

# **MASTERARBEIT**

## **Development of a Framework for the Integration of Real-Time Data in Supply Chain Risk Management Using Simulation Tools**

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# Table of Contents

<b>Acknowledgments .....</b>	<b>ii</b>
<b>Table of Contents .....</b>	<b>iii</b>
<b>Table of Figures .....</b>	<b>v</b>
<b>Table of Tables .....</b>	<b>vi</b>
<b>1 Introduction.....</b>	<b>1</b>
1.1 Motivation .....	1
1.2 The actual Supply Chain and the Perspective of Future .....	2
1.2.1 The Supply Chain Risk Management.....	2
1.2.2 The Real-Time Data .....	5
1.2.3 Simulation in the Supply Chain.....	6
<b>2 Supply Chain and Risk Management .....</b>	<b>8</b>
2.1 Supply Chain Management .....	8
2.1.1 The Flow Concept .....	8
2.1.2 The Relationships between Enterprises.....	10
2.2 Supply Chain Risk Management.....	12
2.2.1 Definition of Risk .....	12
2.2.2 The Risks in the Supply Chain .....	13
2.2.3 The Steps of the Supply Chain Risk Management.....	17
2.3 The Need of Real-Time Risk Management.....	22
2.4 The Role of Business Intelligence for Supply Chain .....	24
<b>3 Real-Time Supply Chain .....</b>	<b>29</b>
3.1 The Kinds of Data .....	29
3.2 The Obtainment of Data .....	30
3.2.1 Big Data.....	30
3.2.2 Cloud Computing .....	34

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3.3	The Integration of the Data .....	39
3.3.1	Real-Time Data Generation: ERP Systems .....	40
3.3.2	Real-Time Object Identification: RFID (Radio Frequency Identification) .....	41
3.3.3	Real-Time Visualisation .....	42
3.3.4	Real-Time Integration of Data and Processes: Electronic Data Interchange (EDI) .....	42
3.3.5	Real-Time Decisions Making: Intelligent Agents .....	43
3.3.6	Real-Time Event Monitoring: Event Managers .....	44
3.4	The Visualisation of the Supply Chain .....	45
<b>4</b>	<b>Simulations in Supply Chain Risk Management .....</b>	<b>47</b>
4.1	Simulation Concepts .....	48
4.2	Monte Carlo Simulation .....	50
4.2.1	The Monte Carlo Procedure .....	51
4.2.2	Monte Carlo Applications .....	57
4.3	Agent-Based Simulation .....	58
4.3.1	The Elements .....	58
4.3.2	Methods for Agent-Based Modelling .....	62
<b>5</b>	<b>Framework for the Supply Chain Management .....</b>	<b>64</b>
5.1	The Reactive Scheduling Concept Approach .....	64
5.2	The Approach for the Supply Chain Management .....	65
<b>6</b>	<b>Conclusions and Outlook .....</b>	<b>68</b>
	<b>Bibliography .....</b>	<b>69</b>

## Table of Figures

Figure 1.1- Supply Chain Risk Management schema [Huisman 2012, p.5] .....	4
Figure 1.2- Local simulation [Terzi & Cavalieri 2003, p. 5].....	7
Figure 1.3- Parallel and distributed simulation [Terzi & Cavalieri 2003, p. 5].....	7
Figure 2.1- Supply chain flow [Musa, 2012 p.5].....	9
Figure 2.2- Bow-Tie risk analysis method [SCRLC, 2011 p.15] .....	20
Figure 2.3- Butterfly depiction of supply chain risk [Sodhi & Tang, 2012 p. 16] .....	20
Figure 2.4- Risk control plan [Musa, 2012 p.5].....	23
Figure 2.5- Risk analysis and control process [Musa, 2011 p.11].....	24
Figure 2.6- SCOR model .....	25
Figure 2.7- SCOR levels [Calderón Lama & Lario Esteban, 2005 p. 3] .....	26
Figure 2.8- SCI model [Stefanovic et al., 2006 p.616].....	27
Figure 3.1- Data pipeline [Agrawal et al., 2012 p. 3] .....	32
Figure 3.2- Results of data integration [Datasax, 2013 p. 8].....	33
Figure 3.3- Architecture of Cloud Computing [Kavita et al., 2012 p. 64] .....	37
Figure 3.4- Cloud Computing model [Kavita et al., 2012 p. 64].....	38
Figure 3.5- RFID chip [Wikipedia, 2008] .....	41
Figure 3.6- EDI's structure [Amece, 2009 p. 8] .....	43
Figure 3.7- Warehouse with agent intelligence [Yung et al., 2000 p. 123].....	44
Figure 3.8- Visualiser's connections [Goh et al., 2013 p. 209].....	46
Figure 4.1- Mathematical models [Raychaudhuri, 2008 p. 91].....	50
Figure 4.2- Case-based models [Raychaudhuri, 2008 p. 91].....	50
Figure 4.3- Framework for selecting input distributions [Lipton, 1994 p. 193].....	52
Figure 4.4- Generation of random varieties [Raychaudhuri, 2008 p. 96].....	54
Figure 4.5- Comparison between Bootstrap simulation with and 1000 samples from the primary bimodal distribution [Raychaudhuri, 200 p. 97].....	55
Figure 4.6- Agent with his interactions [Macal & North, 2010b p. 2] .....	59
Figure 4.7- Agent characteristics [Macal & North, 2006a p. 74 .....	60
Figure 4.8- Topologies for agent relationships and social interaction [Macal & North, 2010a p. 155].....	61
Figure 5.1- Schematic overview of the reactive construction scheduling approach [SZCZESNY & KÖNIG, 2013 p. 4] .....	64
Figure 5.2- Changes in the inbound flows of the framework .....	65
Figure 5.3- Changes everywhere of the framework .....	66

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## Table of Tables

Table 2.1- “Heat” Map of likelihood and consequences [SCRLC 2011, p.18].....	13
Table 2.2- Potential Risks to an Organisation and its Supply Chain [SCRLC, 2011 p. 12-13] .....	18
Table 2.3- Food manufacturer risk Analysis [Dittmann, 2014 p. 25].....	19
Table 4.1- Areas of Supply Chain Management.....	49
Table 4.2- Samples from a bimodal distribution .....	55
Table 4.3- Basic statistics comparison between bootstrapped MC sample and general MC sample.....	56

# 1 Introduction

## 1.1 Motivation

The growing demand of the production, distribution and marketing processes of all kind of products, and the globalisation of all sectors involved in the processes drives a rapid and constant evolution of logistics. So, the organisation and control of logistics becomes a key element in the economic activity. This means being prepared at all times, with adequate mechanisms to quickly and effectively deal with contingences which may arise in any of its phases, moments or intervening variables. Hence, Supply Chain Risk Management becomes important to ensure success in all parts of the process.

In this context, various reasons have led me to perform this study. Firstly, Supply Chain Management is an interesting challenge. The constant and rapid evolution of logistics requires ongoing analysis of actions designed to address unforeseen circumstances and also a constant update of protocols. Not dealing with these unforeseen circumstances quickly and effectively has a significant impact on the business and carries high economic losses. Moreover, the strong competition in the business world involves finding the best service at the lowest cost. All these factors represent an interesting challenge for a novice engineer because they require advancements in the research, design of new technologies, implement strategies, evaluate results, and innovation.

Secondly, Supply Chain Risk Management integrates various disciplines. Given the multiplicity of factors involved, this task requires knowledge of the systems of production and transmission of information, systems costing, transportation of goods, storage... The person in charge of this issue must have a wide field of knowledge in engineering.

Additionally, Supply Chain Risk Management contributes to the sustainability of the planet and to peoples' welfare. While we are promoting an economic activity, and therefore focused on benefits for the business, the implementation of the Supply Chain Risk Management can be carried out taking into account ethics and the contribution to the sustainability of the planet. This can be carried out from the perspective of the "triple bottom line" proposed by J. Elkington (1997). [Christopher, 2011 p. 241-242] The "triple bottom line" concept emphasises the importance of examining the impact of business on three different ways: environment (e.g. pollution and climate change), economy (effect on people's livelihoods and financial security) and society (poverty reduction). *"These three elements – the 3Ps of people, profit and planet – are inevitably intertwined and they serve to remind us that for a business to be truly sustainable, it must pay regard to the wider impact of the activities it undertakes"*.

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Lastly logistics in Barcelona and Catalonia. Phoenicians, Greeks and Romans used to use the Catalonian coast to develop their commercial activity, and in the middle ages Barcelona became the principal enclave of the Crown of Aragon as it expanded its kingdom. After the industrial revolution and during the 19<sup>th</sup> and 20<sup>th</sup> centuries many industries were created (mostly textile) in Catalonia. Nowadays, Catalonia retains part of this industry and faces new challenges like the extension of Barcelona's port and Metro, and the creation of the Mediterranean Corridor. For the Catalonian industry, these new works and the geographical situation of Catalonia provide good professional perspectives for junior engineers. Surely, the knowledge of Supply Chain Risk Management aspects will be of significant help to these new engineers.

All in all, the fact that the Supply Chain Risk Management represents an exciting professional challenge, requiring the integration of different disciplines and teamwork, contributes to the sustainability of the planet and the people's welfare, and that it offers good career prospects in my country have been the reasons that led me to develop this thesis.

## **1.2 The actual Supply Chain and the Perspective of Future**

In this dissertation, the principal aim is to connect three businesses' tools that are normally unrelated. For this, it is necessary to explain how. These three concepts or technologies are useful weapons nowadays for all enterprises and how, with the evolution of the computer technologies, they have become more accessible and easy to manage. However, the problem with these is that they normally operate independently and without any bond between them. In this context, and with knowing the value of the automation of all the enterprises processes, we will try to create a framework where the Supply Chain Risk Management, the real-time data, and the simulation tools, meet. This idea of the framework is not an original invention of the author, but it is an adaption of a framework created by K. Szczesny and M. König in their work "Integration of Uncertain real-time Logistics Data for Reactive Scheduling Using Fuzzy Set Theory". In this chapter, we will introduce briefly these three technologies, describing them, including a short review of their history, their importance in the present and their future perspectives.

### **1.2.1 The Supply Chain Risk Management**

In the first chapter, we will talk about the Supply Chain Risk Management. The concept "Supply Chain Management" was created in 1982 by Keith Oliver, but it has not become popular until the beginning of the new millennium, with internet access facilitating a lot of the communication within and outside the enterprise.

[D'Angelo 2011, p.1] Nowadays, the meaning of Supply Chain Management is commonly not clear, mainly because it is confused with other similar terms like



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logistics or distribution. Distribution refers to the output material flow from the supplier to the customer. That includes different aspects like storage, transportation and warehouse activities. The Council of Logistics Management has defined logistics as: *“The process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements”*. This term was first related to the military but gradually spread among enterprises and includes various separated activities that are coordinated. As we can see, the concept of logistics is broader than distribution since it includes more aspects than the transportation of goods. Supply Chain Management incorporates all of the activities in planning, procurement, manufacturing, inbound logistics, internal logistics, outbound logistics and reverse logistics. It also includes all of the integration systems that a company shares with its suppliers and clients in order to control and evaluate different parameters in a product’s flow like the speed, visibility or the synchronisation of transport.

So, the aim of the Supply Chain Management is to improve the productivity and lower the costs associated with logistics. To reach it, the early collaboration between enterprises is essential, regardless of any downsides (which will discuss in more depth in the next chapter). To maximise all of the Supply Chain’s capabilities that we have described in the last paragraph, it is necessary to have the support of information technologies. The latest great evolution of the communication, the internet, has triggered the possibility of a fully integrated Supply Chain and makes maximising its capabilities possible

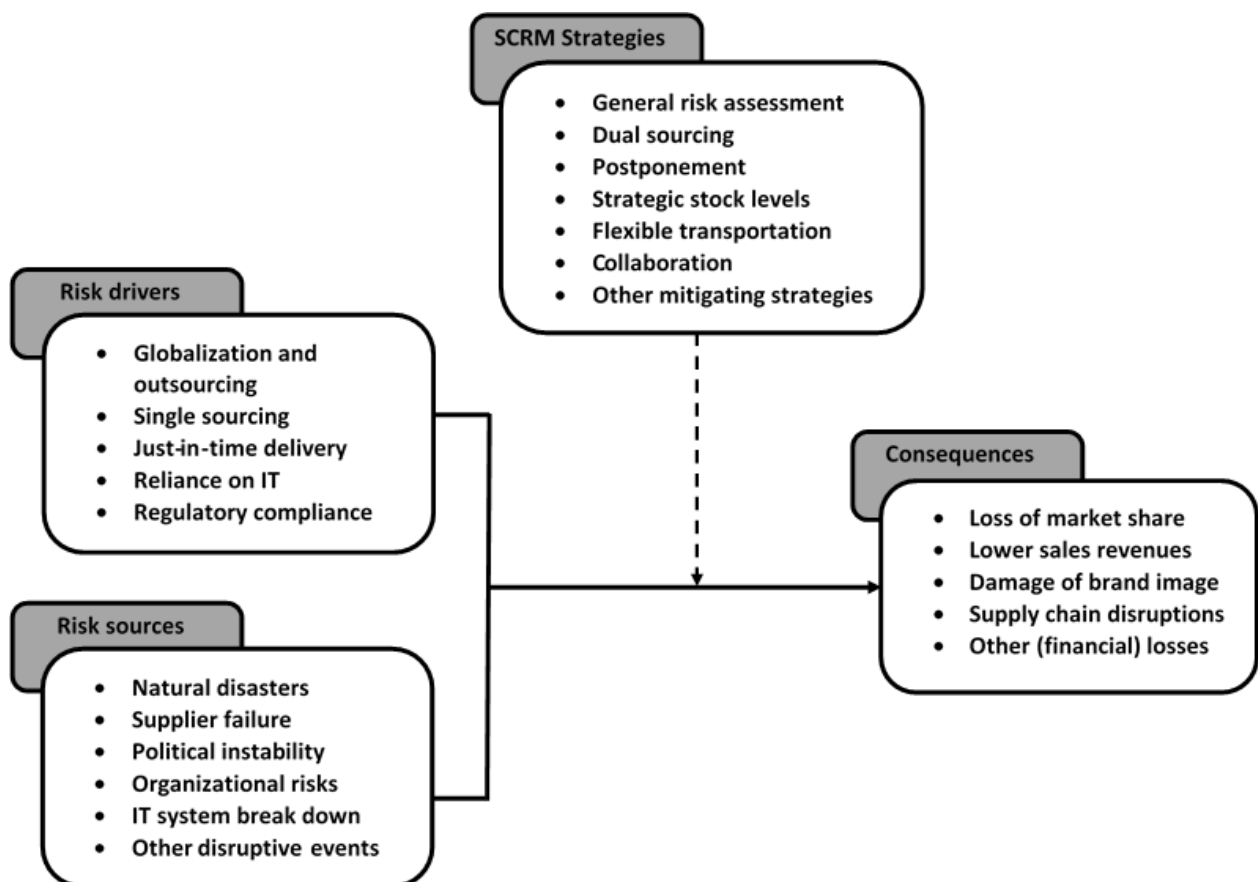
A few examples of enterprises that have successfully introduced the Supply Chain Management’s methods in the company are: Dell Computers, Seven-Eleven and Zara Corporation. Dell Computers, as its own name suggest, bases its business selling computers directly to the client. This allows the enterprise to lower stock requirements and also allow the client to set up the computer as they wish. Seven-Eleven provides products to its shops up to 8 times every day, in order to keep the stock levels and variety of fresh goods high. Zara Corporation has designed a process that is able to identify the consumer’s needs, and in less than 30 days Zara is able to sell that product. These examples want to show that the positive results of those enterprises are based on the good management of the supply chain.

But, in this dissertation we will focus in the part of the Supply Chain Management that takes care of the risks. A good definition of Supply Chain Management is found in Wikipedia: *“It is the implementation of strategies to manage both every day and exceptional risks along the supply chain based on continuous risk assessment with the objective of reducing vulnerability and ensuring continuity”*. From the point of view of a single enterprise, the majority part of the harmful events that can occur are inevitable; but, the consequences that they cause in the firm can be completely mitigated,

depending on the measures that it have been taken (there is an example in the correspondent chapter).

[Huisman 2012, p. 4] The sources that can trigger an undesirable event can take different forms: a single natural disaster like an earthquake or a tsunami could paralyse the production of one plant, or a labour dispute, a supplier failure or the breakdown of the IT system could cause important losses. For instance, in 2001 Nike implemented a new supply chain planning system to automate the ordering process of its shoe division. However, it did not work as well as they planned: Nike explains that the software made false estimations, underproducing the popular shoe models, while selling unpopular varieties at reduced price. Consequently, Nike had to face a \$100 million revenue shortfall just in the quarter after installing the software.

[Huisman 2012, p. 5] In the last paragraph we have seen from where the risks come from. We can also see that there are some policies or strategies that make those risks more likely. Strategies like outsourcing, single sourcing, and just-in-time delivery sound great and are logical in a stable environment because they allow to satisfy the customer's demand while minimising costs, but they entail inherent risks. Therefore, they are called "risk drivers".



**Figure 1.1- Supply Chain Risk Management schema [Huisman 2012, p.5]**

Of course, there are some strategies that an enterprise can adopt to absorb the damages of an undesirable event (or in the best case, eradicate them). These decisions should be as automatic as possible and a risk control and mitigation plan must be executed. In the first chapter we will discuss how to realise that plan with the five steps of the Supply Chain Risk Management and how the plan works. We will also talk about the business intelligence, a set of technologies that allow us to analyse the data to extract some meaningful information of them.

### **1.2.2 The Real-Time Data**

The second concept that we will try to integrate together is real-time data. The capacity of enterprises to get data from the manufacturing and transport processes has increased prominently after the boom of the communication technologies. In this chapter we will not only explain the technologies that exist to get the data, but we will also see how firms can transform them to the shape that they want, integrate them in their systems and share with their partners.

[Barlow 2013, p. 3] Michael Minelli, co-author of Big Data, Big Analytics says: *“Real-Time Big Data isn’t just a process for storing petabytes or exabytes of data in a data warehouses. It’s about the ability to make better decisions and take meaningful actions at the right time. It’s about detecting fraud while someone is swiping a credit card, or placing an ad on a website while someone is reading a specific article. It’s about combining and analysing data so you can take the right action at the right time, and at the right place”*. This quote tries to convey that the most important objective is not to obtain data as fast as possible, resulting in a great quantity of meaningless data, but the analysis and quick response to events that the data identities.

One of the biggest problems in the obtainment of data is the synchronisation between what is collected in one moment and the data warehouse where we have all the historical information. The goal of every enterprise is make this process as fast as possible in order to be able to analyse the data as soon as possible. In a perfect world the data in the warehouse would instantly reflect the facts of the production or transportation system; but in practice, some delay is inevitable. [Guerra & Andrews 2011, p.2] A delay of some minutes is almost always acceptable, so we will refer to real-time data as those systems that maintain a short and acceptable delay in synchronisation. Nowadays most data warehouse are not real-time, instead they typically refresh their information once a day, usually at night. And sometimes data warehouses update their information re-copying everything in the source databases; consequently this daily refresh approach takes a long time and can create a serious scheduling problem since the servers need to stop all the other activity while this is taking place. The main advantage of using a real-time updating system is confidence in

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the reliability of the data, since a loss of trust in the quality or timeliness of the data on which an output is based can render the data useless.

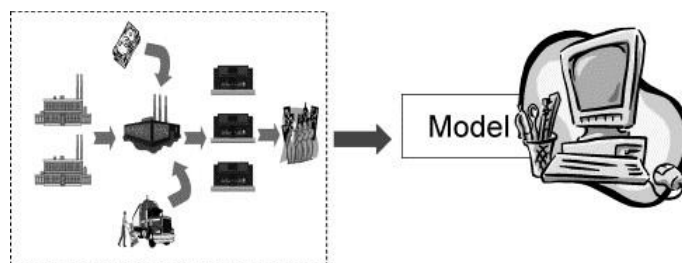
### **1.2.3 Simulation in the Supply Chain**

In the fourth chapter of this dissertation we will discuss about how to make decisions with the data that we have previously obtained. There are some different quantitative methods that can provide the user the best solution for any determined situation. Among these, simulation is one of the most powerful techniques to use, as a decision support system, within a supply chain environment. [GoldSim 2007, p. 2] Simulation is defined as the process of creating a computer model of an existing or proposed system (in our case the supply chain) in order to identify and understand the factors that control the system. As we will see, any system that is based on quantitative parameters can be translated to mathematical equations, and is therefore able to be simulated.

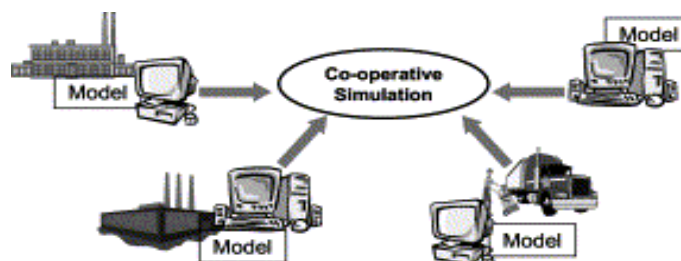
[Terzi S & Cavalieri 2003, p. 4] In the industrial area, simulation has been mainly used for decades as an important support for production engineers in validating new layout choices and correcting the sizing of a production plan. In particular, as the topic of the thesis, supply chain is a typical environment where simulation can be considered a very useful device. [GoldSim 20007, p. 3] However, most models are developed to address particular issues and not to generalised targets. The kind of uses that are usually addressed are the following: optimisation, decision analysis, diagnostic evaluation, risk management and project planning. With optimisation we want to know the optimal operation guidelines with which to maximise or minimise a result. To make decisions we can also compare different alternatives using simulations and check which results are best. As the word diagnostic in the medicine's field means, we use that use to find the reason of a particular problem that is unknown. Project planning refers to the evaluation of potential changes in the supply chain that can result in (sometimes huge) disruptions when they are not suitable, like outsourcing or building a new factory. Within the scope of Risk Management, simulations are used by enterprises in order to know how to prepare themselves for events like a labour strike, problems in the facilities (like a fire or a machine breakdown) or political events. The design of redundant systems and mitigation plans to minimise the impact of undesirable events are also goals of this kind of simulation.

When we talk about the supply chain, we do not have to forget that we are including more than one firm in the concept. [Terzi & Cavalieri 2003, p. 5] The kind of simulations that we have described before can be carried out according two structural configuration: using one simulation model executed by a single computer (Figure 1.2) or implementing more model, executed over more calculation processors (Figure 1.3). The advantages of using the second configuration are the reduction of the simulation

time, the possibility of integration of different simulation tools and languages, and the increase of tolerance to simulation failures.



**Figure 1.2- Local simulation [Terzi & Cavalieri 2003, p. 5]**



**Figure 1.3- Parallel and distributed simulation [Terzi & Cavalieri 2003, p. 5]**

In the fourth chapter we will explain first some basic simulation concepts that will be used in the two simulations that we will explain: Monte Carlo Simulation and Agent-Based Simulation. The first one is one simulation based on repeated random sampling and static analysis and the second is based on the interaction of different agents that change their behaviour while the simulation proceed. The target of both simulation is discover the underlying patterns of the data that we cannot see with the naked eye.

## **2 Supply Chain and Risk Management**

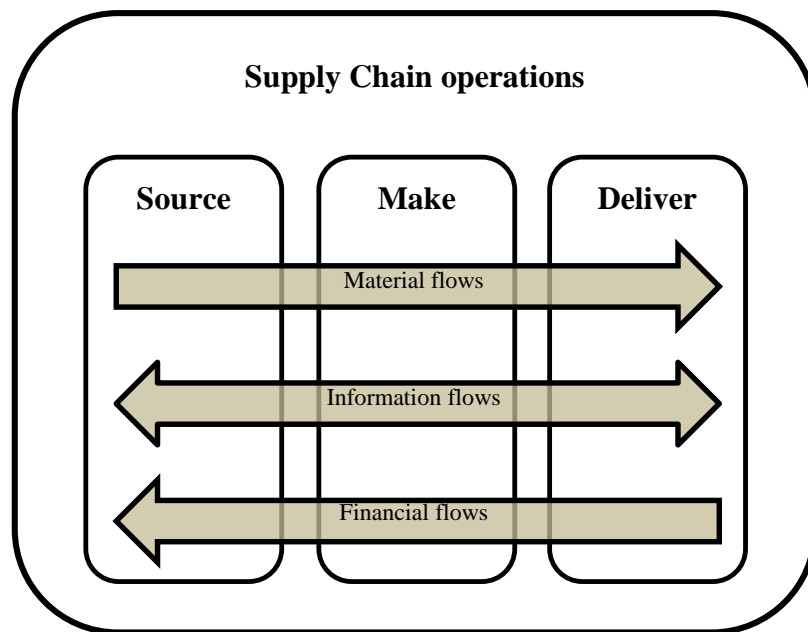
### **2.1 Supply Chain Management**

As Robert Rodin (Marshall Industries) said: “*Today business is about my supply chain vs. your supply chain*”. This approach has changed over the years. Nowadays, companies do not directly compete with another companies, but rather groups of firms compete with other groups. Supply Chain Management covers wide range areas such as logistics, productions, scheduling, facility location, procurement, inventory management, ordering management, and so on.

It is logical to think that it is necessary for members of a “group” to work together as cohesively as possible. They do not have to share the same specific objectives, but it is obvious that the benefits of one will positively affect to the others. Supply Chain Management incorporates two concepts: a collaborative effort that combines many processes in the product cycle, and a total vision of the product cycle: from the introduction of the raw materials to the final product delivered to the consumer. So, SCM refers to this relationship between companies taking care of the operations management, logistics, procurement, and information technology.

#### **2.1.1 The Flow Concept**

There are different ways to explain how a supply chain works. [Chang et al., 2001 p. 26] One very common way is based on the division of the functional areas of Supply Chain Management, into demand planning, master planning, procurement, transportation and manufacturing. But after studying the literature, the most interesting is the one introduced by S. Nurmaya Musa. [Musa, 2012 p.4] It explains that the concept of the supply chain is huge and involves many different terms. But it can be divided into three “flows” that connect the supply chain operations and the global context in which the studied supply chain works. The flows that we will discuss are the material flow, the financial flow and the information flow. It is important to notice that these flows share the same operations of source, make and deliver, and also that they are related and interconnected. So, if one of these flows fails, this disruption will usually create a domino effect that will affect the others.



**Figure 2.1- Supply chain flow [Musa, 2012 p.5]**

[Musa, 2012 p. 12-23] Here, we will describe the flows briefly in order to have a general idea of what we are talking about. The material flow indicates the physical movement of the elements across the supply chain partners. These include the transportation of goods, storage and inventories. In the concept of source/make/delivers that we introduced previously, the sourcing involves the acquisition of physical products or services, make involves the processes of design and production, and deliver involves care of transport of the goods to the clients

The financial flow, also known as cash flow, represents the received and spent cash streams. As we can see in the Figure 2.1, this flow goes in the opposite direction than the material flow. The reason is simple: the buyers pay the provider for the product that they receive.

The information flow includes data about demand, inventory status and order of fulfilment. [Musa, 2012 p. 5] Some authors define that flow in the same direction than the financial flow. But other literature [Stading et al., 2007] states that the information is sent and received by all enterprises involved, thus forming a bidirectional arrow. The information shared across the supply chain is not just the signature of an invoice by a customer when a shipment is received. But rather a continuous flow of meaningful data. Considering that nowadays any information can be easily shared with the partners can be useful, we assume the second approach is the best.

It is important not to forget about the supply chain scope because it usually affects to a large degree the business of a group of companies, sometimes making impossible the

existence of an enterprise. We can describe it like the context where our supply chain works. It includes different issues like logistics, price volatility of energy, political risk, culture, and supply chain partners' relationships.

### **2.1.2 The Relationships between Enterprises**

In the previous point we have seen in a general way how a supply chain is shaped by its actions and flows. In this point we will explain the factors that make this relationship better and stronger, and sort out the groups of enterprises by the cohesion of their work and level of cooperation.

[Simchi-Levi et al., 2013 p. 12] Simchi-Levi and the other authors introduce through their research seven factors that enable stronger capabilities in Supply Chain Management (and also in Risk Management), and calling them enablers. Looking at these enablers it is possible to make an empirical framework of how strong the supply chain of a group of firms is. The seven enablers are:

- Risk Governance – involving the presence of appropriate Risk Management structures, processes and culture.
- Flexibility and redundancy in product, network and process architectures – this factor refers to the ability of our chain to absorb the disruptions due the flexibility and the redundancy.
- Alignment between partners in key-values – cooperation and sharing of the same long term objectives across the supply chain are strategic points to success in the business. Simchi-Levi and the authors conclude that for the main part of the enterprises that is this most important factor.
- Upstream and downstream supply chain integration – supply sharing, visibility and collaboration between supply chain partners.
- Alignment between internal business functions – not just the actions of all the supply chain have to be aligned (as mentioned in the third enabler). The activities between company functions on a strategic, tactical and operation level also have to be coordinated.
- Complexity management/rationalisation – this enabler refers to the ability of the supply chain companies to standardise and simplify the networks and process, interfaces, product architectures that they share.
- Data, models and analytics – development and use of intelligence and analytical capabilities to support Supply Chain and Risk Management functions.

As we have introduced before, the reason to work with the enablers is to define different cohesion levels of a Supply Chain. Other literature [Fisher et al., 2009 p4; Knolmayer et al., 2009 p. 12; Simchi-Levi et al., 2013 p.14] defines this division as those levels report to us the maturity of our chain in an empirical manner. At lower levels, single processes of a firm are not connected with the partner's actual situation; while at the high level all the actions have more than an individual sense. These levels are explained below:



- 
- Level I: Functional Focus. Supply chains are organised with a very low degree of integration and cooperation. Duplicity of activities, absence of coordinating efforts between suppliers and partners and little visibility into the operations of partners are the principal characteristics. When a company wants to design a new product, this labour is performed independently, and just some vulnerability analysis is done. There is not a strategy to face risks together, but the firms simply try to minimise the consequences when an undesirable event happens.
  - Level II: Internal Integration. As its own name says, the internal processes are integrated, information is shared and visibility is provided in a structured way. Basic threats are analysed, and the way to absorb disruptions is through buffers of capacity and inventory.
  - Level III: External Integration. Supply chains feature collaboration across the enterprises. Information sharing is global and visibility high, and some standards are created to facilitate it. Key activities are managed between the partners, and external input is incorporated into internal planning activities. Continuity plans that involve different partners are created to face some possible problem.
  - Level IV: Cross-Enterprise Collaboration. Companies are completely aligned with their supply chain partners on the key activities. Their individual strategies and operations are guided by common objectives. Risk sensors and predictors are supported by real-time monitoring and analytics that work cooperative across the supply chain. Companies' structures and processes are flexible, allowing quick response and adaptability when it is required.

[Simchi-Levi et al., 2013 p. 16] The study of Simchi-Levi concludes that the majority of the enterprises surveyed by them are in the levels II and III. Only a minority (6-10%) are fully prepared. One of the problems to not to achieve the higher level is that it is usually risky for enterprises just to trust in only one supplier, and they prefer to opt for multiple system for acquiring raw materials.

[Knolmayer et al., 2009 p. 11] An old but illustrative and well known example that easily shows us why the proper communication between partners of the supply chain is important is the Beer Game. In the 60's, the MIT Sloan School of Management created it to prove that even a desirable event like the increase of a product's demand can trigger disastrous consequences if the supply chain is not sufficient improved. It explains with a little game the devastating results of the Bullwhip Effect, created by coordination problems. Even the increase of the product demand can trigger disastrous consequences if the supply chain is sufficiently improved. Delays in transferring order information and in fulfilment (due to lead times) and the absence of information sharing are the main reasons for the bullwhip effect. Anyway, nowadays the data transfer is easier than it ever was, due to the technological improvements and this problem is less common.

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## 2.2 Supply Chain Risk Management

### 2.2.1 Definition of Risk

The Word Reference Random House Learner's Dictionary of American English defines risk as: “*a dangerous chance*”. Another definition of risk could be: “*an uncertain event that, if it happens, will have negative consequences for us*”. As we can early see in the definition a risk is based on two concepts: the probability that something happens, and its negative repercussions. As we talk of the risks and how to protect against and mitigate them, we could also talk about opportunities and how to take advantage of them, however this is not the purpose of this work. As its own name indicate, Supply Chain Risk Management tries to identify, estimate, evaluate, and if it were the case mitigate and monitor the different kinds of risks that could create problems in a supply chain.

But, what is the goal of Supply Chain Risk Management? [Rice & Caniato, 2003 p. 22-23] As Rice and Caniato introduce, the purpose is “*to react to an expected disruption and maintain operations after the event*”. They also introduce the concept of resilience. In the mechanical engineering approach, the resilience is the energy that a material can recover after being deformed, being able to recover the same shape it had before the deformation. We can bring that idea to the supply chain scope: a resilient supply chain must be able to react and adapt itself to any event and then return to its normal operation without long term impact from that event. [Mukherjee, 2008] The typical example of why we need Supply Chain Risk Management is Ericsson's crisis in 2000. Its supplier (Royal Phillips Electronics) suffered a ten minutes fire in their storehouse, while Ericson was using a single-sourcing policy. They had not predicted this risk and did not act as fast as necessary. Thus, the material flow was quickly disrupted. Finally, Ericsson's loss was estimated to be \$400 million, with revenues falling 52% over 4 years. It is easy to understand that the problem with the material flow caused the financial crisis because the company could not adapt to the situation. In contrast, Nokia (that had the same supplier) took advantage of this situation and expanded its share of the global market to 30%.

[Musa, 2012 p. 9] In Musa's dissertation, he introduces the definition of risk as “*events with high-impact/low-probability*”. These two characteristics are the key to knowing the impact of risk: the likelihood of occurrence and the impact of it when it happens. [Simchi-Levi et al., 2013 p. 9] Following that concept we can define two categories of risks: the known-unknown (controllable in some degree) and the unknown-unknown (uncontrollable). The first term refers to the likelihood of the event to happen and the second to the damage resulting from it. The common examples of the first group are: raw material price fluctuation, currency fluctuation and energy/fuel price volatility. In the second group we can find environmental catastrophes and geopolitical instability.

The SCRLC (Supply Chain Risk Leadership Council) evaluates the risks with a “heat-map”, showing the risk-events on a matrix defining likelihood and consequence levels. This technique allows managers to easily situate the risks when they have defined them correctly:

**Table 2.1- “Heat” Map of likelihood and consequences [SCRLC 2011, p.18]**

LIKELIHOOD	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
		CONSEQUENCE				

## 2.2.2 The Risks in the Supply Chain

There are a lot of risks that a company must face up and we cannot mention all; machine breakdown, operator illness, job cancellation, due date changes, change in job priority, natural disaster, market changes, change in technology or cyber-attacks are some examples. The most of these examples are risks that a single enterprise would suffer, but the consequence would propagate throughout the chain. A single event can easily disrupt a flow (or more than one at the same time, like in the example in the previous section) of the supply chain. The impact of this disruption can usually be observed all along the supply chain. Accordingly, we must know accurately what the risks are and how they affect us. [Musa et al., 2012 p. 12-22] In this section we will divide the risks following the division of three flows and the scope that we have described in section 2.1.1.

### 2.2.2.1 Disruptions in the Material Flow

The material flow can be disrupted due to transportation incapability, halted manufacturing, lack of capacity, and so on. In the products’ acquisition (source), the most common dilemma is the supplier policy that the company must follow. [Cousins et al., 2007 p. 2-3] Cousins et al. mention two possible exposures that a company must face up: technological and strategic. Technological exposure is caused by an over-

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reliance on a product, process or technology, while strategic exposure occurs when a company has a high dependence on an exclusive supplier. With flexible supplier policies companies can have different alternatives in the case that they have a disruption in the supply chain. As Tang et al., say some dissertations have noticed that switching suppliers has hidden costs and also carries some managerial difficulties. [Tang et al., 2008 p. 27-30]

To facilitate focusing in the core competences, outsourcing has become a trend. The advantage of using this kind of policy is that some manufacturing costs decrease, but on the other hand the enterprise loses control of the raw materials and also has to concern itself with finding the ideal supplier. [Levary, 2007 p. 393] Levary developed a methodology to select the best supplier using the following providers' characteristics: their reliability, their country's risk, the transportation reliability and the reliability of their own suppliers. With globalisation it is easier to go further abroad to find raw materials or suppliers, but we must not forget the consequences that it implies: taxes, fluctuating currency exchange rates, import/export fees and longer transportation.

[Tang et al., 2008 p. 29] The main risks that a company must face up when they manufacture a product (make) are: product and process design risk, production capacity risk and operational disruption. The risk to fail in the design of product and process has urged the companies to work more cohesively at an early stage of the process, involving the suppliers in the design of new products, in order to have a robust design of the product and the processes involved. The production capacity must be mindful of the resource capacity. The capacity and the technological skills (of the company and the suppliers) must be known as soon as possible. For this, the involvement of an experienced supplier in the first steps of the design is greatly helpful. On the other hand, an early supplier involvement worsens the possibilities of obtaining the best provision contracts, as the relationship with the supplier must be described quickly, and the supplier must develop some technology. The operational disruptions are usually three: operational contingencies, natural disasters and political instability.

In the case of delivering, the demand uncertainties are the major problem. It is possible to divide them into the following categories: demand volatility and seasonality, unmet demand and excess of inventory. To face up the seasonality, volatility of fads, new product adoptions and short product life, companies must increase the product varieties and increase the number of channels through which the firm sells their products. In the toy industry, enterprises use the high variety of items and a planned shortage in order to create a big demand from collectors. It is obvious that quick responses to adapting the production is needed when the demand changes. Inventories allow manufactures to be more responsive to demand, but an inaccurate demand forecast can result in excessive stock (with all the monetary drawbacks that it carries). The goal is to find some stock policy that behaves well, even when the demand or the holding cost changes. Another

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problem of inventories is° obsolescence. The trend, nowadays, is to low<sup>34</sup> inventories and produce with the philosophy of the “Just in Time” or “Lean Manufacturing”.

### **2.2.2.2 Disruptions in the Financial Flow**

[Musa, 2012 p. 19-20] Disruptions in financial flow involve the inability to settle payments and improper investments. The main difficulties are the exchange rate risk, the financial strength of the supply chain partners, and the handling and practice. The exchange rate is also a risk that companies have to consider when they buy the raw material abroad, due to currency fluctuations that could make a material more expensive. To mitigate this, firms must be bot time, quantity-flexible in order to make the correct orders for the suppliers.

Sometimes financial problems occur because the suppliers are vulnerable and cannot respond to the cost associated with a change in the normal performance. They suffer from unstable raw material flow and cost, and the customers endure market loss due to unsatisfied order fulfilment. And we must not forget that everything in the supply chain is interconnected and the vulnerability of the financial strength of a partner may easily affect the other components of a supply chain.

In a supply chain, there are a lot of financial transactions among the partners, and nowadays with the outsourcing the number is always increasing. A good plan that says how they have to be is necessary in order to ensure all the companies have liquidity. The adoption of supply chain financing includes early-payment programmers, inventory-ownership solutions and consignment financing.

### **2.2.2.3 Disruptions in the Information Flow**

[Tang et al., 2011 p. 30; Musa, 2010 p. 20-22] The major discussion related to the information flow risk is the information accessibility, accuracy and efficiency. It can be studied from the point of view of supply and demand. Demand characteristics and uncertainty can be related on how functional and innovative a product is. [Lee, 2004 p. 1-10] In order to be adaptive in the changes that can be suffered, Lee establishes that rather than being fast and cost-effective, the enterprises of the supply chain must raise the triple-A characteristics: agile to the changes, adaptable to evolvment and aligned to the same target. Inaccuracy in the information can also carry lot of problems, for instance: when somebody assumes that two similar products are the same. Other problems that we have to watch out for are information breakdowns and security. Depending on the business type of the company this can be critical. To face the problem of intellectual property the companies have a dilemma: the managers want smooth networks along the supply chain in order to allow them to have a great visibility, but hackers may try to obtain data of the companies, accessing the company’s information systems illegally. For this reason, it is necessary to protect that shared information so as

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not be exposed, making the network more complex. Finally, we will discuss the risks of outsourcing. Initially, outsourcing is a great option because they can focus in their core-competences. However, there are some risks that enterprises assume when they do that. Leaving the information to another subject out of the supply chain increases some risks: opportunism among vendors, information security apprehension, hidden costs, loss of control, service debasement, disagreements, disputes and litigation, and poaching. Companies must have some system that notifies them if any condition is out of control.

#### **2.2.2.4 Disruptions in the Supply Chain Scope**

[Musa 2012 p. 17-19] The associated risks to the supply chain scope are less controllable than the others described in the previous sections. Once we have made a long term decision like where to localise a production plan, it is difficult to change some factors so as not to be affected by the environment of the place (country laws, political situation...). There are logistic problems that refer to the problems that a company must face when they have to connect some location common. Examples of this kind of problems are: fuel cost, labour shortage, and port congestion. Other problems also occur when it is necessary to cross any border, such as queues from tighter security and customs delays. The price volatility of energy is one of the main issues in the supply chain: a company must be adaptable and responsive to these changes, in order to lower the dangers that a sudden rise prices can generate. Price of gasoline is raising while new sources of energy are becoming more possible. Enterprises must think if it is worthy for them to change their machinery or transport, to adapt them to the new available technologies.

The environmental risks are related to natural disasters and environmental laws that protect the nature of a country. Developing countries are making efforts, moving forward to match this aspect with the developed countries. Companies that install a plant in those countries are aware of this fact, and they demand, even to their suppliers to comply the most restrictive rules. It is possible to divide the environmental risks that a company must study before having a relationship with the country (like construct a factory or has a commercial relationship with any enterprise of that country) into four different areas: water, energy, soil erosion and air pollution. Political aspects are critical; politicians decide about all the other issues of the supply chain scope that we have previously described. In some countries the price of the energy is regulated and depends on the local government's laws (like the rights of the employee or the environmental restrictions) that can change. Social instability is also a problem; the majority of countries that have cheap labour, do not have a deep democratic culture and it is common place to have protests against the government.

Enterprise must think about the culture and the ethics of the countries where they produce and sell. One recent scandal was when a Primark's shopper found a label

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stitched inside a dress, drawing attention to exploitative work conditions. Probably, the labour situation of the employee who made the dress is “normal” in his/her country, but many first world consumers cannot understand that a huge enterprise does not always treat their employees with similar first world conditions. That problem can entail a lack of confidence of the consumer, and definitely a bad publicity of the company. Last but not least, it is important to take care of which are exactly the supply chain partners’ relationships. Securing relationships with good contracts among supply chain partners can avoid misaligned incentives which can cause hidden action and loss of profit. Limited information or knowledge of the other partner can be a problem that can be solved with monetary initiatives. Of course, good contracts, information sharing systems and trusting partners are the key factors for a supply chain partnership.

### **2.2.3 The Steps of the Supply Chain Risk Management**

As we have seen in the last point, there are a lot of risks that an enterprise must be ready to face and have a plan to avoid potential damage. [Dittmann, 2014 p. 7] Although we will discuss the risk mitigation strategies in this chapter, it is important to highlight that insurance contracts are one of the most underrated way to minimise the consequences. Insurance companies want to share the best practices with their client to avoid losses. They can be key partners in working with firms to minimise the financial effects of disruptions, but more importantly, they can help companies find solutions to prevent the day-to-day problems, thus avoiding the disruption in the first place. They are the most interested in good performance since nobody wins in a loss.

In this section we will introduce the typical steps that every company must develop in order to be prepared. Those steps change depending on the literature that is consulted, but the three basic steps are the Identification, Prioritisation and Analysis, and Mitigation.

#### **2.2.3.1 Risk Identification**

The question that we must propose in this section is: “What can go wrong?” The answers are the different risks that we have extensively explained in the last point 2.2.2. [SCRL, 2011 p.12] Developing a register is necessary for every enterprise to identify baseline risks, but too many organisations start a risk management program without knowing what threats the organisation faces, or what consequences a disruption would have. As a result, some enterprises focus too much on protecting against the wrong threats or too little against threats that matter. Risk identification might begin with a brainstorming of a list. It could help some reference works like the British Standards Institution or the ISO. A summary of these risks is in the next table:

**Table 2.2- Potential Risks to an Organisation and its Supply Chain [SCRLC, 2011 p. 12-13]**

<u>External, End-to-End Risks</u>	
· Natural disasters	· Accidents
· Sabotage, terrorism, crime, war	· Political uncertainty
· Labour unavailability	· Market challenges
· Lawsuits	· Technological trends
<u>Supplier Risks</u>	
· Physical and regulatory risks	· Production problems
· Financial losses and premiums	· Management risks
· Upstream supply risks	
<u>Distribution Risks</u>	
· Infrastructure unavailability	· Lack of capacity
· Labour unavailability	· Cargo damage or theft
· Warehouse inadequacies	· IT system inadequacies or failure
· Long, multi-party supply pipelines	
<u>Internal Enterprise Risks</u>	
· Operational	· Political uncertainty
· Demand variability	· Personal availability
· Design uncertainty	· Planning failures
· Financial uncertainty	· Facility unavailability
· Testing unavailability	· Enterprise underperformance
· Supplier relationship management	

[Dittman, 2014 p. 22] The manner in which our suppliers do business also affect our enterprise. Companies discover that the supplier's reputation is a value asset and have a huge impact on their business. So in order to avoid problems and increase the client's assessment, their third-party suppliers must follow different "rules" like: doing business without any hint of corruption, handling data in a secure manner, or complying with the laws of the countries in which they operate.

### **2.2.3.2 Risk Prioritisation and Analysis**

After knowing the different risks that we must take into account, we must now prioritise the risks. As we introduced in section 2.2.1 when we defined risk, we can evaluate the different risks depending on their likelihood and their consequences. We can create heat



maps or a risk frontier map plotting these two characteristics. The result curve is called the “Acceptable risk” frontier.

[Dittmann, 2014 p. 25] Line organisations have the capacity to deal seriously with only a few high priority supply chain risks. The next example in the next table show how a food manufacturing enterprise prioritising between two risks. It must be noticed that the grades were determined by group consensus.

**Table 2.3- Food manufacturer risk Analysis [Dittmann, 2014 p. 25]**

	<b>Risk 1: Safety of Food Product</b>	<b>Risk 2: Freshness of Product</b>
<b>Severity (1-10)</b>	9	6
<b>Probability of Occurrence (1-10)</b> High probability = 10 Low probability = 1	2	4
<b>Probability of Early Detection (1-10)</b> High probability = 1 Low probability = 10	6	2
<b>Probability Index (1-10)</b> (Multiply Three Items Above)	$9 \times 2 \times 6 = 108$	$6 \times 4 \times 2 = 48$
<b>Recommended Action</b>	Purchase insurance	Audit inventory and ensure stock rotation
<b>Responsibility</b>	Safety engineering	Third party with company oversight

[SCRLC, 2011 p. 15] Once an enterprise prioritises its top risks, it may use a method to understand the nature of the risks. The bow-tie risk analysis method is a form of cause and consequence analysis and it clearly shows the treatment the solution of every risk event depending on the instant when it is. The next figure shows an example of the bow-tie method:

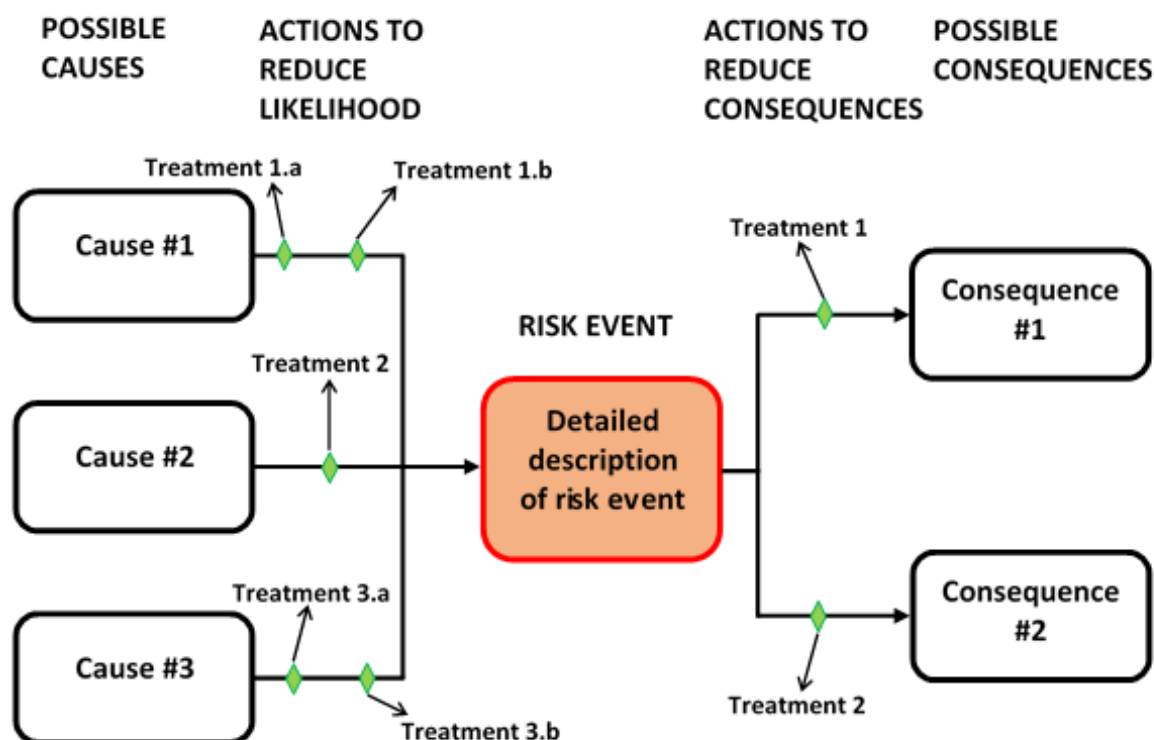


Figure 2.2- Bow-Tie risk analysis method [SCRLC, 2011 p.15]

[Sodhi & Tang, 2012 p. 15] A similar scope is the one given by Sodhi and Tang. They use a “butterfly” depiction where the body of the butterfly is the risk event. The left-hand wing represents underlying causes and prevention efforts that could lead to this event, while the right wing depicts the post-event impact and response efforts.

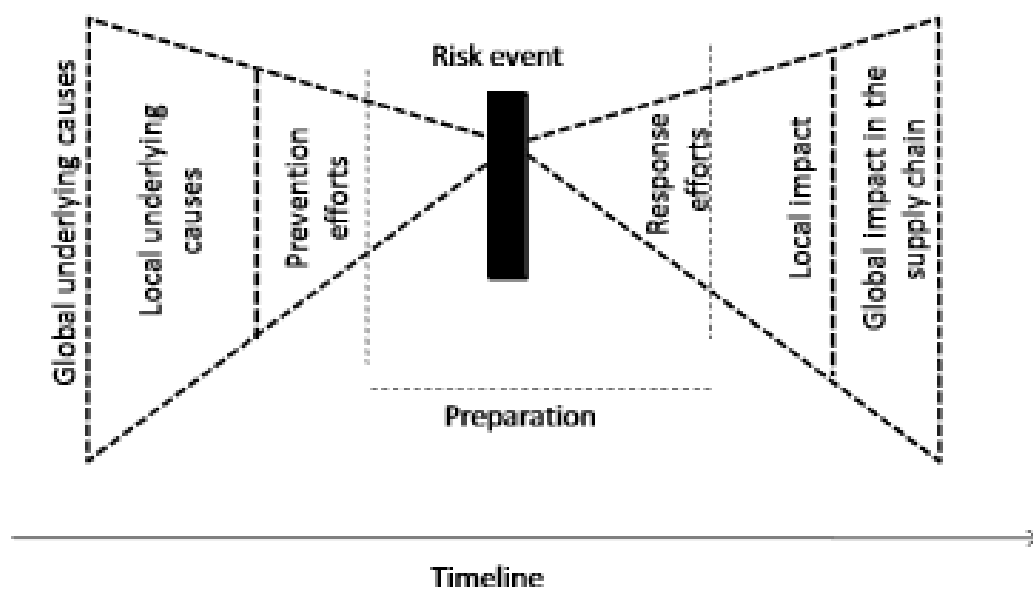


Figure 2.3- Butterfly depiction of supply chain risk [Sodhi & Tang, 2012 p. 16]

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The butterfly depiction is clear when an event has large consequences; however, there can be events in the supply chain whose consequences are small individually but large if aggregated. For example, a stockout for an individual order at a warehouse may have only small consequences, but when we have repeated stockouts, they can lead to large accumulated losses. Thus, the timeline in the butterfly is not anymore lineal, but cyclic, and the smaller impacts accumulate during every period.

### **2.2.3.3 Risk Mitigation**

[Dittmann, 2014 p. 25] A mitigation plan involves some art and some science. Depending on the risk to be mitigated, the plan should focus on reducing either the probability of an occurrence or the degree of impact. One of the most effective methods is to install an early alarm indicator for a risk. Like a serious disease, risk events that are caught early can often be managed successfully. And when a risk is detected, the whole line organisation should be deeply involved, as should all of the other supply chain partners.

Once an enterprise understands its potential supply chain risks and has prioritised and analysed them, it can implement an effective supply chain risk program with its partners that usually has three different steps or components: protecting the supply chain, responding to the events, and continuing business operations while recovering from those events.

The first element is based on a list of guidelines to avoid those risks and their consequences in a passive way. They include: using insurance, having a minimum amount of stock and finding financially strong partners.

[SCRLC, 2011 p. 20-21] Even with the best plans and preventions, enterprises must sometimes face crises in their supply chains. A crisis is an unstable situation that can potentially damage the enterprise and requires urgent attention and action to protect life, assets, property, operations, the environment or reputation. Because of this, enterprises must give strategic and tactical responses in a proactive way. An ideal crisis response include the following steps:

1. Crisis identification: recognition that an incident can affect the organisation
2. Fact finding: gather enough information to prepare a risk assessment.
3. Risk assessment: evaluate the potential impact of the event
4. Crisis team activation and critical incident planning: assemble the appropriate team to provide strategic and tactical support to mitigate the event.
5. Communication to stakeholders: the crisis team has to provide information to the stakeholders. So they know how to act in this special situation.
6. Event control and resolution: the crisis team must assess the remaining risk until the crisis is contained

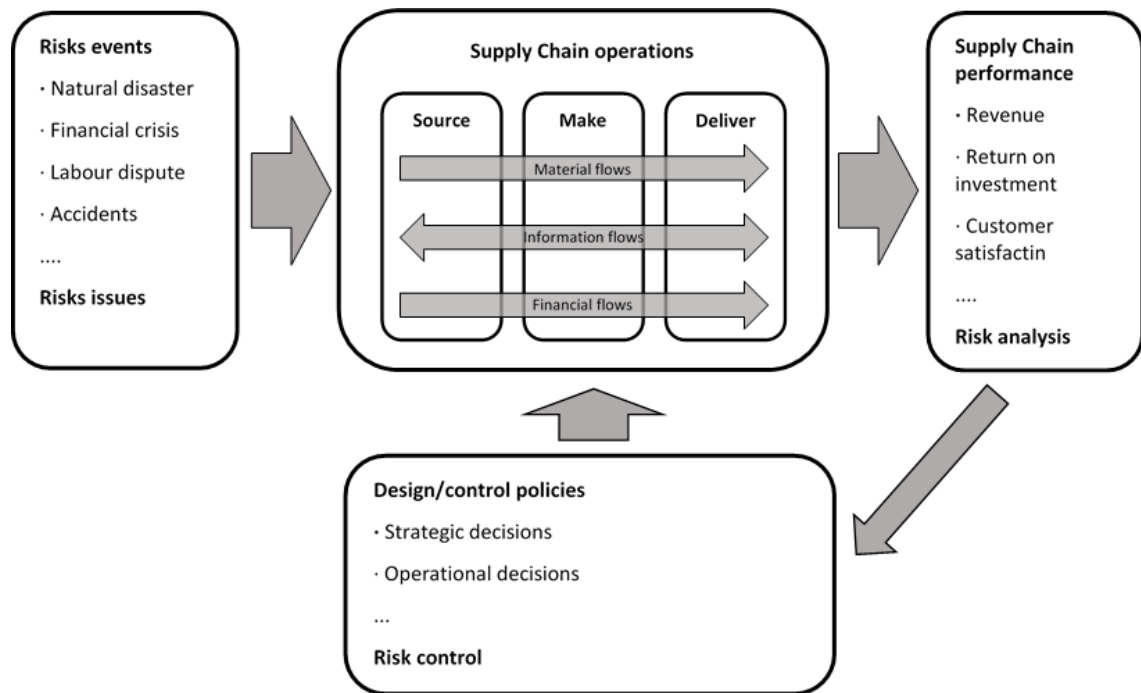
7. Post incident review: once the crisis is contained, the crisis team will review and analyse the organisation's response.
8. Plain maintenance, training and preparation: the organisation should incorporate lessons learned into its crisis management plan and distribute the updated plan to its members and stakeholders.

Business continuity planning comprises those activities developed and implemented prior to an incident that are used to mitigate, respond and recover from supply-chain disruptions. It is an ongoing process, not a one-time project. These plans give an organisation the framework to respond effectively to an emergency. Of course, they must also be tested and integrated along with the other supply chain partners. Specific business-continuity planning programs might include employee assistance, business-impact analysis, emergency-response planning, crisis-management planning, and business-recovery planning.

### **2.3 The Need of Real-Time Risk Management**

As the example (Ericsson's problem) that introduced the previous section shows, nowadays the supply chain of a company is usually huge, involving the suppliers of the suppliers and the clients of the clients. And all of that chain is exposed to all the risks that we have described previously. [Bosman, 2006 p. 4] In the 20's, Henry Ford had his production facility, his own iron ore and coal, and his own freighters to produce Ford steel. And to ensure the availability of other necessary components, Ford also had his own forestry, his own glass works, his own rail lines and even a rubber plantation in Brazil. Nowadays, it seems impossible that a single company could own all of their suppliers in order to totally control the production. And if some company could, it would face other problems. So, companies must think how to mitigate the harmful events that they cannot completely control. [Hendricks & Singhal, 2005 p. 36] Of course, it is an advantage knowing that an event is happening in real-time, in order to alter the impact of the disruption and maintain the continuity of the supply chain. A company has to have a plan to oppose every single undesirable event from the start. Without correct preparation and precaution, it requires quite a long time to the system for recover from the impact. This connects with the concept of the supply chain resilience that we have described in the division 2.2.1.

[Musa, 2012 p. 4-6] In a real-time system, the plan that a company must use to control the risks is the shown in the next figure (2.2). Real-time logistics data must contain information about available material, equipment and personnel as well as updated delivery dates and site conditions in order to be able to work with the proper information.



**Figure 2.4- Risk control plan [Musa, 2012 p.5]**

[Manuj & Mentzer, 2008 p. 136-138; Musa, 2012 p. 4-11] The process for minimising the consequences of risk start much prior to the risk itself. First of all, a company must define which risk events should be considered and analyse how each one of them affect supply chain operations. Without this preparation, it would be impossible to face a dangerous event without any damage. This is the phase of identification of the potential risks, and it does not mean that every risk that we schedule will happen. The second step of the process is the mitigation phase. It means that we have notice that a risk event is happening. It is not as trivial as it seems because some events do not have a kind of indicator or alarm, like the satisfaction of a customer. After identifying that an undesirable event is happening, the techniques that have been designed to mitigate it must be used. While the event happens, it must be controlled and monitored. When the event has finished, the company must analyse if the techniques that they have used to mitigate it were correct and upload their data in order to improve their capability of recovery from that kind of incident. Therefore, we can see that Supply Chain Risk Management is constituted of two elements: supply chain risk analysis and supply chain risk control.

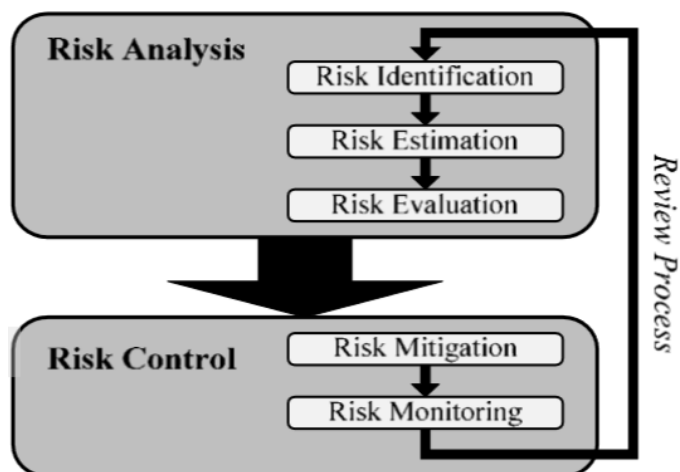


Figure 2.5- Risk analysis and control process [Musa, 2011 p.11]

## 2.4 The Role of Business Intelligence for Supply Chain

[Vural et al., 2006 p. 29] Business Intelligence (sometimes abbreviated BI) refers to the new systems that help enterprises in querying, reporting and analysing the company data. BI can be considered a performance management framework that helps companies to set their goals, analyse progress, gain insight, take action and measure the success. BI was in the past a difficult tool to reach for most enterprises. In the past, the cost of the software, its installation, maintenance and the formation of the employees was not worth it in a lot of cases. But nowadays, the software has become cheaper and easier to manage, so many firms can afford to use it.

[Vural et al., 2006 p. 29; Stefanovic et al., 2006 p. 613; Sahay & Rankan, 2008 p. 29-37] There are more than a dozen tools for Business Intelligence for different issues like: marketing research, competitor analysis, business process re-engineering, and customer relationship management. We will describe those that are associated in the supply chain. For instance, Balanced Flow software takes care of the supply chain stock for a company. Every participant must define a target level for every day of stock. This level can vary from different factors like the confidence in the forecast or the variability of lead times or the reliability for suppliers. Then, the software recommends what to make or order to maintain the specified amount of stock. This information is also shared with the other partners of the supply chain. The software adapts as it works, making it possible for the companies to continue production when there is a shortage of a raw material and notifying the other companies of the reduced production capacity.

[Stefanovic et al., 2006 p. 613-615] BI helps companies to realise their projects. We will describe it briefly: every kind of engineering project is structured in 6 stages: justification, planning, business analysis, design, construction and deployment. Business Intelligence is present in all of these phases, helping to improve the system overall. It is important to note that these steps are no more static in a waterfall methodology: data

and functionality of each new step is extracted and conditions the previous stage. So, instead of the typical waterfall methodology, an agile and adaptive development guide is driven by BI support applications. Some steps must be analysed with a cross-organisational perspective, since they involve in many ways the other partners of the supply chain. These partners must ratify and validate the other firms' plan.

[Stefanovic et al., 2006 p. 615] In the Supply Chain Management field, the appearance of these new techniques has created a new idea: Supply Chain Intelligence (SCI). This concept refers to the capability of revealing opportunities to lower costs, stimulate revenue, and increase customer satisfaction by utilising collaborative decision making. The characteristics of this trend are: information democracy, unstructured data, predictive analytics and the integration of this data in the software. These characteristics can be summarised to say that the data must be accessible to all the users and show what the customers are likely to buy, to allow the system to and run regular operations automatically. SCI is used to manage and measure the assets of a process.

[Calderón Lama & Lario Esteban, 2005 p. 2] To be more aligned, Supply Chain Operations Reference (SCOR) was developed in the year 1996 by the Supply-Chain Council (SCC). It is an industry standard that integrates software, management processes and metrics to measure process performance. [Calderón Lama & Lario Esteban, 2005 p. 2; Stefanovic et al., 2006 p. 616] The SCOR model divides the activities of a business into 5 different processes: plan, source, make, deliver and return; creating a new standard and metric system, allowing the partners of the SC to communicate less ambiguously, and measure, manage and control collaboratively all their different processes.

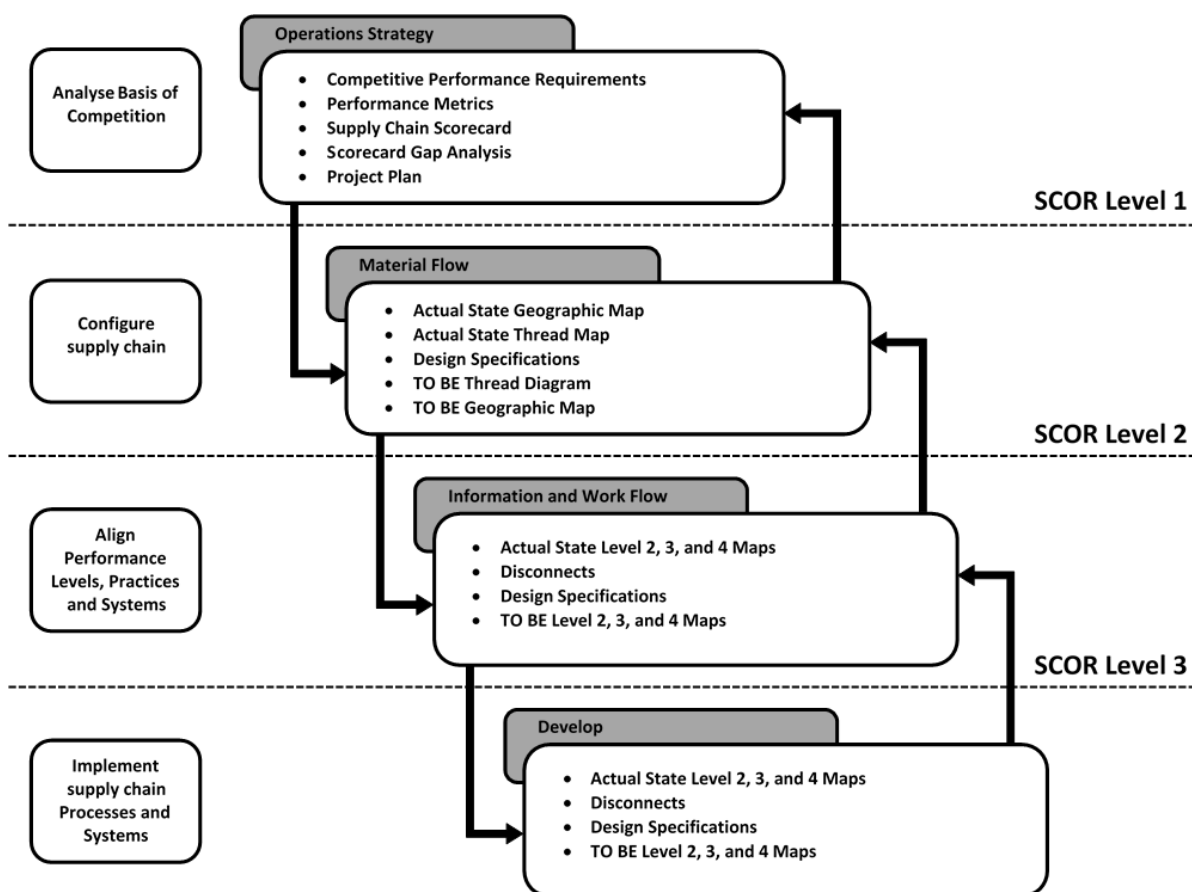


**Figure 2.6- SCOR model**

[Perez Castillo, 2009 p. 21-23] The SCOR's model embraces all the interactions with the clients (from the order entry to the bill payment), all the physical dealings of materials (from the suppliers' supplier to the customer's customer) and all the interactions with the Market. However, it does not try to describe the process activity:

demand generation (marketing and sales), product development, research and development, and some after-sales services.

[Pérez Castillo, 2009 p.22; Calderón Lama & Lario Esteban, 2005 p. 3] SCOR provides three-levels of process detail. Each level of detail assists a company defining scope (Level 1, *Analyse Basis of Competition*), configuration or type of supply chain (Level 2, *Configure supply chain*), and process element details including performance attributes (Level 3, *Align Performance Levels, Practices and Systems*). Below the Level 3, companies decompose process elements and start implementing specific Supply Chain Management practices. In the three levels SCOR handles “Key Performance Indicators” (KPI). These indicators are divided into three different performance attributes: reliability, flexibility, responsiveness, and cost and assets. We can illustrate the different levels in the next figure:



**Figure 2.7- SCOR levels [Calderón Lama & Lario Esteban, 2005 p. 3]**

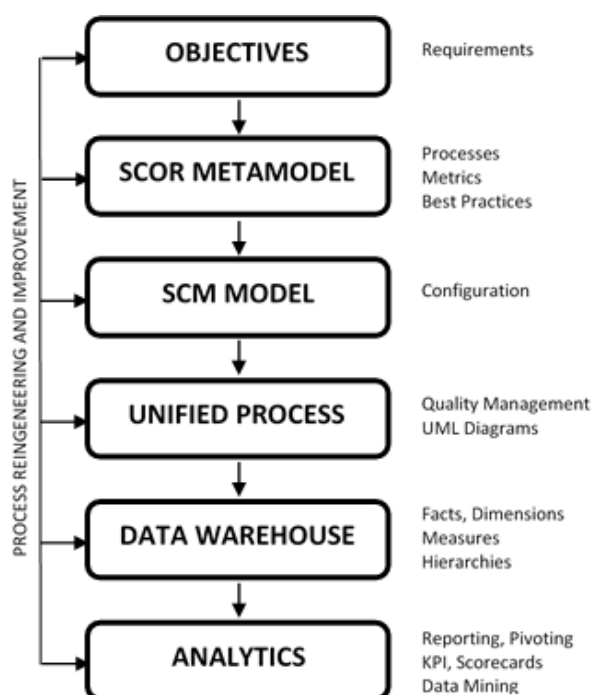
Like the figure above shows, in the first or superior level, companies define the scope and content of SCOR. The basis of the competition are analysed and the competitive performance targets are set. The second level includes different process categories: planning, sourcing, manufacturing, distribution and enabling. The third category decomposes all of the processes mentioned above in a more detailed way. At this level,



an evaluation is also performed in order to calculate the efficiency of every process and the process performance metrics.

[Stefanovic et al., 2006 p. 615] BI recognises the need to create models of the supply chain, providing visualisation, complexity management and communication. The first point is important for us as we can see the relationships between the aspects (as will be discussed in section 3.4). The second is important because humans cannot perform the same number of operations with the same complexity as computers, and instant communication between partners is achievable thanks to the technologies and standards that the companies share. The models can be created in different languages UML (Unified Modelling Language) is very useful because it shows the functions and relationship that are difficult to see, and also offers a standard notation for the business and for the software specialists. XMI (Extensible Model Interchange) allows the companies to exchange their models. All this models have the advantages that they include concepts similar to real life and they are easy to understand.

The details of every supply chain can vary, and every supply chain decide how to implement their processes and the roles that they carry out. The pattern to create a SCI model is as follows:



**Figure 2.8- SCI model [Stefanovic et al., 2006 p.616]**

[Stefanovic et al., 2006 p. 616] A Metamodel has been created by Stefanovic et al., which allows different supply chains to use it. This Metamodel is normalised and contains all the SCOR elements like processes, metrics, best practices, inputs and

outputs. It is very useful because the groups of enterprises that want to use it need to only adjust some parameters, and thus processes, metrics and best practices can be related to specific nodes and tiers. When the particular Model is created from the Metamodel and all the enterprise parameters (such as dimensions and measurements) are integrated into its respective node or level, it is necessary to design a data warehouse. It will enable correct analysis of further data; its proper performance depends of all the independent collaborators of the supply chain. Finally, the last step is to create an analysis system that helps us to measure and monitor the progress toward the organisation's goals, and discovering the important information in the data. If this information is shared through the web with the supply chain partners and clients, they will also be able to use that information (for instance, a client could follow the process of an item that is being produced for them, and know more exactly when it will be delivered).

## 3 Real-Time Supply Chain

### 3.1 The Kinds of Data

As we have explained in the previous chapter, enterprises need a huge amount of data (regarding for example stock, transport, and measures). When they have these information, they can analyse it and move forward in their decisions. In this section we will present the different kinds of data that are possible to obtain and we will debate which is more useful and why.

[Trochim, 2006] We can obtain information about something in two ways: quantitative and qualitative. Quantitative data usually refers to all the numbers, graphics and charts, that describe a phenomena numerically and which are associated to a variable. And, qualitative data are associated to the observations, feelings or impressions, which are associated to generalisations. Image or a video can also belong to that group. The precision of the quantitative data is higher due to the fact that they come from exact measurements of some element, and have the advantage that can be easily illustrated in the forms of tables, graphs, or charts. Whereas qualitative data is more difficult to collect since they can be in form of words or images. Research findings in qualitative data are normally presented in analysis using only words. In other case, they have to be “translated” into quantitative data to make some charts or to tabulate them.

Historically, the collection of data was not automatic: an operator had to check all the important variables that the managers wanted to control. But nowadays, with the implementation of sensors in the production line and in transport, a huge flow of information is easy and cheap to collect. It makes it more difficult for quantitative data to lead us to wrong conclusions, and they are easily programmed to be able to run in different applications. These applications can be programmed with accurate objectives of study that use standard language or parameters. This is not possible with qualitative data, which are guided by the assessment of the subject which is being studied.

In conclusion, qualitative data were important in the past when the techniques of obtaining information were difficult and were usually done by an operator. Today, this technique is obsolete and most of the companies have made a transition to implement sensors that collect that information automatically. And with determinate analysis software it can be a very useful tool that can help the whole supply chain.

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## 3.2 The Obtainment of Data

In this section we will describe two different relatively new technologies that allow us to better handle the data: Big Data and Cloud Computing. Both use modern techniques and technologies to improve the way an enterprise takes, manages, stores and takes advantage of the data that it obtains.

### 3.2.1 Big Data

Big Data refers to the systems that manipulate very large collections of data. It takes care of the capture, curation, storage, search, sharing, transfer, analyses and visualisation of this high volume of data. The amount of data used in some fields (like meteorology, genomics and some complex physics simulations) can be incredibly big, and the amount of data is always increasing, and so the capacity to store this information has also rapidly increased, approximately doubling every 40 months since 1980. [Troester 2012, p. 3] Different examples of these huge data sets are the following: we can mention that Wal-Mart handles more than a million customer transactions each hour and imports all this information into databases that contain more than 2,5 petabytes (1PB = 1000 TB = 1.000.000.000.000.000 Bytes) of data, and Facebook has to update more than 250 million photos and the interactions of 800 million active users with more than 900 million objects every day. These examples represent huge challenges to the engineers that work in those enterprises due to the fact that it is not easy to manage such a large amount of information in a short amount of time. [Agrawal et al., 2012 p. 1-3; Datasax Corporation, 2013 p5] To put into context the size of all this data, 1 terabyte contains 2000 hours of CD-quality music, and 10 terabytes could store the entirety of the US Library of Congress' print collection. In the coming years we are sure to hear about exabytes, zettabytes and yottabytes.

One of the purposes of Big Data is be able to use every byte of information to make the best decisions. Big data technologies do not want just to support the collection of large amounts of data, but also they try to understand and take advantage of its full value. Big Data is named after this concept: its name refers to the big potential that this technology has, to face up the new targets that data sets propose and companies demand to be solved: higher variety, higher variability, higher velocity, higher complexity and, of course, higher volume. [Troester 2012, p. 2] [Dijcks, 2013 p. 3-4] It is important to specify and describe the challenges that every category carries:

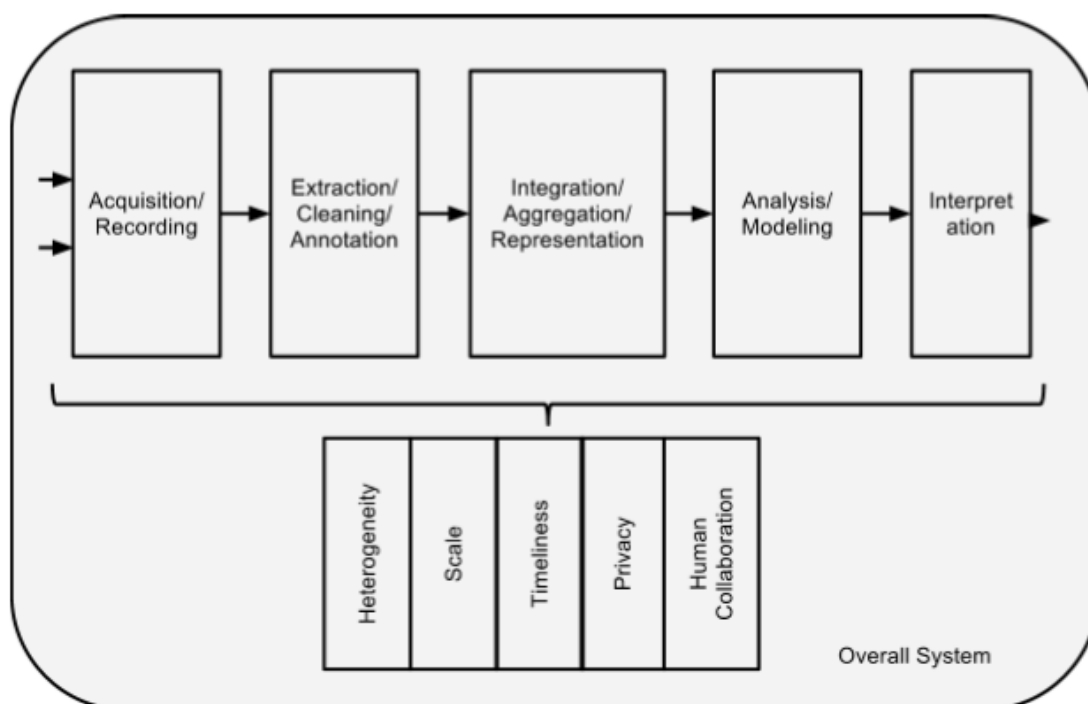
- Volume: this is the clearest point. As we have seen before this need is always increasing as technology evolves.
- Variety: up to 85% of an organisation's data is unstructured (not numeric) for example, as text, videos, audios or images. All of these require different kinds of processes, architectures and technologies for their further analysis.

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- **Variability:** the data shipments vary notably depending on different factors: the hour of the day, the day, season, etc. The system must be capable of processing the peaks and not collapse.
  - **Velocity:** some recently invented systems like RFID and Smart Data permit us to deal with this torrent of data almost in real-time. The possibility of making real-time decisions has increased the need to move the data as fast and agile as possible.
  - **Complexity:** the complexity of managing data refers in the need to link, match and transform the data across the different entities and systems. As we are more able take data from systems that was not possible before, the connections and relationships between the elements has increased, hence systems must face up with this charge too.

The difficulty of transferring the data can become extremely difficult due one of those dimensions, or a combination of some of them. Knowing that not all of the data from one set is useful in some determinate moment, firms can focus on the information that really counts. It is important to remember that the power of the data is “What we can do with it” and not their own possession of it. [Troester 2012, p. 4] The real use resides in fast, fact-based decisions, which are the real business value. There are some different strategies to fight against the big volume of useless data that some enterprises get, like incorporate massive data volumes in analysis (the expensive alternative). Some new processing methods like grid computing or in-database processing which can handle large amounts of data take advantage of it. This alternative must be used when the business depends on analyse of that huge amount of data. However, it can result in delays in the acquisition of results. The other option that we have is determine upfront which data are relevant: store everything, and then discover what is relevant for the company at a later stage. However, today, due the big volume of data, the mentality of many managers has changed. Software has been developed that provides the ability to apply some analytics on the front end to determine data relevance based on enterprise context.

To be able to afford these skills, the advancements during the last 10 years have been substantial. Storage, server processing and memory capacity have become abundant and cheap. The cost of a gigabyte of storage was \$16 in 2000, while nowadays it cost less than \$0,07 [Troester 2012, p. 3]. Storage and processing technologies have been designed specifically for large data volumes, for instance: parallel processing, clustering, virtualisation, grid environment and Cloud Computing. There are three key technologies which allow the handling of Big Data and extract meaningful business value from it: information management for Big Data manages data as a strategic, core asset with outgoing process control; high performance analytics allow us to make rapid insights based on the data; and flexible deployment options gives us the chance to choose between different approaches of how we analyse the data.

We have been talking about the different phases that there are between obtaining the data and making a decision but we have not get explained them clearly. [Agrawal et al., 2012 p. 2-4] The normal process is explained in the following illustration. Sometimes, we focus on the analysis/modelling phase, and we do not notice that it just a part of all the pipeline and we forget that there are more phases. For instance, Big Data has to account for when there is a noisy, non-homogeneous or not upfront model. This architecture system is not built to ideally process all tasks; instead, it is flexible enough to be able to efficiently process different tasks with different workloads.



**Figure 3.1- Data pipeline [Agrawal et al., 2012 p. 3]**

The data pipeline can be described as follows. First we generate the data from one event (it can be structured or un-structured). Not all the data that we can take are enough important to be taken, so we have to know which are the most relevant. Then, we have to transform that data into a form that we can analyse. When we have done the second step, we can represent the data in some way (for example, as a graphic or figure) that we can understand and compare to the old data. Analysis in Big Data is fundamentally different from years ago when they did traditional statistical analysis on small samples. Nowadays, even noisy data could be more valuable than tiny samples because even though some samples are difficult to see hidden patterns and knowledge in, interconnected data and redundant information can be used to compensate missing data, crosscheck conflicting cases and validate trustworthy relationships. Finally, interpretation deals with the understanding of the previous analysis and the decisions that we make accordingly.

[Agrawal et al., 2012 p. 8] [Villars et al., p. 12] We have also mentioned the challenges of the Big Data pipeline. To expand further on these, we can say the following:

- **Heterogeneity:** when human consume information, we can deal with different sources easily. Nevertheless, computers expect homogeneous data, and in consequence, data must be carefully structured.
- **Scale:** managing the large amount of data is not an easy issue. Single processors became rapidly faster in the past, but nowadays the focus is on parallel processing and scalability, but volume is still scaling faster than computational resources.
- **Timeliness:** the flip side of size is speed. There are many situations in which results of the analysis are required immediately: such as if a fraudulent credit card transaction is suspected, it should ideally be stopped before the transaction is completed. We need partial results in advance to arrive to a quick determination (i.e. it is not necessary a full analysis of user's history).
- **Privacy:** depending on the country the laws can vary. Managing private data is both a technical and a sociological problem and there is a great public fear regarding the inappropriate use of personal data.
- **Human Collaboration:** in spite of the advances made in the computational analysis, there are patterns that human can easily detect but computers have a hard time finding. We do not have to forget that data are tools, and sometimes humans are those who must take the decisions.

[Datasax Corporation, 2013 p. 8] Data can be classified like the most strategic impersonal asset, but if they are not used as a weapon against the market competitors, it is guaranteed that the enterprise that does not use them will be at a disadvantage. The next figure shows the 10-year category growth rate differences between the companies that use its data effectively and their competitors:



Figure 3.2- Results of data integration [Datasax, 2013 p. 8]

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EBITDA is an acronym that means Earning Before, Interest, Taxes, Depreciation and Amortisation. Clearly, there exists a big difference between a company that is Big Data leader, and ones that are not. The most obvious example is in the “On-line Retailers”, where we can see how the company leader in Big Data has the bigger rise in revenue, while the competitors lose market share. In the EBITDA side, we can see how the differences increase: the reason could be that the companies with a developed Big Data system can make the accurate decision in the perfect moment that imply a decrease in the internal spending of a company.

In conclusion, Big Data is not just a hype, it is a reality. Enterprises know about its power and some try to utilise it to its full potential. They do not just look for a solution to store their data, but also a system to analyse and make decisions. However, despite of the great analysis of data that is nowadays available, the potential to make advances in many specific scopes of this technology is huge. And we also have seen that the enterprises who take real advantage of the Big Data are those who analyse the most interesting information as quickly as possible; they do not just keep and store it for a long time before use them.

### **3.2.2 Cloud Computing**

[Marston et al., 2011 p. 176] Cloud computing is an emerging phenomenon which represents a change in the way information technology (IT) services are invented, developed, deployed, scaled, updated, maintained and paid for. [Tiwari, Jain, 2013 p. 152] Cloud computing can be defined as: “A *Cloud is a type of parallel and distributed system consisting of a collection of interconnected and virtualised computers that are dynamically provisioned and presented as one or more unified computing resources abased on service-level agreements established through negotiation between the service provider and consumers*”. Nowadays, computers are becoming more and more powerful, costs are decreasing, and they are becoming more pervasive within the organisation, while the amount of data is also growing exponentially. So, the complexity (and cost) of managing this infrastructure has also exponentially increased. The goal of Cloud Computing is to deliver all the functionality of existing information technology services.

[Marston et al., 2011 p. 176] This new technology has been developed when many companies discovered that their capital investments in information technology were often grossly underutilised: servers were used just 10-30% of their available computing power and desktop computers have just an average of less of 5%. It is reasonable to say that companies have researched that issue more for cost optimisation than for improvements in IT per se. [Schramm et al., 2010 p. 4] The two major trends in information technology converge in Cloud Computing: IT efficiency and business agility. It is necessary to use the whole power that modern computers can offer us, with



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little requirement of investment. Also, having a tool that helps us through a rapid deployment, parallel batch processing, business analytics and mobile interactive applications (all in real-time) can make the difference between two rival companies.

[Fisher & Turner, 2009 p.3] Cloud Computing is an information technology service where the computing services (applications, data and IT resources) are delivered on demand to customers over the Web (the so-called “cloud”). Its principal characteristic is that the application works connected with a server (typically the software is accessed using only a web browser), so it is independent of the device and the location. Cloud storage allows storage and synchronisation of files and folders and alleviates the potentially endless and costly cycle of searching for extra storage; it is no longer necessary to delete the old files or buy a new hard disk in order to have enough space for the new ones. [Schramm et al., 2010 p. 4-5] Cloud Computing saves data to an off-site storage system maintained by a third party, in a remote database. The Internet provides the connection between the computer of the user and this database.

[Schramm et al., 2010 p. 4-5] [Marston et al., 2011 p. 178] We can list some advantages of Cloud Computing globally for enterprises and then focus in those that are related to the supply chain. Those advantages are sometimes more reliable than we initially think. Cloud Computing lowers the cost for small firms trying to benefit from the computer business analytics that were traditionally only available for bigger companies. This helps not only small companies, but also third world companies that have traditionally lacked these IT services. Cloud Computing can provide an almost immediate access to hardware resources, with no upfront capital investment for the users, leading to a faster setup time in many businesses. Different end users share the adaptive infrastructure of the cloud in a different way; users are completely separated from each other, and the flexibility of the infrastructure enables to balance the computing loads on the fly as more users join the system. In the same direction as the previous point, Cloud Computing can lower IT barriers to innovation, since it can be observed for many partners, not just for the single company. [Tiwari & Jain, 2013 p. 153-154] Finally, Cloud Computing makes new classes of applications like mobile applications possible and delivers services that provide the location, environment or context data to the user. Focusing on the supply chain approach, Cloud Computing help companies in planning and forecasting since they can collaborate easily, and also in sourcing because the enterprises can know the need of the others using inventory management devices.

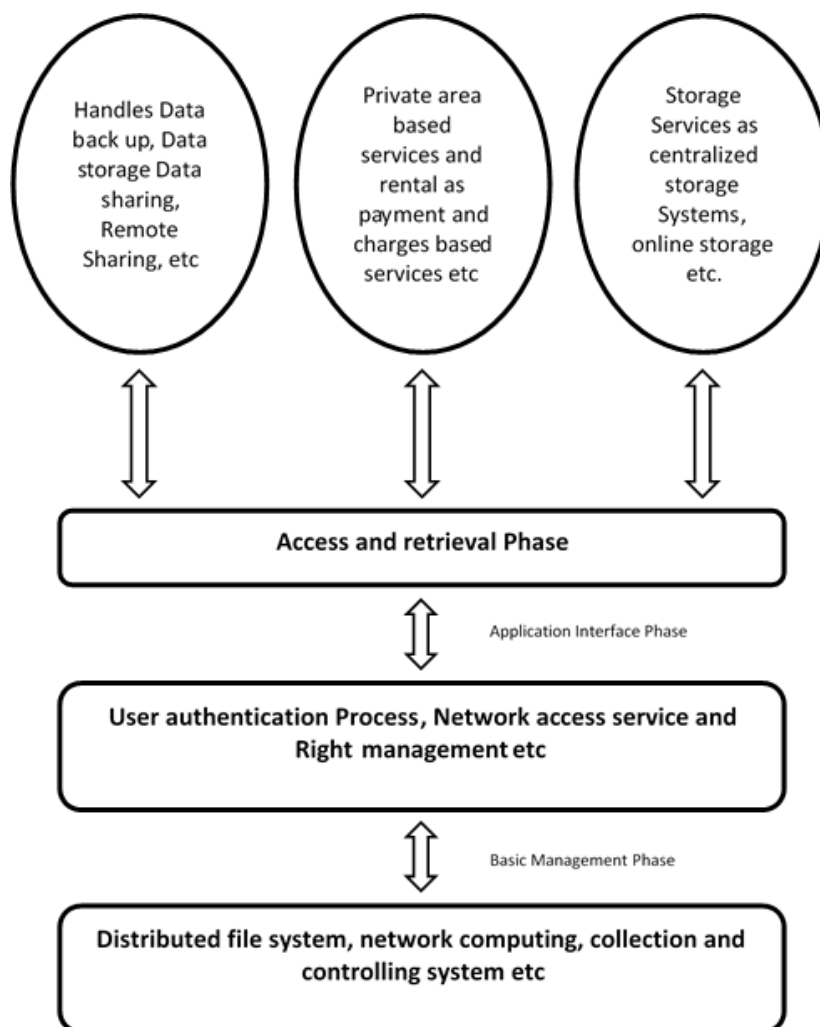
[Ward, 2014; Grossman, 2009 p. 25] Of course, there are some inherent drawbacks of this system. The obvious one is that the availability of the applications depends on the Internet connection, and also, there is a delay time called latency between the request and the delivery of the data. Additionally, firms lose physical control of the data that they put in the cloud. Providers have been, until recently unable to guarantee the exact location of a company’s information. Another disadvantage is that the provider cannot

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guarantee the full availability to the system 24 hours/day, 365 day/year. For instance, Amazon Web Services Service Level Agreement (SLA) commits a 99.95% of the annual uptime. For small or medium enterprises should be enough, but for large organisations it could be insufficient for mission-critical applications. Other disadvantages are the security that the enterprise of Cloud Computing has, the flexibility that offers and the price of the service.

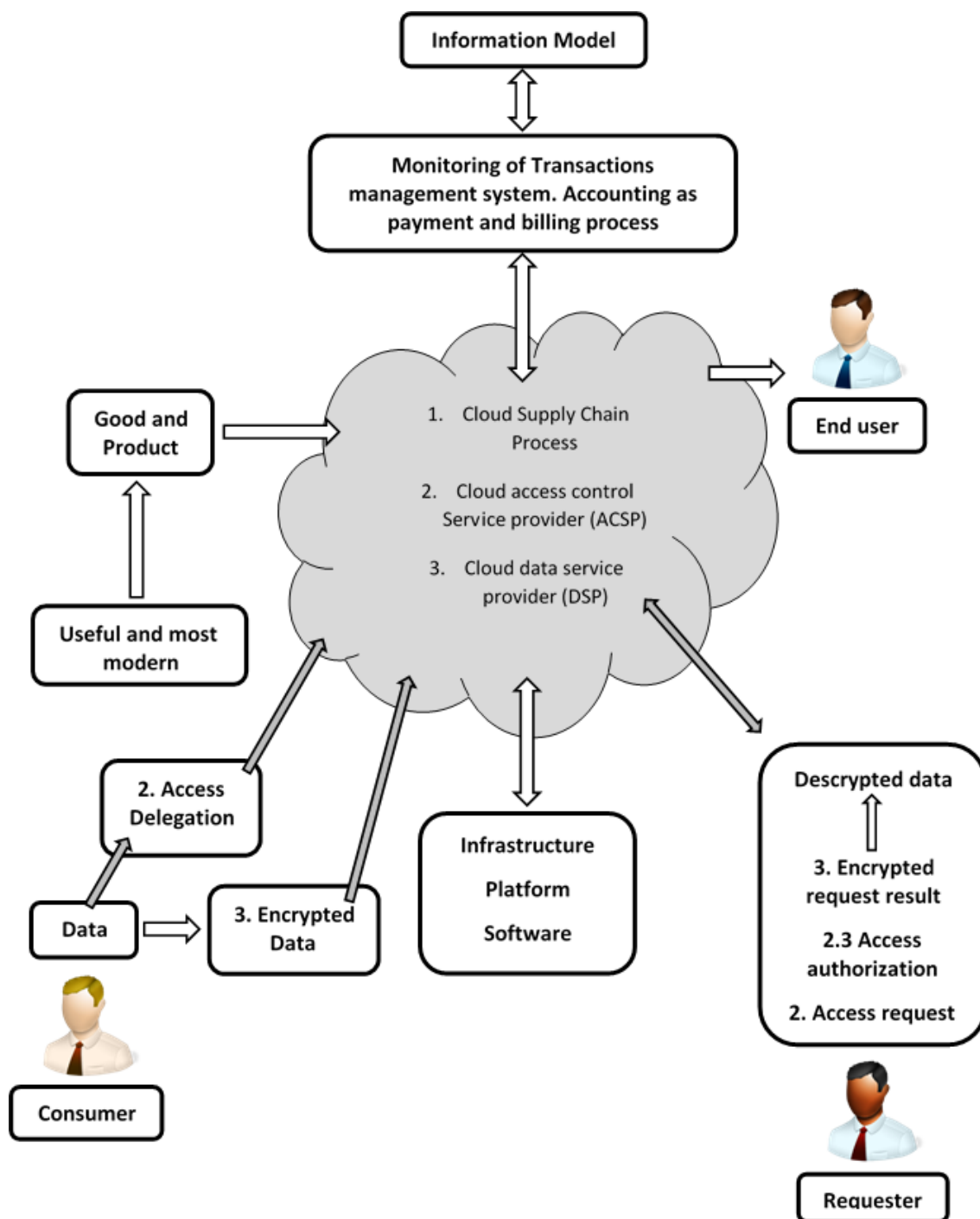
[Tiwari & Jain, 2013 p. 153; Schramm et al., 2010 p. 9] Since the first versions of cloud platforms were integrated into the supply chain in the years 2010-2011, its evolution has been very rapid. In the beginning, early pilots were focused on the administrative processes for making simple analytics. During the next phase (2011-2013), the technology was more mature and aided in more complex processes like pricing optimisation, replenishment planning, order processing and transportation load building. Nowadays Cloud Computing allow enterprises in process that need the collaboration between many entities and tighter integration. Nevertheless, the evolution and fully performance of the Cloud Computing will take several years to achieve. [Marston et al., 2011 p. 178] The three core technologies that will enable it –virtualisation, multitenancy and Web services- are taking shape. Virtualisation is the technology that enables to operate with an emulated computing platform instead of a physical device. The virtual system behaves like a physical system; the difference is that we can configure the virtual one on demand and maintain and replicate it very easily. Multitenancy refers to a single instance of an application serving multiple clients, allowing better utilisation of system resources, in terms of memory and processing overhead. And lastly, a web service is software designed to support machine-to-machine interaction over a network.

[Kavita et al., 2012 p. 64] [Ferguson & Hadar, 2012 p. 7] The typical architecture presented in Cloud Computing is the following:



**Figure 3.3- Architecture of Cloud Computing [Kavita et al., 2012 p. 64]**

When we want to adapt this system to the supply chain model we must think that the supply chain involves more than one user and has to contain different aspects. We want the information that the data contains in order to be able to monitor some process. We define three different users depending on his task: the End User should have access to the infrastructure, platform and software, and also to the information itself. A trusted person (called Requester) can have some information when he produces his password. The main task of the Consumer is to integrate the data to the system. We can see this process in the next figure:



**Figure 3.4- Cloud Computing model [Kavita et al., 2012 p. 64]**

[Fisher & Turner, 2009 p. 4-5] There are different models that computing providers can offer according the services that they want to hire. The Infrastructure as a service (IaaS) is the most basic service. It offers computers and other resources like servers or a network. Platform as a service (Paas) offers also a computing platform, typically including operating system, programming language, database and web server. And Software as a service (SaaS) provides the client access to application software and databases. The application runs on the cloud, eliminating the need to install and run the

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application in the client's computer. Of course, the architecture would need to be changed depending on the infrastructure chosen, as the complexity depends on which is chosen (Saas being the most complex).

When we have talked of the architecture we have differentiated three different consumers or users. But in the Cloud Computing's environment there are more individuals than just simple users. The individuals involved are called stakeholders, and the most important are the client and provider. [Marston et al., 2011 p. 183-187] But, there are other important roles that are performed by other entities. A short description of these roles follows:

- Consumer: they purchase a system from the providers. They must ensure that all the services that they have contracted are working correctly. When all works as it was designed, users can dedicate more man hours to developing new applications for the organisation instead, of spending their efforts maintaining the system.
- Providers: Cloud Computing providers own and operate the systems used to deliver the services to the consumers. The provider's task is also to do the maintenance and upgrades of the Cloud Computing system.
- Enablers: the enablers are the organisations that sell products and services that facilitate the delivery, adoption and use of Cloud Computing. They are also specialised firms that will provide monitoring software, platform migration software, etc. The enabler's role has increased since many of the Cloud Computing service providers lack the core competencies of interacting with customers.
- Regulators: the role of the regulators is to arbitrate in the debates that involve the Internet and its use. This regulator bodies can be national and international agencies and their job is also to create laws that can fix some paradigms, such as: if some private data is stored in a different country than its owner, which country's privacy laws should be followed by the providers? The distributed nature of Cloud Computing and the ownership of the data is their main target.

### **3.3 The Integration of the Data**

In this section we will talk about how we can integrate the data in our systems and which technologies can help us to do it. First of all, we have to be clear about the technology of obtaining data and introducing it into the supply chain, due to it changes depending on the kind of industry that we analyse. [O'Leary, 2008 p. 3-4] For instance, in the electrical power distribution field, the electricity must be scheduled and dispatched to the consumers in real-time. The company could have a forecast of how much electricity a plant must produce, but it can change easily by different factors like weather changes or a special event like a concert or football match. So, in this field, they have to be focused in the visualisation of the demand. In other fields like the electronic markets, the most important issue is to get the better product from a reliable

provider, so that they focus in evaluate the suppliers (and also the buyers), customise the products and price the goods in real-time. In regards to the topic of this thesis, Supply Chain Risk Management, there are common steps that a supplier must take to integrate data into their database. Some of these steps will be explained more accurately in the following parts of the work, like the visualisation in the next section 3.4.

[Pontani et al., 2007 p. 3-5] In the field of a supply chain and logistics, the goal for the companies is to obtain an “autonomic supply chain”, it is an innovative concept, for which the goal is to automate the uptake of information and be able to generate a corresponding analysis and response, if necessary. Hence, we could define an autonomous supply chain as a supply chain that makes its own decisions, or can work by itself. [O’Leary, 2008 p. 6] Now, we will introduce the different issues or abilities that an autonomous supply chain requires, and after, in the correspondent subsections we will describe the different technologies that provide us that help. These abilities and capabilities are:

- Obtain data in real-time.
- Provide information to the systems about the objects that are being processed.
- Allow the humans to visualise the whole system.
- Integrate different systems so that they can work together.
- Operate “intelligently” in all the simultaneous settings that occur across the supply chain.
- Monitor the operations and decide what to do if pre-specified events occur.

### **3.3.1 Real-Time Data Generation: ERP Systems**

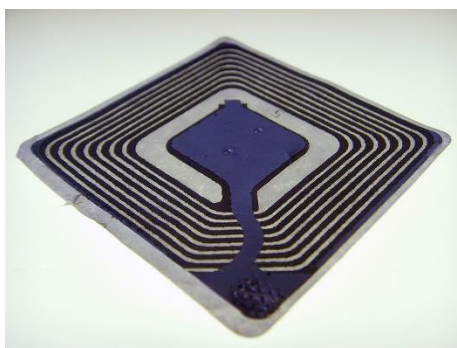
The first step to get the autonomous supply chain is to integrate the data that we get in to our system. To make that possible Enterprise Resources Planning Systems (ERPs) are designed, allowing data to be shared across many boundaries and divisions within a company. [Fitrix, 2011 p. 2-4] ERP systems are an outgrowth of materials requirement planning systems (MRP) that were initially designed for inventory control in the 70s. ERP Systems consist of series of integrated modules, from accounting, distribution, marketing and sales, manufacturing, to human resources. The ERP system helps us in managing the connections with the other subjects that interact with us. [Tarn et al., 2002 p. 26-27] The most important factor for that system is the business process, not a specific module, because real-time data for autonomic systems must be all-pervasive-

[Tarn et al., 2002 p. 29] Despite the advantages, ERP systems do have some problems. For instance, it takes a lot of time to implement a system; the complexity lies in the data standardisation, adoption of the underlying business model, and the involvement of a large number of stakeholders (people or companies that can affect the company). The average ERP implementation takes 23 months. Another problem is the hidden costs that

it brings to train the staff for this system, or the data conversion. These inconveniences make this application not worthwhile for small-medium firms.

### **3.3.2 Real-Time Object Identification: RFID (Radio Frequency Identification)**

In order to control all the items that move across the supply chain the technology of RFID was created. Radio frequency identification (RFID) allows companies to identify and track all the objects across the supply chain in a wireless way. [Liberia, 2010 p. 5-6] There is not a need to establish line-of-sight between the laser scanner and the object, like with a barcode scanner; rather, the “tag” transmits the information when it detects that it has been requested. [O’Leary, 2008 p. 6-7] Not only manufactured goods can be monitored with RFID, but also train cars, trucks, pallets. RFID provides a unique identifier for whatever the tag is attached, in real-time. Readers in predetermined positions can follow the position of items of interest. This is not just used in the factories as another application can be payment in public transportation or access to restricted areas. In our field, this system helps to minimising misplaced inventory and also the leakage of goods. There are two kind of tags: active and passive. Most RFID tags are passive; they do not have a power source, have limited range, and they only answer when they are required (therefore they are called “responsive”). The passive tagged objects are usually not mission-critical. In contrast, there are also active tags that have their own power source and a longer range, but of course they are larger and more expensive. Active tags are called “intelligent” because tagged objects can interact with the other intelligent tagged objects. For instance, an objects tag can contain the date of expiration of a product, or different information like the temperature changes that it has suffered. In the chemical industry it is very useful; a tag can alert the system if two components that react are near.



**Figure 3.5- RFID chip [Wikipedia, 2008]**

### 3.3.3 Real-Time Visualisation

Due to RFID technology, visualisation of a supply chain is not as complicated of an issue as it has been in the past. The ability to keep the track of items in real-time allows creating different techniques like flow maps, which can help to see where the problems are and mitigate them. As it is a very important issue, it will be expanded on to in the next section, 3.4.

### 3.3.4 Real-Time Integration of Data and Processes: Electronic Data Interchange (EDI)

Information must be shared across the company and also across all the supply chain. So, systems must be able to “talk” and communicate with other systems and all the processes must be integrated across the SC. At first, EDI tried to replace the physical support (paper) of all the mercantile documents that the entities exchange. [Swatman & Swatman, 1991 p. 1-2]. Nowadays, its goal is to integrate all the commercial documents of an enterprise with the least (or no) interaction of the companies. These electronic documents have to be able to be sent and read automatically, so companies have to apply a common format and syntax for all these documents. [González Gómez, 2001 p. 6-7] The advantages of using this system are: better quality of the information, since there is a higher exactitude, and the possibility of transmitting information at any time. It does not matter if the partner does not work 24h/day, he will receive always the information. So, the cycle of sales-bills-payment becomes more agile and the expenses of manage information decrease. [O’Leary, 2008 p. 8] [Amece, 2009 p. 6-8] The basic components of an EDI, apart from the firms, are:

- The transmission medium: traditionally, firms have used value added networks (VANs) due to the security that guarantee. But nowadays, with improvement of security, Internet-based EDI has become a real choice.
- Information formats: these days it is essential to know English to communicate all over the world. EDI also needs a “language”, with a common format, structure and vocabulary that all companies involved can understand. The most common standard language is XML. Extensible mark-up language (XML) gives another important capability to facilitate data integration: XML does not require classic value added networks. XML offers flexibility in the definition of its standard, since XML does not specify the semantic content of data exchanged. So, in order to use correct XML, it is critical to develop in-house semantic standards.
- Message translator: as the language of exchanged information is complex, enterprises need an interpreter to translate these messages to the users. That software allows the company to send the information directly to the partners.
- Administrative systems: the ERP (Enterprise Resource Planning) is the tool that stores, manages and provides access to the information of all the commerce.



Usually, it makes up the function of the translator too, so it is not always necessary to get two different elements as one is enough.

The partner enterprises must have a similar infrastructure. The EDI's structure is the following:

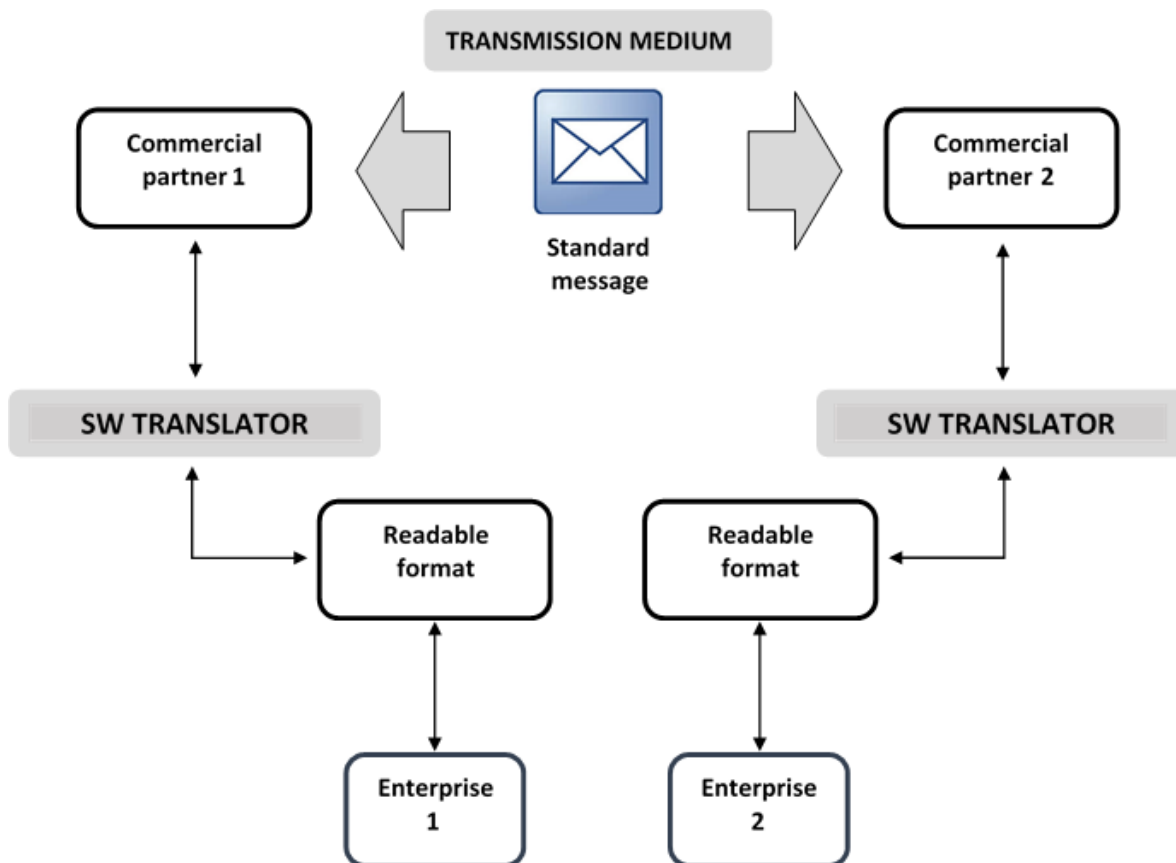
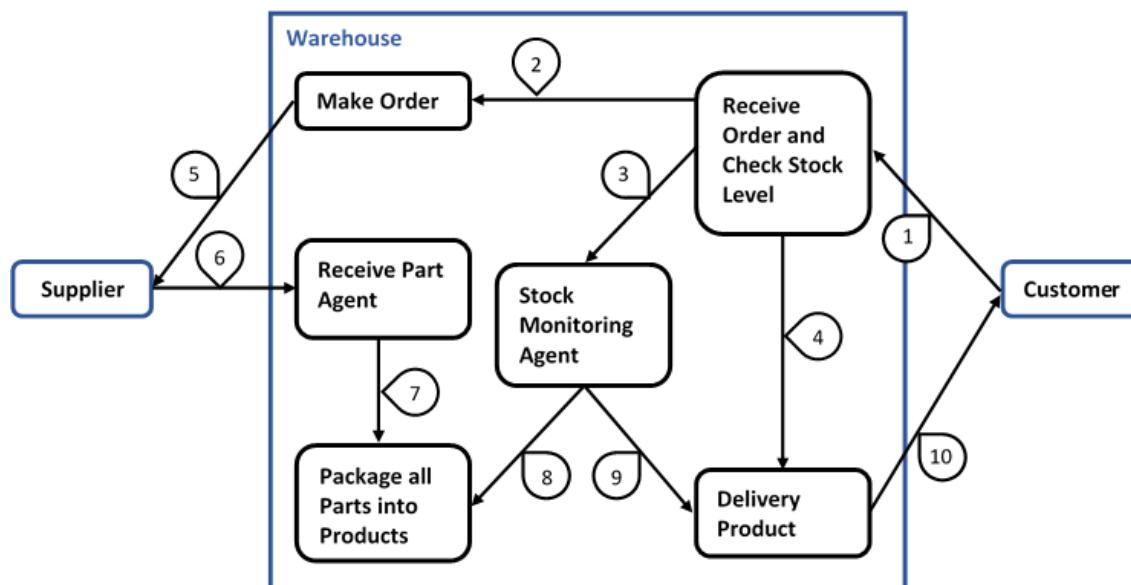


Figure 3.6- EDI's structure [Amece, 2009 p. 8]

### 3.3.5 Real-Time Decisions Making: Intelligent Agents

[O'Leary, 2008 p. 9] Intelligent agents are required, since humans can control just a limited number of tasks. Of course, the number of tasks performed by software is limited but incredibly enormous if compared with a human. The ultimate goal is to create an adaptive supply network that can sense and respond as fast as possible to evolving conditions, such that the entirety of the supply chain (and partners too) can intelligently, cooperate simultaneously, in order to keep the alignment between them. The agents would take care of verifying configurations, product pricing and the status of an order. Intelligent agents could also be employed in similar circumstances to those of other real-time enterprise applications. For instance, they could be used to schedule production or transportation activity.

We illustrate in the next figure the performance of a simple warehouse, and how it has grown in complexity.



**Figure 3.7- Warehouse with agent intelligence [Yung et al., 2000 p. 123]**

[Yung et al., 2000 p. 122] All processes present in the above diagram have a purpose. At first, we receive the consumer order (1). Here, there are two different possible scenarios: if the warehouse has enough stock (4), it delivers the product directly to the customer (10), or in the case that there is not enough (2), we demand more stock from the supplier (5), and a stock monitoring agents initialise to follow that process (3). When we have enough stock (6, 7), the agent realises as such and delivers the order to satisfy the consumer (9).

### 3.3.6 Real-Time Event Monitoring: Event Managers

As in other real-time systems, supply chain systems need to define events that are able to happen and also how to manage the supply chain if those events occur. If, for instance, a supplier does not provide raw material, we must have a plan for it. An intelligent agent should be able to recognise that situation, and then take the responsibility for choosing the correct decision depending on the current circumstances; the system could look for another provider, rearrange the production, or stop it until the shipment arrives.

[Croxtton et al, 2001 p. 17-18] An event manager can also be established for a chain of events, not just individual events. The event manager can be built to include knowledge about those chains, and sets of dependent events (such that they are designed to process streams of events). And when it becomes aware that an incident is occurring, it has to activate the triggers and contingencies associated with the event according to its magnitude. The drawback is obvious: we can only prevent the events that have happened or that we can imagine as possible. For instance, nobody could have predicted the Islamic revolution in Turkey, Egypt, Libya, Tunis or Syria, or the Ukraine's crisis and how they affected industries in those countries. For an autonomic system, creating a

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knowledge base of events and contingencies associated with each potential event is critical in order to enable the system to be autonomic.

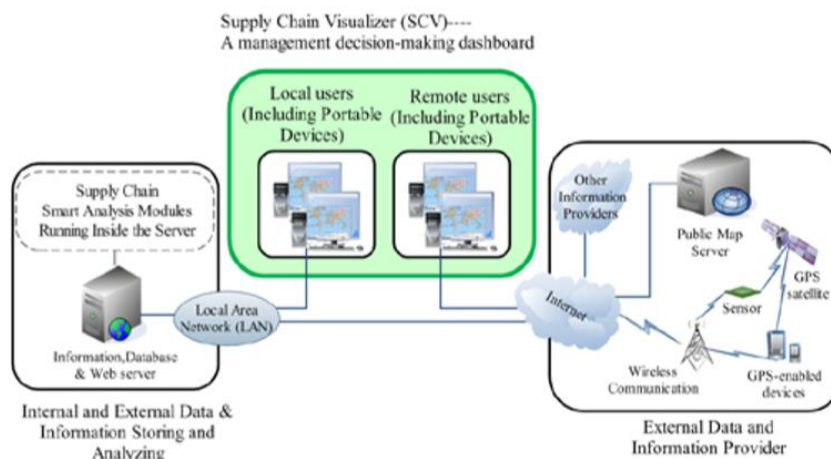
### **3.4 The Visualisation of the Supply Chain**

As we have introduced in the previous section, the visualisation of the supply chain is a big issue that deserves to be treated separately due the need to provide end-to-end supply chain visibility for an efficient management of a complex supply chain. Modern technologies such as RFID and the Internet provide the potential to increase the supply chain visibility in a high-resolution manner. The data and events can be represented digitally, along with all the details of the supply chain. Data can be integrated like we have explain in the previous chapters. [Goh et al., 2013 p. 208-210] The essential objectives of the visualisation for our Supply Chain Risk Management must be: the display of the data and the supply chain, the tracking and monitoring in real-time of anomalies; and the deployment of tools in a timely manner to handle those anomalies. The designer of this tool has to choose which data has to be displayed and which not. This implementation must also provide the users a way to explore the large sets of data, and also to make some relevant statistics of it.

A Supply Chain Visualiser regularly acquires data from the data processing modules. This includes risk identification and mitigation, analysis, modelling and simulation. The critical items that we have to survey are the following:

- Inbound and outbound logistics: aids in detecting signs of delay in a shipment and also to understand the movement of material and parts along the supply chain.
- Inventory level: having a level of inventory in a designated and controlled range helps to overcome unforeseen events with minimal cost, and to prevent obsolescence.
- Order fulfilment and manufacturing operations
- Risks such as natural disaster that might affect part or all the supply chain.

[Hu et al., 2010 p. 1237] The framework of a visualiser system has to involve different “modern” techniques, such as the Internet, mobile communication, GPS, GIS (geographic information systems), and database and server technologies. The internal (focal company) and external (public domain) information must be able to be manipulated in order to extract information from local and remote users. The next figure shows the framework of a visualiser and its connections with a supply chain’s data and the external data that come from another sources.



**Figure 3.8- Visualiser's connections [Goh et al., 2013 p. 209]**

In the previous chapter we have spoken about how to generate the information from the own enterprise, but it is important to recognise that there are also public sources that provide external data which are sometimes underestimated. [Min et al., 2004 p. 5-6; Goh et al., 2013 p. 209] These public sources can bring us up to the 90% of the required information. Some of this information is distributed over the Internet; to extract it, web-spiders or bots can be used, and in most of the cases this information must be converted from unstructured to structured, and then processed. Real-time alerts of natural disasters can be monitored and utilised when a risk to the company is evident.

To sum up, the visualisation is a key tool in Supply Chain Risk Management, because when it works properly it allows the operators to respond very fast to disruptions. The visualiser does not have to include just the intern data; a system must to allow the external data to be integrated in the software.

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## 4 Simulations in Supply Chain Risk Management

In the last two chapters we have seen the organisation of a supply chain and how the data are integrated into the enterprises' systems. In this chapter we are going to explain the uses that we can give to that data, focusing on determinate simulations like the Monte Carlo simulation and Agent-Based simulation. Modelling and simulating are tools that are widely used, not just in the field of the engineering (we do it in electronics, thermodynamics...), but also in other fields, such as marketing, urban models and consumer behaviour. Of course, we can utilise them in our Supply Chain, to try and predict the consequences of an event or action. [Safety and Reliability Society, 2011 p. 4] In this regard, we have to discuss why it is create worthy to make a simulation; rather than use an analytical modeller (like deterministic equations). As we will see in this chapter, Monte Carlo and Agent-Based simulation are very flexible, and even empirical distributions can be handled and the results can be easily understood by almost everybody (also non-mathematicians). The disadvantages are obvious: we need a computer, it is only a simulation (the accuracy depends on the number of runs) and it usually takes more time than an analytical process. However, the advantages are much bigger than the disadvantages; nowadays it is possible to have a computer with enough power to make many calculations in a short time.

As we have seen in the section 2.1.2 in the Beer's Game example, due the Bullwhip effect, a poor plan can easily propagate to the whole supply chain. It causes a lot of problems in the supply chain, such as cycles of excessive inventory and then backlogs, poor product forecast, unbalanced capacities, poor customer service, uncertain production and plans. Event simulation allows the evaluation of operating performance before the system's implementation. It also allows the companies to perform "what-if" analyses, and it permits the comparison of various alternatives without interrupting the real system. [Chang & Makatsoris, 2001 p. 26] The questions that we usually want to answer when we do a simulation are the following:

- Which supplier policy is achieving best delivery performance under the predicted demand pattern?
- Which supplier policy is most robust under demand fluctuation?
- Which is the most cost saving inventory policy?
- How could profit be impacted by adding more capacity?
- What is the trade-off between delivery performance and inventory cost when building more inventories?
- What is the impact of information accuracy on the manufacturing performance?

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## 4.1 Simulation Concepts

There are different kind of simulation programs; some are designed as interactive tools to be used by a human, not as a real-time decision-making tools, and there are others which are directly linked to control system to dispatch tasks. The benefits of using the first kind of tools are that they help the operator to understand all the processes with graphics or animations. They sometimes also allow one to create unexpected events in certain areas using a probability distribution, which is perfect for understanding the impact of these events on the supply chain. Finally, it is possible to know and test what-if alternatives, knowing beforehand the path to choose when a risk come up in order to minimise the damage. [Gunasekaran et al., 2001 p. 82-85] These authors define three different management levels depending on the horizon time of the decision. They are usually classified as strategic, tactical or operational. A strategic decision is related to the company's strategy and is long term (years) and takes the involvement of most partners in a supply chain. Tactical decisions are mid-term (months) and operational decisions are related to the day-to-day activities like demand procurement, production, warehouse and distribution. [Chang & Makatsoris, 2001 p. 27] For all this nature of decisions, it is important to follow different procedures proposed by Chang and Makatsoris:

- Understand the supply chain process and planning process.
- Design scenario. Depending on the problem areas is not reasonable to model every detail of the supply chain.
- Collect all the data.
- Performance measures.
- Define a target for each performance measure.
- Define termination condition.
- Evaluate the supply chain policies/strategies.

[Chang & Makatsoris, 2001 p. 28] As we have introduced in the first point of this work (2.1.1), a classic division of the supply chain is by its functionalities or areas. The information that we need can also be structured by this criterion. So, in the next table we present all the data that a company must have access in order to make a simulation in one of these fields:

**Table 4.1- Areas of Supply Chain Management**

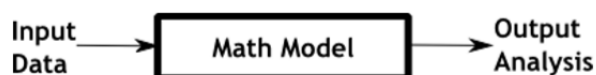
Area	Data required
Manufacturing Process and time information	Manufacturing process data (process time, queue time, setup time...) Calendar data (shift information, holiday information, preventive maintenance information) Machine data (number of machine, mean time to failure, mean time to repair, alternate resources data, preventive maintenance time) Bill of material structure
Inventory control polices information	Safety stock level, reorder point. Inventory level of finished products, raw material and intermediate parts. Any stock location in shop floor
Procurement and logistics information	Supplier lead-time Supply lot size Supplier capacity Procurement horizon Procurement time
Demand information	Due date Priority Start and end data Demand pattern
Policies/strategies information	Order control policies, dispatch policies

[Frantzén & Moore, 2011 p. 697] When an enterprise use a simulation-based real-time prediction, it is important that the system has the capability to interface with the databases to obtain the information. The firm has to develop the hardware and software enough to process the simulation in a short time (or be, at least, pseudo real-time), and have the capability to interface with the control system and receive the feedback of it. With this, companies need to be agile enough to adjust and rebuild plans in real-time and respond to unexpected events in the supply chain. Here below, we will describe the operation of two simulation methods that can be used in order to help us to take advantage of some events.

## 4.2 Monte Carlo Simulation

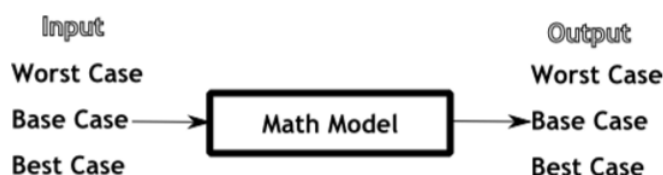
[Bautista Abraham, 2004 p. 3] This is maybe the most famous nondeterministic method of simulation. It means that for the same input we can have different outputs. It was developed during the Second World War, with the construction of the atomic bomb in Los Álamos. Later, with the development of the computer, it became more important since as it became more useful. [Bautista Abraham, 2004 p. 4; Raychaudhuri, 2008 p. 91; Kroese et al., 2014 p. 1-2] This method relies on repeated random sampling and static analysis to compute the results. Monte Carlo is one simulation that is perfect to perform a what-if analysis, as it closely related to the experiments that we do not know the answer to beforehand.

In a mathematical scenario, we use formulas and mathematical expressions that together can be named as a model. And when we provide that model an input, the result is one, or more than one, output. An easy schematic diagram of the process is the follow:



**Figure 4.1- Mathematical models [Raychaudhuri, 2008 p. 91]**

The problem is that in our case, the input parameters depend on different external factors, and the input can vary by a large degree. When we do not consider the variation of these parameters and use their “normal” values, we call this base case. We can also develop the two other typical cases: the best and the worst case.



**Figure 4.2- Case-based models [Raychaudhuri, 2008 p. 91]**

[Raychaudhuri, 2008 p. 91] This approach is not very good: first of all, it is difficult to evaluate the best and worst case scenarios for every single input variable. And of course, all input variables may not be simultaneously at their best or worst level. Another less important reason is that increasing the number of cases forces us to deal with the problems of versioning and storing. Here is when the Monte Carlo simulation shows its strength, due to it allowing us to methodically investigate the complete range of risks associated with each risky input variable.



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## 4.2.1 The Monte Carlo Procedure

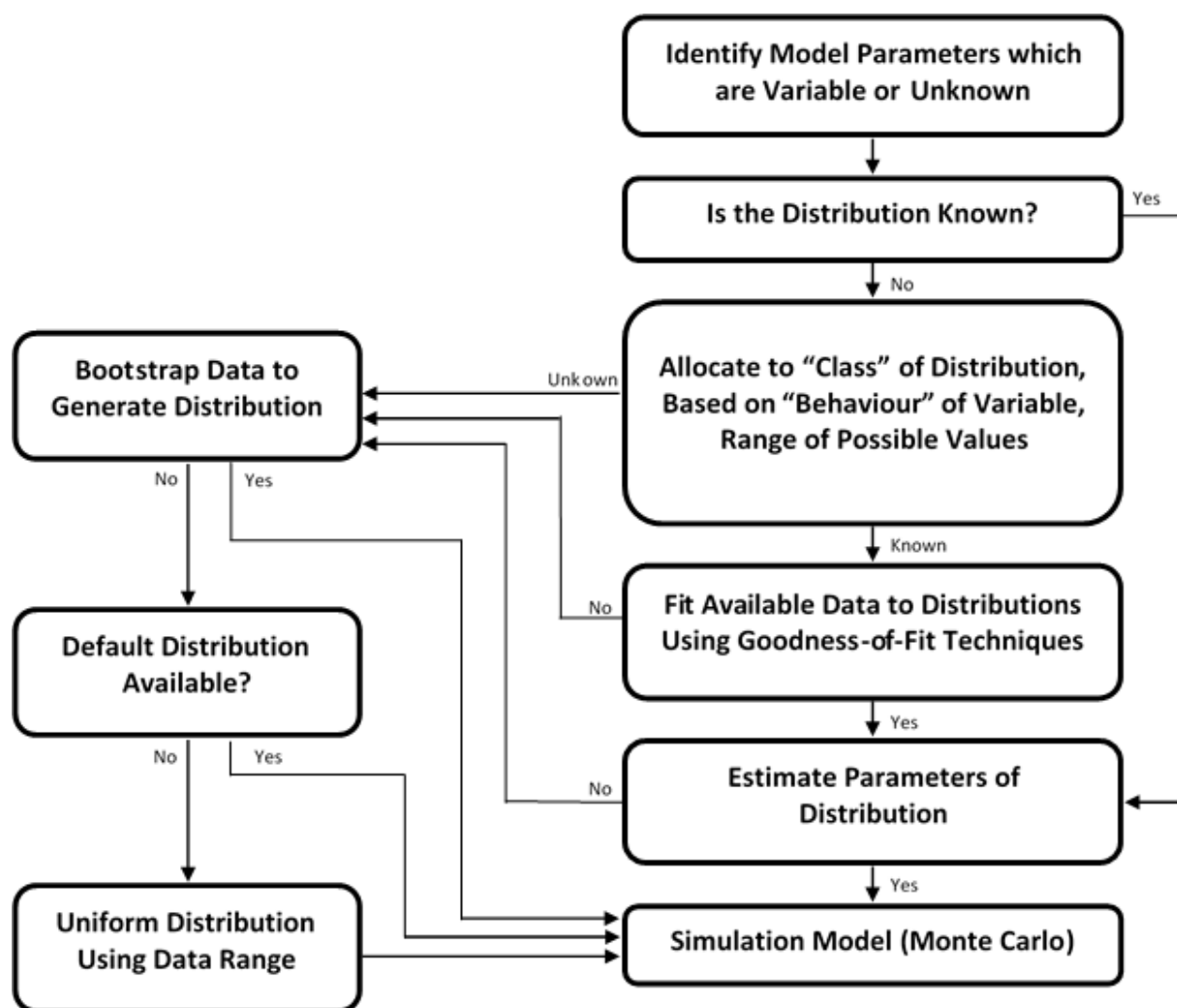
[Simon, 1997 p. 154; Bautista Abraham, 2004 p. 4] The Monte Carlo simulation has the following steps: first of all, in Monte Carlos method, we relate every input parameter with a statistical distribution, then, we draw random samples for each distribution that will be our input variables. As we have described before, for every set of input parameters we obtain a set of output parameters. We collect all those outputs values, of all the simulations that we have done, and we perform statistical analysis on them, in order to have results on which we can base our decisions. We have described simply how the Monte Carlo simulation works, but it is interesting to focus on every part of the methodology. [Raychaudhuri, 2008 p. 92] It is made up of the following 4 steps, but only the second and the third are formally part of the Monte Carlo method.

1. **Static Model Generation.** As we have explained in the beginning of this chapter, we try to develop the closest model to the reality with mathematical relationships. When we have it, we can generate output results from the input parameters.
2. **Input Distribution Identification.** This step can seem simple but is the most complicated. The risks originate from the stochastic nature of the input variables and we try to identify the underlying distribution of them. This step needs historical data for the input variables to help us.
3. **Random Variable Generation.** After identifying the distribution in the last step, we generate a set of random numbers from these distributions. We use one random sample of every distribution and we take the first outcome result. Then we repeat the method with a new random varieties for the input distribution until we have a big enough set of outcome results.
4. **Analysis and Decision Making.** When we have all the results of the previous step, we perform a statistical analysis in the set of outcome results, in order to have a base in which base our decisions.

Now we are going to expand up on the second and the third points, explaining in detail the procedures that they entail. After, we introduce the basic statistical methods that we can use to analyse the results of that method.

### 4.2.1.1 Input Distribution Identification

The goal of this step is clear: identify the most suitable probability distribution for a given set of data. As a proof that we have done it correctly, the result distribution must be able to generate the given data since it is identified by that parameter set. [Lipton et al., 1994 p. 193] Lipton et al. introduce an arrow diagram that shows the steps to identify correctly the distribution:



**Figure 4.3- Framework for selecting input distributions [Lipton, 1994 p. 193]**

[Raychaudhuri, 2008 p. 93; Lipton et al., 1994 p. 195] There are different standard procedures for fitting data to distributions. We will introduce them and see the advantages and disadvantages of using some of them:

- Method of Maximum Likelihood (ML): This method help us to make inferences about the details of the underlying probability distribution from a given data set if we assume that the data are independent and identically distributed. The great advantage of this method is that when the samples tend to infinity, the bias tends to zero.
- Method of Moments (ME): this is a method of estimating population parameters such as mean, variance, median, and so on. The mean squared error is bigger than in the ML method. However, in some cases, the likelihood equations may be intractable, even with computers, while ME estimators can be quickly and easily calculated. We can combine the first method with this, making that the solution of the Method of Moments will be the first approximation to the solution of the Method of Maximum Likelihood.

- Nonlinear Optimisation: the decision variables are the unknown parameters of a distribution. This method is less efficient than the others, and often takes more time.

As the diagram of the author shows, when we have the resulting distribution, it is advisable to prove if the distribution that we have discovered fits to the dataset that we had. This is called Goodness-of-fit. The most famous is the Chi-square test and it is possible to be used in both continuous and discrete cases.

#### 4.2.1.2 Random Variable Generation

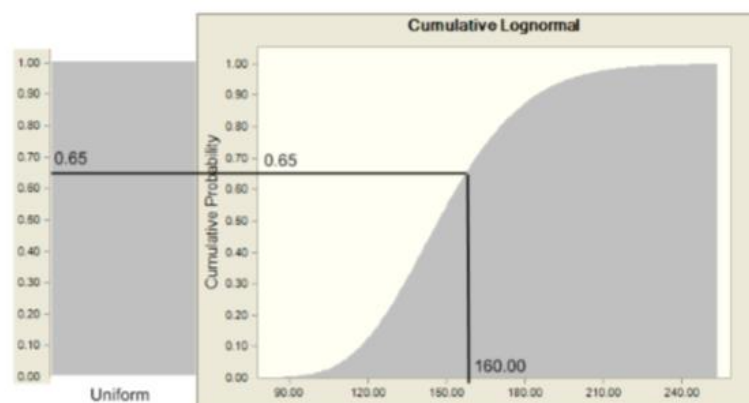
After identifying the underlying distribution of the input parameters, we have to create random numbers to introduce to that distribution, in order to have specific values of some variables. Here, we will explain two ways to generate random variables: one from a distribution function, and another that helps us when we do not have any input distribution.

##### 4.2.1.2.1 Inverse Transformation Method

[Fishman, 1996 p. 149-156; Raychaudhuri, 2008 p. 95-96] This is the most direct route to generate a random sample from a distribution. We use the probability density function (PDF) for a continuous distribution, or the probability mass function (PMF) if our distribution is discrete. With these functions we create the cumulative probability distribution function (CDF). It is continuous and always increasing between (0, 1). The process is very simple and is based on two steps:

- First we generate a continuous number between 0 and 1. [ $U \sim U(0, 1)$ ].
- And then, we use the CDF of the distribution (we denote that  $F$ ). We create  $F^{-1}$ , which is the inverse of the function  $F$ . So, we return  $X = F^{-1}(U)$ , which is a random number of the distribution. We notice that that  $F^{-1}(U)$ , always exists when  $U$  is  $[0, 1]$ .

[Raychaudhuri, 2008 p. 96] We will make a little example to show it. Our curve is a lognormal distribution. When we produce the CDF, it has the form that the image shows. We generate a random number (for instance 0,65) between 0 and 1, check the correspondence to the CDF and we can see that it is 160. So, this is a random value from the lognormal distribution. We can also perform this with discrete distribution, knowing that the PMF will be a step function with discrete jumps.



**Figure 4.4- Generation of random varieties [Raychaudhuri, 2008 p. 96]**

An important advantage of this method is that we can generate random number from a truncated distribution. But as we have seen before, the best advantage is the flexibility that it has to handle continuous and discrete distributions. The biggest disadvantage is that this method becomes difficult to implement if there is no closed-form inverse CDF for a distribution, which can be solved with an iterative method.

#### 4.2.1.2.2 *Bootstrapped Monte Carlo*

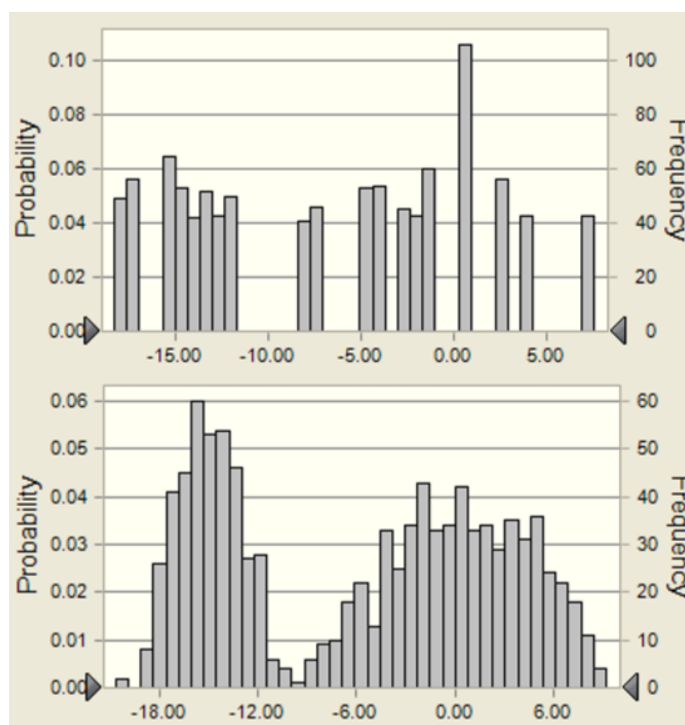
When it is not possible to obtain an underlying distribution for an input variable (the prerequisite to using the first method), we use Bootstrapped Monte Carlo. [Karlis, 2004 p. 11-12] This simulation is based on repeatedly simulating samples of the original set. This method provides good results for simulation purposes. It is important to note that we also have to use a random number generator with a uniform distribution to choose the indices of the array where the samples are. Bootstrapping can be very effective in the absence of a parametric distribution. However, the disadvantages of this method are that we assume some facts of our samples (like the independence) that are not guaranteed. So, sometimes the results are not correct.

As we have done in the Inverse Transformation Method, we will show an example to illustrate how it works. [Raychaudhuri, 2008 p. 96-97] First, we take 20 samples from a bimodal distribution (we take that samples from this known distribution in order to see how the method distort it). The samples are also called bootstrapped samples:

**Table 4.2- Samples from a bimodal distribution**

7,58	-2,16
-13,08	-2,56
-13,70	-3,84
-1,27	-7,28
2,44	-12,30
-15,56	-18,32
-13,00	0,62
3,79	-4,45
0,28	-14,60
-17,03	-8,18

And now we make 1000 random choices of the 20 numbers that we had in our Table. The next figure shows 2 histograms: the top one show the 1000 samples from the bootstrapped Monte Carlo method, and the bottom has 1000 samples from the original bimodal distribution.



**Figure 4.5- Comparison between Bootstrap simulation with 1000 samples from the primary bimodal distribution [Raychaudhuri, 200 p. 97]**

At first sight, we can see that the difference between the two histograms is large, but when we calculate the basic statistics from these two sets of samples we notice that the parameters are not drastically different (considering that the bootstrap was done from only 20 samples). If we had more data points to perform the bootstrap sampling, the

result would be undoubtedly better, but for that number of samples the result is sufficient.

**Table 4.3- Basic statistics comparison between bootstrapped MC sample and general MC sample**

	BS Sample	MC Sample
Number of Trials	1000	1000
Mean	-6,79	-5,76
Median	-4,45	-4,02
Mode	-15,56	-
Standard Deviation	7,51	8,28
Variance	56,39	68,58
Skewness	0,08	-0,04
Kurtosis	1,74	1,53
Coeff. of Variability	-1,11	-1,44
Minimum	-18,32	-20,62
Maximum	7,58	9,21
Range Width	25,90	29,83
Mean Std. Error	0,24	0,26

#### 4.2.1.3 Statistical Analysis

After generating the results of the Monte Carlo simulation we must analyse them. The most common use of them is similar to an empirical distribution, with one being able to calculate the basic statistics (like percentiles and confidence bands). The accuracy of the values from these statistics improves as the number of trials increases. [Pripp, 2012 p. 15-20; Raychaudhuri, 2008 p. 97] The basic statistics that we use are the following: mean, median, standard deviation, variance and skewness. The number of values that we have is N, and they are represented like  $x_i$ , where i comes from 1 to N. Here we explain how to calculate the statistics:

- Mean ( $\bar{x}$ ):  $\bar{x} = \frac{1}{n} \sum_i x_i$
- Median: 50<sup>th</sup> percentile
- Standard Deviation (s):  $s = \sqrt{\frac{1}{N-1} \sum_i (x_i - \bar{x})^2}$
- Variance ( $s^2$ ):  $s^2 = \frac{1}{N-1} \sum_i (x_i - \bar{x})^2$
- Skewness:  $Skewness = \frac{\sum_i (x_i - \bar{x})^3}{(N-1)s^3}$
- Kurtosis:  $Kurtosis = \frac{\sum_i (x_i - \bar{x})^4}{(N-1)s^4} - 3$

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## 4.2.2 Monte Carlo Applications

After showing how the Monte Carlo Method works, we will give an overview of its applications. Some are related with the supply chain, but there are other well-known applications that not. We can differentiate the financing problems, the reliability analysis, mathematical and statistical physics and engineering. [Kroese et al., 2014 p. 3-5; Glasserman, 2003 p. 19] Monte Carlo simulation in finance is used by financial analysts for various scenarios: they do what it is called like Real Option Analysis, where MC is used to characterise the potential project's NPV (net present value); and also another important characteristics, such as its volatility. Financial analysts can also do Portfolio Analysis. For each simulation, the behaviour of the factors impacting the component instruments is simulated over time, and the value of the instruments calculated. They can then observe the real value of the portfolio with its statistical characteristics and draw conclusions. Monte Carlo simulations can be also used in another financial analytics like option analysis or personal financial planning.

[Alexander, 2003 p. 91] In the field of reliability analysis one tries to know if a system or component is able to perform its work under stated conditions for a specified period of time. It starts evaluating the failure distribution of the components, then the model generates random numbers for these distribution and we analyse the output results to get the probability of various failure events. This method is usually applied to evaluate what is more worthwhile: to change one broken component or to replace it. [James, 1980 p. 1185-1186] In Mathematics, Monte Carlo simulations are used to numerically solve complex multi-dimensional partial differentiation and integration problems. For instance, MC is used for simulating quantum systems, which allow direct representations of many-body effects in the quantum domain. The statistical uncertainty can be reduced with more simulation time. MC simulations are also used in various engineering disciplines, such as we have seen with the reliability of mechanical components. For instance, in chemical engineering, the effective life of pressure vessels is estimated using MC. Electronic and software engineering are other fields where this simulation method can be used.

[Raychaudhuri, 2008 p. 99] Finally, we will explain the options of software that are available to use the Monte Carlo simulation. It is possible to be programmed in some language like C, C++ or Java following the steps that we have explained before: generate random uniform numbers for specific distributions and then make the output analysis. Nowadays, many programming languages include the MC simulation as a library to make its implementation easier.

As we have seen, Monte Carlo Simulation is a very useful mathematical technique for analysing uncertain scenarios. Since it was invented some years ago in Los Álamos, it has gained importance due to the huge increase in available computational power.

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Nowadays, simulation has become an easy tool for obtaining effective results for forecasting. This method seems more complicated than it is in reality, as the implementation can be difficult but the concept behind of the method is very easy to understand: its success has largely been a result of its inherent simplicity.

### **4.3 Agent-Based Simulation**

After investigating the Monte Carlo Simulation, we will now investigate Agent-Based simulation, a completely different approach to what we have seen in the previous section [Macal & North, 2010b p. 1]. Agent-Based modelling and simulation (ABMS) is a relatively new approach to modelling complex system composed of entities that not only interact with the environment, but also with themselves. These entities are usually called agents. Normally, this method is used in the social sciences where it has a wide range of applications, such as in socio-economics, consumer behaviour and opinion dynamics. [Gilbert, 2008 p. 11-12] But, of course, it is possible to also use it in the Supply Chain's approach; modelling a SC we can study, for instance the order fulfilment processes, to know if the management policies are correct. An example could be, if we want to know the impact of information sharing in a supply chain,

[Helbing & Balmelli, 2012 p. 26-27] These agents have various behaviours and interact with one another in turn, influencing their primary behaviour. Complex systems are composed of several items interconnected, whose links create new information that was not previously visible to the observer. The diversity among the agents in their attributes can be better observed within the system, rather than individually. Sometimes patterns that were not programmed arise from the agent interaction; this emergent behaviour is the most interesting component of Agent-Based system. [Gilbert, 2008 p. 2] The main difference between Agent-Based simulation and other simulations is that Agent-Based models offer a way to model social systems that are composed of agents who interact and influence each other, learn from their experiences and data, and change their behaviours in order to be better suited in the environment. [Macal & North, 2010a p. 151] This concept is used in a lot of disciplines, from modelling behaviour in the stock market, to modelling the adaptive immune system. This large scope is possible since the software has been rapidly improved upon and new, more effective approaches to Agent-Based models have been developed.

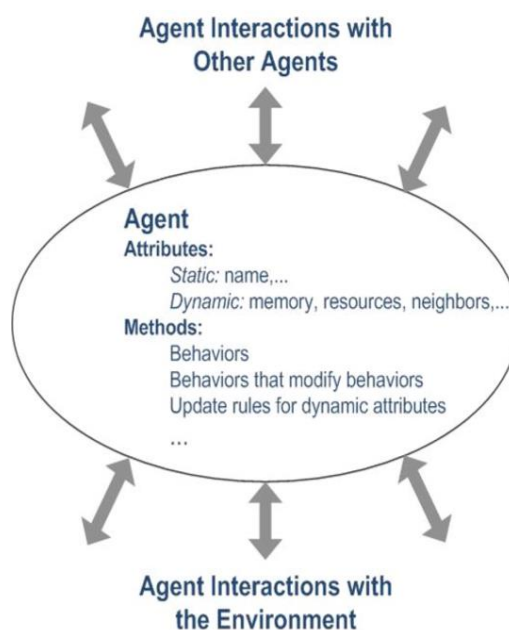
#### **4.3.1 The Elements**

[Macal & North, 2010a p. 152; Macal & North, 2006b p. 24] An Agent-Based's model simulation contains three elements that every developer must identify, mode, and program, in order to create the Agent-Based model. These are:



- A set of agents, including their attributes and behaviours.
- A set of agents' relationships, with their underlying topology: agents that involve and kind of interaction.
- The environment (it also interact with the agents).

The elements' typical structure is the following:



**Figure 4.6- Agent with his interactions [Macal & North, 2010b p. 2]**

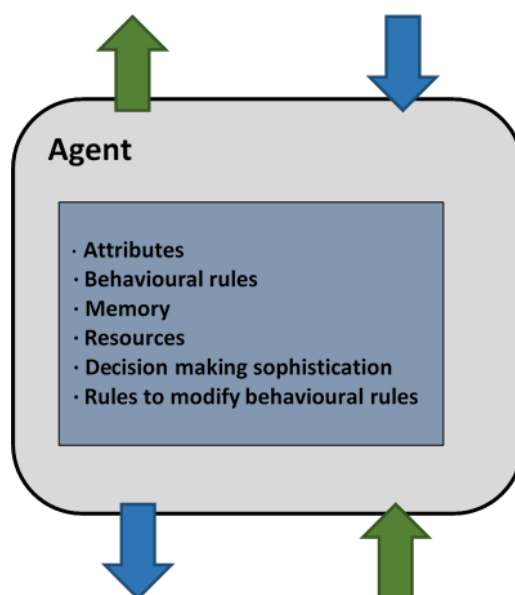
#### 4.3.1.1 Autonomous Agents

[Macal & North, 2006b p.4] The most important characteristic of an agent is the capability to act autonomously, without external interaction (environment or other agents). [Macal & North, 2010a p. 153] The most common situation is that agents try actively to achieve their goals, and then passively their behaviour is altered by the interaction with other agents or with the environment. It must not be forgotten that another characteristic that defines an agent is its capability to learn. [Macal & North, 2006a p. 74] [Macal & North, 2010a p. 153-154] The main characteristics for modelling an agent in practice are the following:

- **Self-contained:** an agent has a border. We can easily identify one, and differentiate one from another, and clearly see what part is of it and what is not.
- **Autonomous:** it can work alone without the influence of the environment or the other agents.
- **Has a state (or various):** it represents the essential variables of the agent associated with his current situation.

- Social: it has interactions that can influence its behaviour or state. An agent recognises the traits of the other agents and reacts to them.

This characteristics are shown in the next illustration:



**Figure 4.7- Agent characteristics [Macal & North, 2006a p. 74]**

It is possible to make another classification: [Macal & North, 2010a p. 154] the attributes of an agent can be static (not modifiable during the simulation), or dynamic, (modified as the simulation progresses). For instance, we can say that the name of an agent is a static attribute, while a dynamic is the memory of the past interactions.

#### **4.3.1.2 Interacting Agents**

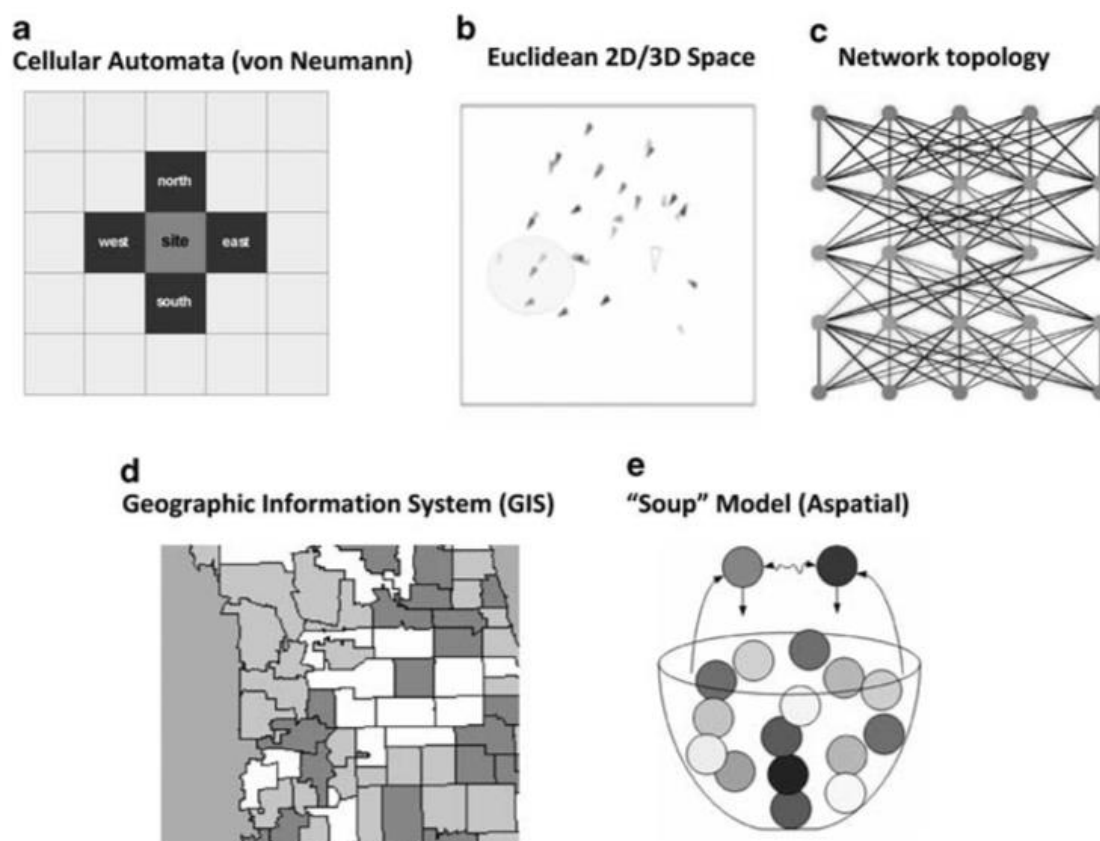
The agents' interaction is the reason why that model has been developed. [Macal & North, 2010a p. 154-155; Gilbert, 2008 p. 15] The two principal issues of the modelling agent interaction are: first the connection (or not) with who, and then the mechanism of the interaction. As we have explained before, the agents are not linked to a global aim that drive them to a global optimisation. The agent with whom an agent interact is called the neighbour. This definition is important because the information is shared to the neighbours, not to all the others agents around. Generally, the information is extended by the simulation runs.

The topology of the interacting agents explains how the agents are connected to each other. [Macal & North, 2010a p. 154-155] The most common topology is based on nodes (agents) and links (relationships), and it denotes which nodes can interact with others. For instance, the agents can be the members of a social network like Facebook, for which we want to obtain the likelihood of contact with the friends of a friend. As we have introduced the concept "neighbour" in the previous paragraph, we can define now the neighbourhood: it is range in which an agent has influence (or in Facebook's case,

our own friend's group). It is not only his close physical space, but also it can be in his social space.

In the early beginning, the first Agent-Based models were implemented in the form of cellular automata (CA) [Wolfram, 2002]. It was a method created in the 50's to study biological systems, and its principal characteristic is the grid in which this method is computed. It can be in different dimensions, with the simplest case being a line (1-D). But, with two dimensions it start to be more complex, due to needing have different kinds of grids depending on the maximum interactions that the agents can afford, these could be, for example, triangular, square or pentagonal. 1-D and 2-D grids have the advantage that we can easily draw the interactions and see the neighbours clearly. This method is based on coloured cells that change their status (usually the status is binary: "on" or "off) depending on the status of itself and its neighbours.

Nowadays the most common topologies that we can find are in the figure below (including the example of the cellular automata).



**Figure 4.8- Topologies for agent relationships and social interaction**  
[Macal & North, 2010a p. 155]

[Macal & North, 2006b p. 10; Macal & North 2010a p. 155] The figure (a) is the Cellular Automata that we have explain before. The figure (b) is a Euclidean space model, where the agents roam in higher than one dimensional spaces. The network topology (c) define the links generally. The user must define these links between the

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nodes and state if they are static (do not change), or dynamic (they can change depending on a characteristic). In the geographic information system (GIS), the agents move among the different sections (d). The most strange or different is the “soup” model, or aspatial model (e), where pairs of agents are randomly selected for interaction and then returned to the soup. It is possible that some models include agents that are in different topologies.

#### **4.3.1.3 The Environment**

[Gilbert, 2008 p. 6] The environment is the virtual world where the agents act. It can be a neutral place where the agents interact, without having any effect –for example, it has not any sense that the soup model’s environment had any effect to the agents-. But other environments can represent geographical spaces like in a GIS, and it may constrain the agent actions.

### **4.3.2 Methods for Agent-Based Modelling**

In this section, we will discuss how to create and take advantage of an Agent-Based model. To design, implement and make the model run, we will need a computer that simulates the agent behaviours and the interactions. Nowadays, different software based on some programming languages provide this capability. We will support the explanation in the previous paragraphs, where we have explained the elements that we need in the simulation.

#### **4.3.2.1 Agent Model Design**

[Helbing & Balmelli, 2012 p. 35-37] If we want to create a model from the beginning, we have to develop a strategy or a pattern. In this case, the most widely used is generate some questions whose answers make aware of what we need to use. The list can be huge and anybody can use it with more or less detail, adding or obviating points. We will mention only those that are critical. The most important question is “why”: we must have a purpose, or ask ourselves which questions the model should answer. Then, we have to choose the agents (with their various behaviours) that will appear in the model. This is not a trivial step, as there are many variables which must be considered. We have to answer the question: ”How do they interact with each other and with the environment?”.

It is important to also note that, depending on the accuracy of the answer that we want to obtain, the level of care we will take in designing our simulation. [Macal & North, 2006a p. 77] Minimalist models are not commonly used to make decisions, due to they are based on a lot of idealised assumptions. When we have the results of the simulation we should compare them with previous results, to check if they are logical, as just one wrong attribute of an agent can completely change the simulation.

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#### 4.3.2.2 Agent Model Implementation

[Davidsson et al., 2006 p. 4-5] The implementation refers to all the computer tools or devices that make our simulation possible. Nowadays, there is no clearly dominant platform. [Macal & North, 2010a p158] Depending on the level of difficulty of the simulation, the platforms can vary from Microsoft Excel to C++, C or Java, the last three requiring a good knowledge of programming. There are also some specialised tools that have the advantage of ease of learning, compatibility, and more power to simulate large projects, so programming knowledge is not always required. When the simulation is too complex for our computer, or there is a lack of computing hardware or software, and there must be a compromise between the complexity of the agents, the number of agents, and the time that we have to run the simulation. Hence, large sized simulation use relatively simple agents, and vice versa.

#### 4.3.2.3 Agent Modelling Services

[Macal & North, 2010a p. 159] Apart from the simulation, there are some “extras” or services that are commonly required for implementing large-scale models. These include the project specification services, agent specification services, input data specification and storage services, and model execution services. We will describe them briefly: Project identification provides a way for modellers to identify which sets of resources constitute each model. The three most common approaches are library-oriented, integrated development environment (IDE) and hybrid. The first is based on libraries of routines organised in an application programming interface (API) which are used by modellers to make the models calling the functions. The second approach uses code or model editing programs to organise the model construction. And the hybrid approach, as its name suggest, allows the developer to use libraries and an IDE. Agent specification services help us to give the attributes and behaviours. These services use a general programming languages such as C++ or Java. Input data specification and storage services is a tool that helps the users of a simulation to set up and run the model. Standard storage formats include XML files, spreadsheets, databases, and GIS files. And last, Model execution services allow us to not only interact with the simulation, but also view it, display the agents in 2 or 3 dimensions, and be able to modify the attributes of agents during the execution. It also can have the option of not see the simulation and going directly to the statistical results.

## 5 Framework for the Supply Chain Management

The aim of the other three chapters is explain the different parts that form this thesis: the Risk Management, the real-time data and the simulation tools. We have explain this concepts in the Supply Chain Management's scope and now we will try to relate them in that context. To achieve that purpose we will try to develop a framework, seeing the steps that has to been used to create it. The process will be as follows: first we will explain one framework created by Szczesny and König in its context and then we will make different changes to adapt that framework to our scope.

### 5.1 The Reactive Scheduling Concept Approach

The idea of the framework came when I read the dissertation of the professors Szczesny and König of the University of Bochum. [SZCZESNY & KÖNIG, 2013 p. 2-8] In their work they explain how to integrate the uncertain real-time logistics data for reactive construction scheduling. They propose a schema for reactive construction scheduling in which logistics data are considered for controlling and updating construction schedules, as we can see in the next figure:

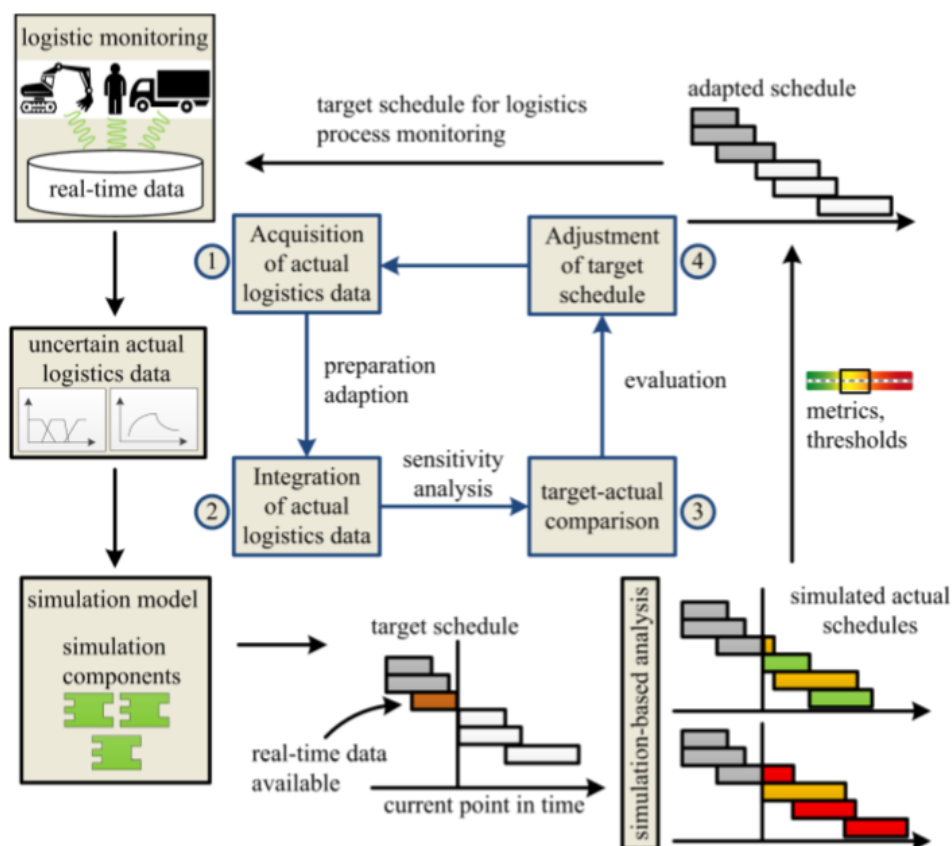


Figure 5.1- Schematic overview of the reactive construction scheduling approach [SZCZESNY & KÖNIG, 2013 p. 4]

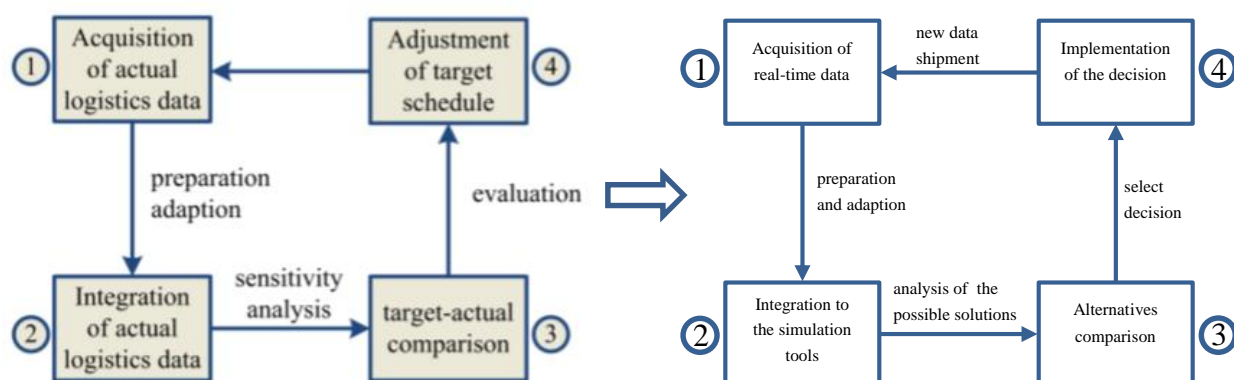
[SZCZESNY & KÖNIG, 2013 p. 2] The structure of this figure is based on four steps according to their reactive scheduling concept. To easily define this concept we can say that it takes care to manage a construction (in this case) project efficiently creating a schedule representing the current progress. It must be noticed that it is a closed circuit; all the stations are connected and there is no final station where all the processes will be in a perfect and finished status. The idea is that we have to always improve the different stations, and the improvement of one is the beginning of the improvement of the other. Thus, it is a never-ending loop.

At first, we have the station of “Acquisition of actual logistics data”. As its name suggests, in this step we get not only the data: we also prepare it and adapt it, making it more understandable. That data normally includes information about the availability of material, equipment, personnel, and of course the requirements of the system like the delivery date and cost of the labour. In the scope of their work that data also includes the access to the construction site and also information of the required personnel.

Then, the prepared data are integrated into a simulation model where other real-time constraints are also collected. In that moment the simulation is run and after few moments the results are displayed. After that, a sensitive analysis has to be performed, which in this context that means that we have to study how the uncertainty in the real-time logistics affects the schedule and the project duration. Finally, the result of this study shows the effects of the different alternatives that can be possible. From this we must decide which alternative will be the best for our system. We must then take that decision and then re-adjust another time the schedule to update it.

## 5.2 The Approach for the Supply Chain Management

When we try to adapt this schema to the Supply Chain’s scope, we have perform various changes. All of these changes should be thought to adjust integrate all the systems that we have explained in the past three chapters. Firstly we will explain how the internal flow changes:



**Figure 5.2- Changes in the inbound flows of the framework**

The inbound flows refers to the global process. The changes that we have done are based on the differences between both approaches. The first phase is the same: new data is received by the systems and we translate them to the forms and languages that are simpler to understand, and also used in the simulation tools. During that step, the data can be superficially analysed in order to have a fast approach, or to detect any anomalies. In the second step we perform the simulation with the data that we have recently received and also with the information that we already had before. We run the program and we receive the results from the different alternatives. At this moment we have to make the decision to take advantage of the power of that technology. We make the decision that we believe that is the best solution and we implement it. We believe that it is important to inform the system that we have changed the status, so it will keep that in mind for the next round. The differences between the two systems, in this inbound round, were not very big and all of the adaptations that we have made have been detailed, without changing the aim of the schema.

Then, we will describe the changes that will be in the outside circle:

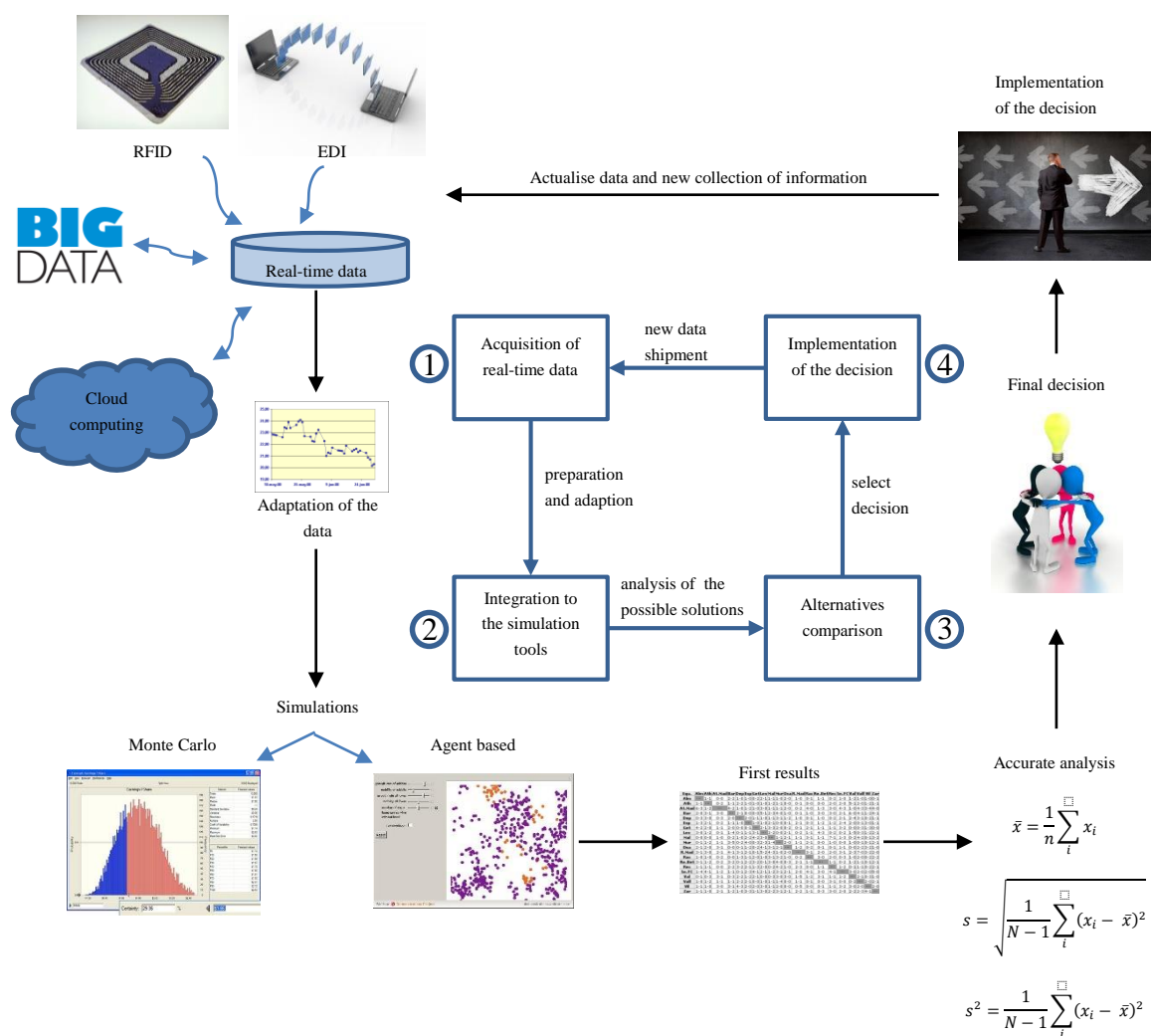


Figure 5.3- Changes everywhere of the framework



As we can see in the last figure, we have introduced multiple changes from the primitive approach. In the beginning, our ways to capture data is from our RFID sensors, and also from our partner's collaboration (EDI). We store that information using the technologies of Cloud Computing and Big Data. Before we will make our simulation, it is perhaps necessary to change the data to the format that is needed by that software. Once we have it in the correct format, we can utilise one or both of the simulation methods: Monte Carlo or Agent-Based. The results will be almost instantaneous but to understand them we will have to make an accurate analysis using statistical procedures. Now, the program must take the correct decision based on the previous outcome, and implement it. Our data center must notice that we are in another state than before and it must refresh its own information and also share the new condition to our supply chain partners. This is how the loop is constructed. One of the goals of this method is that the process will be almost instantaneous and autonomic; just using the human help when anomalies happen.

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## 6 Conclusions and Outlook

Thanks to this thesis we have been able to start to discover how to integrate together three elements of logistics that did not appear to have any relationship beforehand. These three topics (Supply Chain Risk Management, real-time data and simulation tools) have become a key issue for every enterprise, since the boom of the Internet has allowed them to reach their whole potential. But almost nobody has tried to put them together in a framework and utilise them together. I think that in the future there will be more works in the same field as mine.

As we have seen, most of the enterprises do not have a mature supply chain and few work really cohesively with their partners. The framework developed must seem impossible for the main part of them, but with the fast development of the software and the increase preoccupation for the control of all the product cycle, it won't be strange if in few years it is a common tool in the business field.

We have also seen that that collaboration between partners was a key factor for all of the managers of the companies. A single failure or a breakdown can cause the loss of the big part of the business for a company (like in the example of Ericsson's crisis in 2000) and ultimately their bankruptcy. In the other hand, some enterprises are able to take advantage of these factors, anticipating to them, seeing their causes, their potential damage and the better way to elude the negative effects.

The data procurement and integration is more complicated than we commonly think. It requires different stages that have been explained in-depth, from the time we get them until the time we can make decisions using the information that they bring. New technologies like Big Data and Cloud Computing help us to capture, storage, transfer, analyse and visualise the data. They allow us to use our data more flexible, adapting their capabilities to our problem, so that we can use them to their greatest potential.

Simulations methods like Monte Carlo and Agent-Based need to become more present in today's companies; it is a perfect tool to anticipate events. Monte Carlo was originally developed for physics and Agent-Based for social science, but nowadays their purpose can be used for other purposes, such as in a Supply Chain Risk Management scope.

Finally, I would like to say that as an engineering student I have learned that the perfection is a goal that we will never obtain but we will always have to pursue. This paper has been a constant challenge for me for several reasons, chiefly from the lack of connected information of the three issues that make the development of the framework very hard. Since I started my studies in industrial engineering, I always have found logistics interesting but it has never been my specialty. And finally, writing and studying for this paper in a language that is not native to me has been a great challenge.

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