750+0.21499514i -0.12412750-0.21499514i

> Re(eigen(WLMan_Obj)$values)
[1]  3.06488758 -0.03244379 -0.03244379
> Re(eigen(WLMan_Obj)$vectors)
          [,1]        [,2]        [,3]
[1,] 0.9628019  0.96280192  0.96280192
[2,] 0.1066861 -0.05334305 -0.05334305
[3,] 0.2482550 -0.12412750 -0.12412750
> vec_WLMan_Obj<-Re(eigen(WLMan_Obj)$vectors)[,1]
> vec_WLMan_Obj
[1] 0.9628019 0.1066861 0.2482550
> rank_WLMan_Obj<-vec_WLMan_Obj/sum(vec_WLMan_Obj)
> rank_WLMan_Obj
[1] 0.73064467 0.08096123 0.18839410
> lambda_WLMan_Obj<-Re(eigen(WLMan_Obj)$values)[1]
> lambda_WLMan_Obj
[1] 3.064888
> n=3
> CI_WLMan_Obj<-(lambda_WLMan_Obj-n)/(n-1)
> CI_WLMan_Obj
[1] 0.03244379
```

```
> rank_WLMan_C1
[1] 0.11053142 0.06270109 0.22750100 0.59926650
> rank_WLMan_C2
[1] 0.43303619 0.09807045 0.05597416 0.41291919
> rank_WLMan_C3
[1] 0.29961082 0.05067331 0.32485794 0.32485794
> rank_WLMan_Obj
[1] 0.73064467 0.08096123 0.18839410
> FinalRank_WLMan<-0.73064467*rank_WLMan_C1+0.08096123*rank_WLMan_C2+0.18839410*rank_WLMan_C3
> FinalRank_WLMan
[1] 0.17226324 0.06329867 0.23195545 0.53248264
```

```
> ProdPlanMan_C1<-matrix(c(1,3,1,1/3,1/3,1,1/3,1/5,1,3,1,1/3,3,5,3,1),4,4,byrow=T)
> colnames(ProdPlanMan_C1)<-c("R1","R2","R3","R4")
> rownames(ProdPlanMan_C1)<-c("R1","R2","R3","R4")
> ProdPlanMan_C1
          R1 R2        R3        R4
R1 1.0000000  3 1.0000000 0.3333333
R2 0.3333333  1 0.3333333 0.2000000
R3 1.0000000  3 1.0000000 0.3333333
R4 3.0000000  5 3.0000000 1.0000000
> eigen(ProdPlanMan_C1)
eigen() decomposition
$values
[1]  4.043493e+00+0.00000e+00i -2.174673e-02+4.18799e-01i -2.174673e-02-4.18799e-01i -5.604733e-17+0.00000e+00i

$vectors
              [,1]                    [,2]                    [,3]             [,4]
[1,] -0.3336547+0i  0.1185958-0.1812056i  0.1185958+0.1812056i  7.071068e-01+0i
[2,] -0.1303871+0i  0.0498692+0.1386732i  0.0498692-0.1386732i  1.141521e-16+0i
[3,] -0.3336547+0i  0.1185958-0.1812056i  0.1185958+0.1812056i -7.071068e-01+0i
[4,] -0.8719795+0i -0.9404690+0.0000000i -0.9404690+0.0000000i -2.052735e-15+0i

> Re(eigen(ProdPlanMan_C1)$values)
[1]  4.043493e+00 -2.174673e-02 -2.174673e-02 -5.604733e-17
> Re(eigen(ProdPlanMan_C1)$vectors)
           [,1]       [,2]       [,3]          [,4]
[1,] -0.3336547  0.1185958  0.1185958  7.071068e-01
[2,] -0.1303871  0.0498692  0.0498692  1.141521e-16
[3,] -0.3336547  0.1185958  0.1185958 -7.071068e-01
[4,] -0.8719795 -0.9404690 -0.9404690 -2.052735e-15
> vec_ProdPlanMan_C1<-Re(eigen(ProdPlanMan_C1)$vectors)[,1]
> vec_ProdPlanMan_C1
[1] -0.3336547 -0.1303871 -0.3336547 -0.8719795
> rank_ProdPlanMan_C1<-vec_ProdPlanMan_C1/sum(vec_ProdPlanMan_C1)
> rank_ProdPlanMan_C1
[1] 0.19983200 0.07809127 0.19983200 0.52224472
> lambda_ProdPlanMan_C1<-Re(eigen(ProdPlanMan_C1)$values)[1]
> lambda_ProdPlanMan_C1
[1] 4.043493
> n=4
> CI_ProdPlanMan_C1<-(lambda_ProdPlanMan_C1-n)/(n-1)
> CI_ProdPlanMan_C1
[1] 0.01449782
```

```
> ProdPlanMan_C2<-matrix(c(1,5,5,3,1/5,1,1/3,1/5,1/5,3,1,1/3,1/3,5,3,1),4,4,byrow=T)
> colnames(ProdPlanMan_C2)<-c("R1","R2","R3","R4")
> rownames(ProdPlanMan_C2)<-c("R1","R2","R3","R4")
> ProdPlanMan_C2
          R1 R2        R3        R4
R1 1.0000000  5 5.0000000 3.0000000
R2 0.2000000  1 0.3333333 0.2000000
R3 0.2000000  3 1.0000000 0.3333333
R4 0.3333333  5 3.0000000 1.0000000
> eigen(ProdPlanMan_C2)
eigen() decomposition
$values
[1]  4.1980679+0.0000000i -0.0304398+0.9067657i -0.0304398-0.9067657i -0.1371884+0.0000000i

$vectors
              [,1]                  [,2]                  [,3]          [,4]
[1,] -0.8732476+0i -0.9130760+0.0000000i -0.9130760+0.0000000i -0.6619103+0i
[2,] -0.1021775+0i  0.0256281+0.1125153i  0.0256281-0.1125153i  0.1022584+0i
[3,] -0.1957355+0i  0.1654073-0.0696120i  0.1654073+0.0696120i -0.3459539+0i
[4,] -0.4343800+0i -0.0047692-0.3474874i -0.0047692+0.3474874i  0.6570646+0i

> Re(eigen(ProdPlanMan_C2)$values)
[1]  4.19806793 -0.03043976 -0.03043976 -0.13718841
> Re(eigen(ProdPlanMan_C2)$vectors)
           [,1]         [,2]         [,3]       [,4]
[1,] -0.8732476 -0.913076021 -0.913076021 -0.6619103
[2,] -0.1021775  0.025628146  0.025628146  0.1022584
[3,] -0.1957355  0.165407336  0.165407336 -0.3459539
[4,] -0.4343800 -0.004769192 -0.004769192  0.6570646
> vec_ProdPlanMan_C2<-Re(eigen(ProdPlanMan_C2)$vectors)[,1]
> vec_ProdPlanMan_C2
[1] -0.8732476 -0.1021775 -0.1957355 -0.4343800
> rank_ProdPlanMan_C2<-vec_ProdPlanMan_C2/sum(vec_ProdPlanMan_C2)
> rank_ProdPlanMan_C2
[1] 0.54389630 0.06364058 0.12191252 0.27055060
> lambda_ProdPlanMan_C2<-Re(eigen(ProdPlanMan_C2)$values)[1]
> lambda_ProdPlanMan_C2
[1] 4.198068
> n=4
> CI_ProdPlanMan_C2<-(lambda_ProdPlanMan_C2-n)/(n-1)
> CI_ProdPlanMan_C2
[1] 0.06602264
```

```
> ProdPlanMan_C3<-matrix(c(1,3,1/3,1/5,1/3,1,1/5,1/7,3,5,1,1/3,5,7,3,1),4,4,byrow=T)
> colnames(ProdPlanMan_C3)<-c("R1","R2","R3","R4")
> rownames(ProdPlanMan_C3)<-c("R1","R2","R3","R4")
> ProdPlanMan_C3
          R1 R2        R3        R4
R1 1.0000000  3 0.3333333 0.2000000
R2 0.3333333  1 0.2000000 0.1428571
R3 3.0000000  5 1.0000000 0.3333333
R4 5.0000000  7 3.0000000 1.0000000
> eigen(ProdPlanMan_C3)
eigen() decomposition
$values
[1]  4.1169824+0.0000000i -0.0037480+0.6933829i -0.0037480-0.6933829i -0.1094864+0.0000000i

$vectors
              [,1]                    [,2]                    [,3]           [,4]
[1,] 0.18467467+0i -0.17297433+0.02916744i -0.17297433-0.02916744i  0.24094104+0i
[2,] 0.08688903+0i -0.01028824-0.09126804i -0.01028824+0.09126804i -0.08860316+0i
[3,] 0.41208656+0i  0.00913311+0.37376971i  0.00913311-0.37376971i -0.50058316+0i
[4,] 0.88799225+0i  0.90609394+0.00000000i  0.90609394+0.00000000i  0.82674869+0i

> Re(eigen(ProdPlanMan_C3)$values)
[1]  4.116982443 -0.003748027 -0.003748027 -0.109486390
> Re(eigen(ProdPlanMan_C3)$vectors)
           [,1]         [,2]         [,3]        [,4]
[1,] 0.18467467 -0.172974331 -0.172974331  0.24094104
[2,] 0.08688903 -0.010288241 -0.010288241 -0.08860316
[3,] 0.41208656  0.009133114  0.009133114 -0.50058316
[4,] 0.88799225  0.906093939  0.906093939  0.82674869
> vec_ProdPlanMan_C3<-Re(eigen(ProdPlanMan_C3)$vectors)[,1]
> vec_ProdPlanMan_C3
[1] 0.18467467 0.08688903 0.41208656 0.88799225
> rank_ProdPlanMan_C3<-vec_ProdPlanMan_C3/sum(vec_ProdPlanMan_C3)
> rank_ProdPlanMan_C3
[1] 0.11750425 0.05528549 0.26220121 0.56500905
> lambda_ProdPlanMan_C3<-Re(eigen(ProdPlanMan_C3)$values)[1]
> lambda_ProdPlanMan_C3
[1] 4.116982
> n=4
> CI_ProdPlanMan_C3<-(lambda_ProdPlanMan_C3-n)/(n-1)
> CI_ProdPlanMan_C3
[1] 0.03899415
```

```
> ProdPlanMan_Obj<-matrix(c(1,3,1,1/3,1,1/3,1,3,1),3,3,byrow=T)
> colnames(ProdPlanMan_Obj)<-c("C1","C2","C3")
> rownames(ProdPlanMan_Obj)<-c("C1","C2","C3")
> ProdPlanMan_Obj
          C1 C2        C3
C1 1.0000000  3 1.0000000
C2 0.3333333  1 0.3333333
C3 1.0000000  3 1.0000000
> eigen(ProdPlanMan_Obj)
eigen() decomposition
$values
[1]  3.000000e+00 -1.110223e-16  0.000000e+00

$vectors
          [,1]       [,2]       [,3]
[1,] 0.6882472  0.8635201 -0.8846517
[2,] 0.2294157 -0.3931330  0.1474420
[3,] 0.6882472  0.3158788  0.4423259

> Re(eigen(ProdPlanMan_Obj)$values)
[1]  3.000000e+00 -1.110223e-16  0.000000e+00
> Re(eigen(ProdPlanMan_Obj)$vectors)
          [,1]       [,2]       [,3]
[1,] 0.6882472  0.8635201 -0.8846517
[2,] 0.2294157 -0.3931330  0.1474420
[3,] 0.6882472  0.3158788  0.4423259
> vec_ProdPlanMan_Obj<-Re(eigen(ProdPlanMan_Obj)$vectors)[,1]
> vec_ProdPlanMan_Obj
[1] 0.6882472 0.2294157 0.6882472
> rank_ProdPlanMan_Obj<-vec_ProdPlanMan_Obj/sum(vec_ProdPlanMan_Obj)
> rank_ProdPlanMan_Obj
[1] 0.4285714 0.1428571 0.4285714
> lambda_ProdPlanMan_Obj<-Re(eigen(ProdPlanMan_Obj)$values)[1]
> lambda_ProdPlanMan_Obj
[1] 3
> n=3
> CI_ProdPlanMan_Obj<-(lambda_ProdPlanMan_Obj-n)/(n-1)
> CI_ProdPlanMan_Obj
[1] 0
```

```
> rank_ProdPlanMan_C1
[1] 0.19983200 0.07809127 0.19983200 0.52224472
> rank_ProdPlanMan_C2
[1] 0.54389630 0.06364058 0.12191252 0.27055060
> rank_ProdPlanMan_C3
[1] 0.11750425 0.05528549 0.26220121 0.56500905
> rank_ProdPlanMan_Obj
[1] 0.4285714 0.1428571 0.4285714
> FinalRank_ProdPlanMan<-0.4285714*rank_ProdPlanMan_C1+0.1428571*rank_ProdPlanMan_C2+0.4285714*rank_ProdPlanMan_C1
> FinalRank_ProdPlanMan
[1] 0.24898401 0.07602688 0.18870063 0.48628838
```

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