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Supply Chains and disruptive events: an Inventory Management System perspective

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Summary

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INTRODUCTION

This study is based on the analysis of the most popular and widely used inventory management systems. In particular, the focus is on their strengths and weaknesses when they are adopted by a company operating in an unstable environment, in which sudden adverse events may potentially disrupt its supply chain.

The driving motivation behind the exploration of this topic is mainly related to the recognition that in the current historical period, as has been largely demonstrated by the serious implications of the spread of the Covid-19 pandemic, it is no longer possible for a company to operate without taking into consideration what consequences a disruptive event might have on its business and consequently to wonder whether its business model is robust enough. Whereupon, adverse events resulting in an interruption of the normal functioning of supply chains are in recent years increasingly a source of interest for scholars from multiple perspectives, ranging from their prediction to the ways to recover quickly after their occurrence. The growing enthusiasm about the topic can be mainly linked to the phenomenon of globalization, which has brought cost advantages to many companies but at the same time it has exposed them to greater risks and weaknesses.

The purpose of this research is then to further spur companies to look not only at cost convenience but also at the characteristics related to the inventory management system that they choose, inasmuch this strategic decision is one of the several factors affecting a firm's resilience and robustness to sudden adverse events.

For this reason, after introducing what is meant by disruptive events and what may be their effects on a supply chain, three different main approaches to warehouse management will be considered: MRP, DDMRP and lean production. At first, they will be compared with each other from a theoretical point of view, highlighting their key features with a focus on whether or not they are able to face disruptive events effectively.

Afterwards, throughout the analysis of two emblematic real case studies, related in particular to the current semiconductor components shortage that has caused widespread problems for companies operating in different industries and to the challenges imposed to the Japanese carmaker Nissan due to the introduction of Brexit, concepts previously mentioned with respect to the Lean approach will be further investigated.

Finally, thanks to the use of analytical techniques applied to one of the previously exposed real cases, a decision tree model and the subsequent analysis of the resulting alternative scenarios will be proposed, investigating what would be the possible different outcomes of those situations in the case in which it has been followed either a lean production method or the logic of MRP.

The aim of this final stage of research is then to examine the behaviour of these different types of inventory management systems also from an analytical point of view, trying to reach some useful insights for a company dealing with today's challenging environment.

CHAPTER 1: Supply Chain Disruptions

For the purpose of this thesis it results essential to provide an initial definition of the wide concept of supply chain disruptions and in which ways the disruptive events causing them may be categorized. This will be done in order to better frame the problem relating to this issue and to introduce the context in which the subsequent analysis contained in this document will take place.

In the first section of this chapter many specific terms will be briefly presented to clarify some relevant concepts in the context dealt with, followed by a first categorization of disruptive events divided according to their likelihood of occurrence and the estimated extent of their impact on companies.

In the following section, a quick overview of the main perspectives according to which the existing scientific literature faces and analyzes the topic of supply chain disruptions will be presented. It will be also underlined which is instead the chosen perspective adopted in this specific research, highlighting the reasons why it results important to take into consideration this point of view as well as those prevalent in the literature to date.

The third subchapter introduces another way of categorizing adverse events that can have significant effects on supply chains. There is also a brief description of some of the major and well-known events that in recent times have adversely impacted the supply chain of a large number of companies, splitted in accordance with the relative group of disruptions these events belong to. The choice to present them divided according to the nature of their origins has been made in order to provide a useful introductive framework for when, in the third chapter, emblematic case studies belonging to specific groups of disruptive events useful to exhibit the main object of this thesis will be deeply analyzed. Moreover, this categorization is also worthwhile to provide a broad overview of which and how many events can be called disruptive, underlining how they are multiform phenomena.

Finally, in the concluding section of the present chapter, there is an in-depth analysis of the possible effects that can occur on supply chains. However, it is always taken into account that each company has its own peculiarities and that each adverse event belonging to different groups can have very varied impacts. An absolutely negative event for one company may turn into a unique opportunity for a different one.

1.1 Main concepts

According to a basic but well-formulated definition of supply chain, it "*refers to processes that move information and material to and from the manufacturing and service process of the firm. These include the logistics processes that physically move products and the warehousing and storage processes that position products for quick delivery to the customer. Supply chain in this context refers to providing products and service to plants and warehouses at the input end and also the supply of products and service to the customer on the output end of the supply chain*" (Jacobs & Chase, 2020, p. 4)

It can also be considered as a complex network of relationships between different types of actors involved in various steps of the production process, each with their own interests while sharing a common concern for the protection of flow of goods and information along this connected system, allowing its proper functioning. This is a delicate task that supply chain managers are called upon to deal with, configuring proper supply chain management as a fundamental activity within a company.

But this fragile balance is severely tested when a certain event suddenly hits the supply chain causing a disruption of variable degree along it, negatively impacting its performance compared to the previous situation.

Relying on the Cambridge Business English Dictionary, a disruption can be defined as "*an interruption in the usual way that a system, process, or event works*" (2021). Consequently, an adequate definition of a supply chain disruptions may be "*unplanned and unanticipated events that disrupt the normal flow of goods and materials within a supply chain*" (Craighead et al., 2007, p. 132).

The analogy widely used in the past to indicate this type of adverse situation was the one of "the broken link in a chain" and in those days it worked well. It can be easily observed, however, that in today's times supply networks have become increasingly complex and therefore seldom as straightforward as they were in the past.

Nowadays it seems more appropriate to think about supply chain coordination as gears in a big machine, which need meshing at the same time. According to this more fitting analogy, any disruption would therefore make everything stop simultaneously: the "wrench in the works", as the common saying.

In this adverse scenario, the primary goal of every affected company is of course to return as quickly as possible to the situation present before the disruptive event has occurred, thus coming back to hear the supply chain hum like a well-oiled machine. This fundamental challenge is faced by supply chain disruption management, according to various steps that will be briefly presented in the final section of this chapter.

Going back one step, it seems also essential to underline a concept that can be effectively expressed through the words of Pliny the Elder, even if obviously in this case the context in which they are used is totally different from the original one. "*In these matters, the only certainty is that nothing is certain*" wrote centuries ago the famous Roman philosopher, a statement that takes on a different meaning when referring to today's supply chains. The global environment in which most supply chains operate today is in fact undeniably pervaded by a high level of uncertainty, which requires companies to carefully evaluate the riskiness of the supply chain strategies they intend to undertake and those already in place.

Jacob F. R. and Chase R. B. in their book "*Operation and Supply Chain Management*" (2020) define supply chain risk as "*the likelihood of a disruption that would impact the ability of the company to continuously supply products or services*" (p. 25).

Starting therefore from the assumption that it is therefore impossible to know precisely how and at what moment the supply chain will be tested by an adverse event, what is instead in the hands of managers is to try to consider also the risk in their supply chain strategies, by developing plans to deal effectively with these disruptive events and by attempting to mitigate their impact on their businesses.

The risk of each of these events can be assessed taking into account two fundamental dimensions: the estimated likelihood that each of them will occur and the consequences that would have on the supply chain in case of their occurrence. In this regard, Brown A. and Badurdeen F. (2014) described how a simple risk matrix may be very useful for visually depicting in an effective way these two characteristics of disruptions. In Figure 1 is shown an example of this type of matrix.

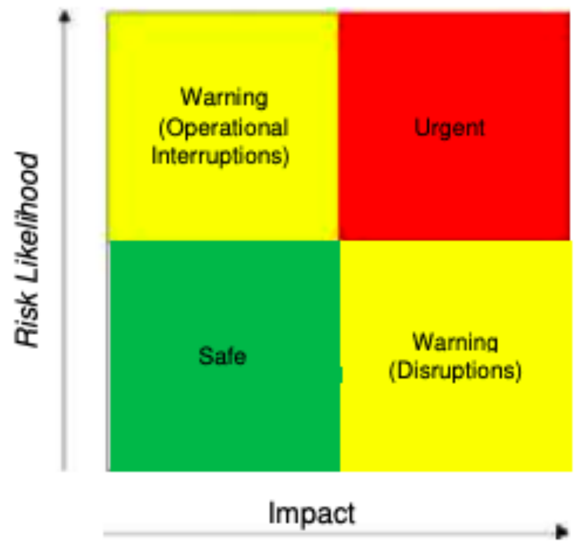


Figure 1: Risk Matrix (Brown A. and Badurdeen F., 2014)

Although it is a communication tool that proves to be very effective, it has a limit that immediately catches the eye: in this matrix, in fact, events with low impact and high probability of occurring are presented with a level of emergency analogous to the one shown for events with high impact and low probability. This schematization could therefore be misleading, since from a manager's point of view it is undoubtedly different to try to manage and cope with a risk of the first type and a risk that belongs instead to the second one.

In the following sections there will be an attempt to shed more light on the reasons for which this last statement was made, also pointing out what kind of risky events are chosen to be at the center of the attention in this thesis and what are the underlying motivations for this decision.

The disruptive events that may have potential negative effects on the supply chain will in fact be divided according to the first criterion mentioned above, which is widely used in the literature that focuses on this topic: high likelihood and low impact events, the also called common or operational disruptions, and low likelihood and high impact events, which can be considered the disruptive events par excellence.

1.1.1. High Likelihood - Low Impact events: Common Disruptions

The category of the common disruptions (also known as the operational ones) includes all the types of events that tend to occur with a certain degree of frequency and end up affecting the supply chain, although they usually do not have a very serious impact on it. These risks should certainly be avoided, as they always bring problems to normal functioning, but when they happen fortunately do not lead to a total paralysis of the supply chain.

Just to mention some examples of this wide group, may be considered common disruptions for instance the possibility of a batch of defective or poor-quality products, forecast errors, a poor supplier performance, a machinery that suddenly jams, transportation breakdowns, etc.

These kinds of events are associated specifically with the day-to-day management of the supply chain, which may be commonly addressed with the help of semi-automated Decision Support Systems and with the use, for example, of safety lead time or safety stocks, or even with additional overtime or by implementing controls, thus allowing the company to not be forced to invest too much of its scarce resources in defending itself against these operational disruptions. However, they should not be taken lightly, as even if they are low impact events, they happen with a high frequency, consequently their combination with each other might also result in an overall huge impact on companies.

Due to their characteristic of occurring with quite high probability, predictive models with an acceptable degree of reliability can be constructed for this group of disruptive events. In fact, people dealing with the supply chain risk management are able to estimate with a reasonable level of accuracy what is the probability that a given event will occur undermining the normal functioning of the supply chain under consideration, thus allowing them to be better prepared to respond to this threat. This estimate is calculated based on historical data collected over the years, which helps risk managers in modeling operational risks. Typically these operational risk models are formulated in a way focused on assessing changes in economic factors such as the expected profit or cost might be. In fact, risk mapping (of which an example has already been presented previously) necessitates the evaluation of the relative frequency of a certain event with respect to the prospected aggregate severity of the loss. Depending on the result of this assessment, some of those risks may be considered acceptable and the related monetary damage deemed a normal cost of doing business. Under certain circumstances, the company may have the opportunity of insuring itself against the expected loss, while in facing other risks this is not possible and it is therefore necessary to plan and to apply specific supply chain strategies to mitigate the damage.

Although for this specific topic there is a very vast literature, which addresses this question from multiple points of view and provides various effective solutions to the problem, it will not be further explored in this research, as it is not its main focus.

1.1.2 Low Likelihood - High Impact events: the Black Swans

The literature has largely focused on finding the best way to minimize the risk of the occurrence of disruptive events in general, trying to prevent in advance their consequences, but the evidence suggests that certain events with potential huge impact on supply chains cannot be forecasted and prevented, even with an accurate risk planning.

In particular, disruptive events belonging to the category characterized by low probability of happening and high level of potential impact can end up influencing, or even drastically changing, a market, an industry, a sector, a company, as they hugely modify the environment within which they are used to exist. In some cases, they immediately impact the source of the critical resources they need to survive and succeed, while in other cases the impact could be indirect, as these adverse events could negatively affect one of the different stakeholders belonging to the same supply chain and due to that having consequent repercussions also on the other partners. This is one of the reasons why in many cases it has been noticed that the impact on a particular company's business is not evident in the immediate aftermath of the event, thus ending up causing a disruptive impact only after a certain period of time.

Since historical data on these rare events are by definition limited or even non-existent, their risk is very difficult to quantify using the aforementioned traditional risk management models. As a result, very often companies are not prepared adequately for the possible impact of these rare events, preferring instead to focus their attention more on the previous risk category, which result easier to manage. In recent years, however, the evidence has highlighted how these events with low probability and high impact are becoming more frequent than ever before, deserving therefore the devotion of at least a part of the company resources in an attempt to avoid or mitigate their effects. But it is not just about companies, in fact, in order to not be caught completely unprepared, also governments and any public and private institution should be more careful in their forecast about rare events.

Among the researchers and scholars who have thoroughly analyzed the subject of these rare events emerges the name of Nassim Nicholas Taleb, currently a finance professor and writer, formerly a Wall Street trader. He was responsible for the popular diffusion of the term "black swan event" to indicate an unpredictable event that goes beyond the normal expectations about a situation and that has potentially very strong consequences (for further information see "*The black swan: the impact of the highly improbable*", Taleb, 2007).

This specific term was not actually coined by Taleb, he borrowed it from an ancient Western belief according to which all swans are white and they can just be white, as up until that time they had been the only ones that could be observable in nature. In 1697, however, a discovery that left everyone stunned took place, turning the tables. In fact, it was the year in which a Dutch explorer named Willem de Vlamingh unexpectedly found that in Australia there were also swans with black plumage. It was a truly unexpected event for zoology. What is therefore astonishing in this story is not the discovery of black swans per se, but how a single observation can in an instant invalidate a generally accepted claim deriving from millennia of confirmatory sightings of swans that are just white. It is also necessary to stress that after this discovery, it seemed more than obvious to the researchers of the time that swans with black plumage must exist, just as it was well known that other species of animals in different colors also existed. Only with a retrospective view then the observations that had been made on other animals seemed to logically imply the hypothesis of the black swan, but only after that the empirical evidence has validated it.

After this introduction to the argument, it is clearly pointed out as the main problem with these types of events is the lack of knowledge linked with these events with the attributes of rare occurrence and very serious consequences. The best thing that can be done to treat these adverse events is then recognizing that they may occur in any form and any moment, and to try to ensure to be prepared to react as best as possible to whatever could happen.

It is also emerged what are, according to Taleb, the three fundamental attributes indispensable in order to call an event a black swan:

1. it has to be an event that is so rare that the relative possibility that it may occur is unknown;
2. when it occurs, it involves an impact that can be considered catastrophic;
3. only with hindsight it is possible to explain it logically, referring it back to a less random event but rather to a more predictable one (although sometimes it is done in a way that is forced and not so useful).

Regarding the last point, it has been noticed in fact that observers of these rare adverse events, recognizing how much they are of great historical importance, are very eager to explain these events after the fact has occurred and speculate on how it could have easily been predicted. What needs to be pointed out is that such retrospective speculation, however, never actually will help to predict any of the future black swans that could happen, as these could be anything, from a war to a natural disaster or a credit crisis.

But the black ones are not the only swans described by Taleb in his famous book published in 2007, which also defined what other two types of swans look like.

"*A grey swan is a highly probable event with three principal characteristics: it is predictable; it carries an impact that can easily cascade; and, after the fact, we concoct an explanation that recognizes the probability of occurrence, but shifts the focus to errors in judgment or some other human form of causation*." (Taleb, 2007) From this statement it emerges as in this second category of disastrous events the main problem that worries Taleb is the great lack of judgment that occurs in the moment in which men face with high probability events that can have a potential cascade effect.

The last swan, the white one, is instead described as "*a highly certain event with three principal characteristics: it is certain; it carries an impact that can easily be estimated; and, after the fact, we concoct an explanation that recognizes the certainty of occurrence, but again, shifts the focus to errors in judgment or some other human form of causation*." (Taleb, 2007). In this case the main related problem to those events is the incompetence and the ineptitude that occur when it comes to high likelihood events and their subsequent effects.

What can be easily noticed and it is also relevant to point out is how this latter category, the white swans, can be traced straightforwardly to the one of the common disruptions that was previously analyzed.

Table 1 summarizes the main features associated with each of the three kinds of swan events.

Denomination	**Black Swan events**	**Grey Swan events**	**White Swan events**
Certainty	Highly Improbable	High Probability	High likelihood
Principal Characteristics	• Unpredictable • Massive impact • After the fact, it is explained to appear less a random and a more predictable event	• Predictable • Impact can easily cascade • After the fact, focus is shifted on errors in judgement or other human form of causation	• Certainty • Impact easily estimated • After the fact, focus is shifted on errors in judgement or other human form of causation

Tab 1: Categorization of the three types of swan events

Returning to the main focus of this section, it is noticed that black swan events can cause tragic damage to an economy, as they can negatively affect both markets and investments.

Throughout history there have been several events that can be labeled as black swans and it has been noted that they can take very different forms. Some well-known examples are the first and second world wars, the drop of the Soviet Union, the rapid increase of Islamic fundamentalism, the 9/11 terrorist attacks, or the impact of the spread of the Internet and the financial crises occurred earlier in 1987 and more recently in 2008. Many scholars believe that even the historical moment in which this research is being written can be considered as a black swan event. Although in many interviews Taleb firmly claims that the spread of a virus around the entire world was a largely predictable event and therefore it should be more correctly labeled as a white swan, the public opinion broadly maintain that the pandemic caused by Covid-19 can be defined as a black swan event, since it meets all the required criteria. Indeed, as Taleb rightly argues, the threat of a virus was well known, but the unpreparedness in which governments around the world were caught in 2020 shows that it was considered as a very anomalous event and that its possibility of occurring was extremely low. It has also had very disastrous consequences, not only for public health but also for the economy. Even the last criterion is met given that only now, as the pandemic has manifested itself, it may be easily explained and people all around the world are wondering why nobody was sufficiently ready for the event.

Therefore, as was highlighted previously, they are highly rare but due to their great impact it is then necessary not to ignore them at all and to take into account the possibility that a black swan event may occur in any time and manifest itself in various forms, therefore trying to plan how to react to their consequences. Evidence has shown that even with the use of robust models a black swan event cannot be prevented, so even relying on standard probability and forecasting tools, as may be for example the standard distribution, may fail to predict them because those kinds of statistics are based on samples of past observations and depend on large population of data, which by definition are never available for extremely rare events. And it is not only a matter of that, because there is also the threat to get the least desirable result using these data extrapolations, inasmuch in this way the vulnerability of the organization to black swans may also potentially increase, ending to propagate the risk and at the same time offer false security. Therefore, the black swan theory has the main function of suggesting that what is not known is much more important than what is known. In fact, all the available knowledge can be used to be prepared for what is conceived as to be every possible eventuality, only to be then proven wrong by a single black swan event.

There are many theories aimed to try to avoid or at least minimize the impact of these events on the supply chains. According to some scholars, for instance, diversification is the key to offering some degree of protection when a black swan event occurs.

The point of view that will instead be adopted in this research is the one which starts with the assumption that black swan events occur inevitably and the only uncertainty in this regard is when and how they will occur. Consequently, companies should also take into account this relevant factor, in addition to the purely economic ones, when deciding which business model is the most convenient to adopt for them and what is the approach to inventory management and planning that allows them to be better prepared for the arrival of these rare catastrophic events.

1.2 Literature overview

The topic of supply chain disruptions is becoming a more and more popular subject of investigation among researchers, experiencing an increasing rate of the amount of relevant literature produced especially in recent years. In fact, even if this is not a new concept and these events have always taken place developing the curiosity of scholars who were interested in studying their effects on companies, in the last decades this topic has acquired more and more importance. The reason is an aggregate of several factors, such as the evident increase in the rate and in the incidence of natural disasters. The most relevant and likely reason, however, can be easily identified in the phenomenon of globalization which has increasingly interested companies in search all around the world of cost advantages in terms of both raw materials and labor. This has determined that supply chains, especially the ones of the companies involved in manufacturing activities, have become increasingly long and stratified over time. In this way, they have undoubtedly gained a competitive advantage over the other firms that did not take the decision of producing and/or obtain supplies mainly abroad, but in this manner they also end up with exposing their supply chains more than before to the risk of sudden interruptions.

Supply chain researchers have then looked at this relevant issue from different points of view, taking into account distinct phases for the management process in case of a disruptive event occurs. In the following two subsections, the two main stages will be illustrated. Figure 2 summarizes these concepts in a progressive time-series profile, distinguishing between pre-event and post-event management.

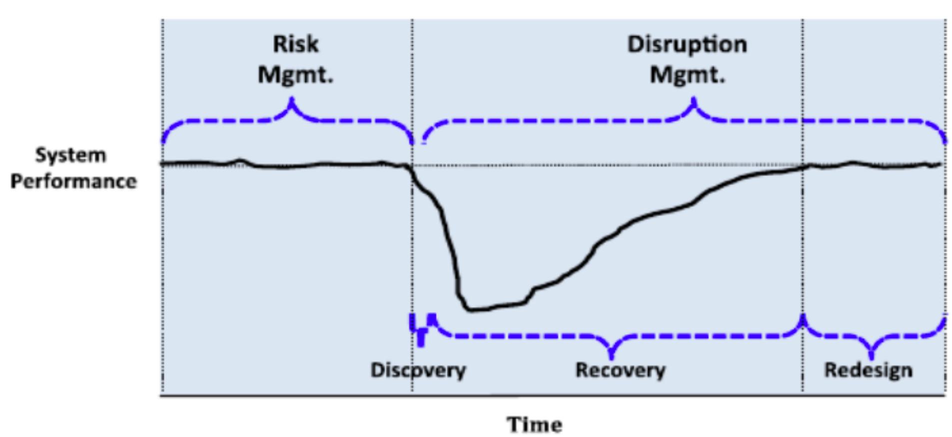


Figure 2: Time-series profile of concepts. Adapted from Sheffi (2005) and Zobel et al. (2012)

1.2.1. Supply Chain Risk Management

One of the most widespread perspectives about this topic is the one focused on the first phase represented in Figure 2, referring to the Supply Chain Risk Management (SCRM). This stage may be seen as the process of taking some strategic measures aimed at identifying, evaluating and trying to mitigate the risk in a specific supply chain. An approach to SCRM to be described as comprehensive requires the accurate management of all categories of risk, for all layers of supply and for all risk likely targets (such as all locations and all suppliers, all the partners and more). From this point of view, a good SCRM result then an essential element to incorporate and integrate into the core functions of a company.

This perspective highlights how crucial it is for an enterprise attempting to understand the right way to make risk planning within the organization increasingly accurate and reliable, trying to predict and prevent disruptive events in an effective way before they could hit businesses with likely undesirable damages.

This branch of literature is thus more concerned with providing guidelines to managers in developing efficient organizational plans, helping them to elaborate an optimal strategy using the right resources to be able to forecast and to be well prepared for potential disruptions that could occur in the future and affect their companies.

Traditional methods for managing possible risks related to the supply chain are based on the construction of predictive models that take into account any potential event that could lead to an interruption of a company's operations and its related supply chain. For each of these events, both their probability of occurrence and the magnitude of their impact are taken into consideration. Hence, thanks to this methodology, the level of risk of the adverse events is quantified, in a way considered sufficiently reliable as it is based on past experience and historical data.

However, this technique can work well only with events belonging to the category of common supply chain disruptions that are categorized as high likelihood of occurrence and low impact on business, while the events with characterized by low probability of happening things are instead different. In fact, the latter are connected by definition with an almost non-existent amount of recorded historical data that are essential to build a meaningful predictive model, making in this way impossible a reliable risk forecast using the aforementioned methodology.

Being able to predict a rare event is therefore a current complex challenge for every organization, which cannot use traditional risk management methods even for these low probability disruptions. And not only that, the evidence has also highlighted how risk managers, regardless of their experience and ability in doing their job, are unable to predict and prevent all the disruptions that can occur due to sudden events, as they sometimes occur unexpected regardless of the accuracy of their risk planning.

1.2.2. Supply Chain Disruption Management

Another substantial part of the literature is instead focused not on how to predict and prevent disruptive events before they hit companies, but on the successive phase represented in Figure 2. In this case, researchers are interested in the Supply Chain Disruption Management phase, hence focusing on defining what may be the most effective actions for a manager to take to be able to respond effectively after a disruption has impacted his company, in order to recover from the shock occurred as quickly and successfully as possible.

The goal is to obtain an evident improvement both in the robustness of the entire supply chain, which indicates the extent of its strength and its ability to remain effective and operational despite any future adverse event that may occur, and of its resilience, which may be seen as the ability of a given system to come back to its initial condition after it has been disturbed.

However, as Macdonald and Corsi (2013) point out, this branch of literature has mainly focused on one at a time of the subcategories into which the process can be broken down, while less attention has been paid to the overarching disruption management process and how the relevant factors characterizing its various sub-phases can affect each other.

As is indicated in Figure 2, these subcategories are named as discovery, recovery and redesign. Discovery refers to the moment in which men perceive the occurrence of the event and become aware of the supply chain disruption. It is only after this discovery that managers can begin to suppress the adverse event and/or initiate the recovery process, so the speed with which it is recognized that a certain event or interruption is taking place is crucial, also because it affects directly the magnitude of the financial impact and the service failures. Just after this point in time, recovery, which is a phase entirely aimed at returning the supply chain to its original state, can begin. Eventually, the hypothesis of a redesign phase of the supply chain after the recovery one can also be evaluated, so as not to simply restore the initial state of the system but also to move it towards a new, and presumably even more desirable, state after the occurrence of the disruption.

1.2.3. A new theoretical perspective

Even if the importance of further developing both in the research focused on the pre-disruption event and the one focused on the post-disruption is not doubted and is still worthwhile, however in this thesis will be emphasized mostly another relevant dimension. Indeed, managers trying to minimize the problems caused by sudden events hitting the correct flow of materials and information along the supply chain should not only take into consideration the traditional approaches that frequently resulted not so efficient as desired. In fact, starting from the assumption that sooner or later every company will incur in some sort of disruptions (despite the considerable efforts may have been made in the elaboration of risk management) it is important also to analyze how the managerial choices originally made about the planning method can be relevant and influencing in the moment in which the disruptive event occurs.

Hence, the scope of this research is to investigate how an internal strategic choice, in this case the specific business model adopted in the company, may influence the severity and the consequences of a disruptive event over a firm and affect also its speed and ability to recover.

Based on the existing available theoretical literature and on some empirical cases, a complete analysis of what may be the advantages and disadvantages of adopting each particular planning method, investigating which among them is capable of better responding to any events that can suddenly hit the company, will be given.

The main goal is to find a way to achieve an improved supply chain robustness throughout a strategy based not only on the traditional management approach but also on the development of the inventory management method, that, if well-chosen and managed, might even permit to

improve the ability of the supply chain to maintain an acceptable (and at the best hypothesis, also high) level of performance also under the effects of a sudden high-impact disruption.
However, before moving on to this analysis that will be done in the following chapters, it is considered of fundamental importance to provide a general overview of the phenomenon in question in the following section that propose a typology of categorization of disruptions and briefly analyze real cases, necessary to better frame the problem of severe events that can affect the supply chain of a company.

1.3 Systematic approach: Disruptions categorized according to their nature

The use of categories to differentiate the potential disruptive events is a common practice of traditional supply chain risk management. A way to distinguish these events one from the other is the one described in the first section, thus taking into account their probability of happening and the expected magnitude of their impact on the supply chain. But that is not the only useful existing partition. Indeed, scholars who studied and analyzed this wide topic have enriched the literature with several tips on how these adverse events can be divided into groups, for instance relying on who they affect, on their likely duration, or on the supply chain echelons they hit.
Moreover, disruptive events are also commonly categorized depending on their nature and this is the approach chosen to be explained in this section. Many of these widespread catalogs are short and concise, as the one proposed by Murphy in 2006, that distinguish only three different groups: internal man-made events (such as the aforementioned operational disruptions), external man-made events (for instance trade barriers) and natural events.
For the purposes of this research it was chosen to adopt the categorization proposed by Pells D. L. (2009), which is more detailed than the Murphy's one. Each group in which Pells divided these adverse events will be examined below, along with briefly discussed emblematic real-life examples of disruptions belonging to each of them, useful to better frame the issue. It does not presume to be a complete and exhaustive list, but it is sufficient to give an overview of the major events that can disrupt and create problems in a supply chain.

Before proceeding, however, it is necessary to emphasize that only in some situations global events affect all types of businesses and all supply chains. Hence it could be pointed out that many of the potentially disruptive events that will be presented below are more likely to occur in some parts of the world than in others, hitting consequently only few companies. But the evidence requires to taking into account also the fact that supply networks are increasingly connected at global level, and therefore it seems prudent to seriously consider their eventuality and probability of impact in any case, regardless their physical more likely location of occurrence.
Furthermore, by analyzing the disruptions that occurred in the past, it can be noticed that several times the events belonging to one specific category are closely linked to another group of turbulent events. Moreover, there are also situations in which one of them can be identified as the cause of another one. It is therefore necessary to pay further attention when trying to repair a disruption that has occurred in the supply chain following a specific event, since there is the possibility that further events will manifest in connection or triggered by the first, so also this risk must be considered to be able to recover the supply chains completely and not just partially.
In addition, it is also emphasized that sometimes the immediately visible impact on companies is not the only one to occur, since in the long term further effects can be seen, causing a disruptive impact only after a certain period of time. This hidden risk is also worthy of consideration.

1.3.1 Extreme Weather and Natural Disasters

Mother Nature does not always prove to be kind and merciful with companies as sometimes it even demonstrates to be the worst nightmare for businesses, particularly when they are caught unprepared and they had been decided in the past to outsource many of their core supply chain functions. It should also be borne in mind that, whether are earthquakes or hurricanes, tsunamis or wildfires, or even floods or blizzards, the episodes occurred in recent years highlight the undeniable evidence that the world is increasingly experiencing more adverse natural events than it has ever seen before. While it is beyond the scope of this thesis to investigate how this fast-paced pace of natural disasters is attributable to the climate change that is taking place, it seems inevitable to at least mention it as a possible influencing factor of it.

What is relevant for the purposes of this analysis is instead that when one of these events occurs, it affects in big ways not only local companies but also larger businesses. In fact, any type of natural disaster almost inevitably affects global supply chains at least in part, as deliveries are postponed or paused, ports are closed, cargo flights are canceled, and supply and demand are unbalanced. In extreme cases, depending on the severity of the circumstances and the overall preparedness surrounding them, some supply chains may even completely come to a halt following one of these events. This often ends up creating a ripple effect, a particular consequence that will be better explained in the following section, as companies in the affected area may be incapable to procure on time the supplies they need or may receive fewer shipments than they were normally used to. And this, obviously, affects in the end the consumer as well. Recovery can be very costly and difficult, as well as time-consuming, for each partner belonging to the affected supply chain.

The first case in point that springs to mind thinking about mother nature complicating things for global supply chains is the recent news of the Suez Canal block aused on March 23, 2021, by the giant container ship Ever Given that ran aground blocking maritime traffic along an essential global artery. This 224,000-ton colossus over 400 meters long is one of the many Ultra Large Container Vessels (ULCVs) that guarantee Europe the arrival of goods and raw materials from Eastern countries and also allow Europe to export its products to Asian markets. It was reported that the ship lost power due to the strong wind and the huge sandstorm that hit that area, thus causing it to deviate off course, in a narrower part of the Canal. While it would seem excluded that the cause is exclusively of these natural events, as a technical problem or human error is also suspected, what is certain is that the strong gusts of wind have further complicated the unbundling of the ship, an operation lasting seven days of uninterrupted effort. The Ever Given is one of the largest ships in the world, with 20.000 containers which have therefore suffered delays in their delivery. But not only matter of that, as during the days of the blockade almost 400 boats carrying goods remained waiting to pass the strategic language of the sea that allows to connect the Mediterranean and the Red Seas.

What is certain is that the long times have affected the destination ports of the many boats that remained at anchor for a week, as the number of docks in ports is limited and working the incoming goods at the same time will overload the terminals. Furthermore, fewer ships unload, fewer ships leave and fewer empty containers return to China to be loaded and shipped again. Supply chains are at the end of the line: in recent months, blank sailings practices (cancellations of calls up to the entire voyage) have exacerbated the shortage of containers when demand has returned to grow as economic activities resume. The result was an exponential increase in container freight costs. Fears that the Suez blockade will drive prices even higher are therefore widespread. About 12% of world trade passes through the Suez Canal and it is estimated that each week of delay means a loss of transport capacity on the transpacific route of 7.6%. It is in this logistics ecosystem already severely weakened by Covid-19 that the Suez accident intervenes. Therefore, the Suez cork is blown, but the bottlenecks still remain.

Another recent example of this type of natural disasters is the 2011 Tohoku earthquake that occurred on March 11 off the coast of the Tohoku region of northern Japan, with its epicenter at sea and subsequent tsunami, whose huge anomalous waves devastated the nearby coasts. It was the most powerful seismic event ever measured in Japan and the fourth worldwide. This disastrous event resulted in estimated costs of over $ 210 billion for Japan and affected supply chains around the entire world. Just to name a few emblematic cases, the well-known car manufacturers Toyota, G.M. and Nissan temporarily closed their factories not only in Japan but also in the United States, as they were unable at that time to both ship and receive the parts needed to continue their production. It goes without saying further that companies that depend on the Japanese's Just-in-Time deliveries have been left in a lurch.

The last symbolic case that will be presented is the one of Hurricane Florence, a tropical storm that hit the eastern United States of America in September 2018, especially pouring in North Carolina. In addition to the large number of victims, also in this case catching up with back deliveries required a great deal of effort for the supply chains that remained involved. As mentioned earlier, the most affected region was North Carolina, where both the Port of Morehead and the Port of Wilmington have experienced significant damages to their warehouses and other surrounding buildings as well as numerous empty containers were pulled down by the hurricane, thus further delaying their reopening for recovery efforts. And not only ports, but road and rail links have also been affected, with the largest trucking disruption caused by floods

recorded along Interstate 95 through the Carolinas. Some of the industries that were hit hardest due to this adverse event included North Carolina's emerging biotech industry, as well as the automotive, textile, pharmaceutical, agricultural and manufacturing sectors.
What needs to be stressed, however, is that many US cities now have safety regulations that require companies located in the territory to be at least somehow fortified against this type of natural disasters or they risk to face high fines due to their non-compliance. In developing nations the situation is quite different, thus requiring further caution because the repercussions of these adverse events can be even worse. But the strategy based on avoiding risks as much as possible is almost always not compatible with the one aimed at keeping business costs low, a widespread approach particularly in those developing countries. In this regard, it can be noted in particular that, despite the evidence suggesting that China is a large hotbed of natural disruptive events, ranging from windstorms and earthquakes to annual floods, numerous suppliers and companies fail to take appropriate precautions to address these types of risks. China in past decades has become a popular source for companies looking for very cheap labor, but it is known that by putting all their eggs just in the Chinese basket they are consequently also opening up to considerable supply chain risks. The threat of a disruption in the supply chain related to a natural disaster in China is particularly alarming as it would have a vast negative and lasting economic impact. This slowdown in the global economy would occur as China is not only a crucial exporter of goods, but also a vital importer of goods. Consequently, this would lead to shortages in countless consumer and industrial products, presumably leading also to inflation and devastating the share price of enterprises.

1.3.2 Manmade Disaster or Disruptions

As anticipated for natural disasters, the globalization of supply chains has led to commercial logistics becoming even more unstable than before and more subject also to the impact of human-made disasters. These man-made disasters can be defined as disasters in which the main or direct cause of a certain emergency is identifiable in human action, which may or may not be deliberate. Anthropogenic disasters can be defined as disasters in which the main or direct cause of a certain emergency is identifiable in human action, which may or may not be deliberate. In fact, man-made events could be involuntary such as accidental spillage of toxic substances or interruptions of nuclear power plants, be caused intentionally such as poisoning or terrorist attacks. It seems relevant to point out that in the logistics literature there are few direct references to issues relating to the impact of man-made disasters on the supply chain. An emblematic example of this type of disruptive events will be analyzed below, which will highlight how many large companies have lost millions of dollars (and in some cases billions) as a result of these events and due to their supply chains that have become increasingly lean, further exposing them to the risks of man-made disasters.

The well-known attacks of 11 September 2001 are often considered by public opinion as the most serious terrorist attacks of the contemporary age, consisting of a series of four coordinated suicide attacks against the United States of America by a group of terrorists belonging to the terrorist organization al Qaeda. On that infamous morning four airliners were hijacked by 19 terrorists and two of them were crashed into the North and South Towers of the World Trade Center, in the Lower Manhattan neighborhood of New York, a plane was instead crashed into the Pentagon, headquarters of the Department of Defense, while the last one crashed in a field in Pennsylvania, following a heroic revolt of the passengers. The attacks killed 2.977 people and injured over 6.000, as well as countless damages for a sum still difficult to estimate.

Dwelling instead on the focus theme of the present research, it clearly emerges as right after the following days after this terrorist attack producers from all over the world have begun to experience major disruptions to the flow of materials in their assembly plants. Toyota for example experienced a lengthy production outage at its manufacturing facility located in Indiana, the Sequoia SUV plant, as one of its suppliers was unable to do its job as it was waiting for steering sensors which were usually shipped by air from Germany, but at that time air traffic was closed. Ford has also experienced how it can be a huge problem having their trucks loaded with many components essential to the production being delayed at the Mexican and Canadian borders, resulting in the intermittent downtime of several of its assembly lines. From these considerations it appears that companies are vulnerable not only to attacks on their assets, but attacks that can affect other elements in their entire ecosystem, such as their suppliers, transport suppliers, customers and communication lines, must also be considered.

Not only Ford and Toyota, but many other manufacturers as well proved to be very vulnerable to transport disruptions as they have previously decided to manage their inventory according to a Just-in-Time logic, which involves holding only the material required for the operation of production for only a few days or even hours. In addition, many American and European companies have, since that disruptive event, reconsidered how wise it is actually to rely on the use of suppliers located overseas. Without doubts offshore suppliers can be much less expensive, but it is still important to take into account that they may require longer delivery times due to their location and that they also may make the company in question more susceptible to possible interruptions in the transport system.

What is also critically important to point out is like these serious disruptions were not caused by the terrorist attack itself, but rather by the response that was given by the US government following the attack: from the closure of the American borders to the complete shutdown of air traffic, as well as the massive evacuation of many buildings across the country.

From this perspective, cooperation between the public and private sectors also becomes of a fundamental importance, thus pushing companies to manage and improve their relations not only with their supply chain partners but also with the local and international governments, in order to ensure that the aims pursued and the interests protected are as much as possible the same for both.

1.3.3 Human Health & Social Factors

Given the historical period in which this document is being written, it is impossible to analyze this specific category of adverse events without naming the Covid-19, an infectious respiratory disease caused by the virus that the scientific community called SARS-CoV-2, which belongs to the coronavirus family. The first confirmed cases of this disease were found in China starting from beginning of 2020, and then it spread all over the world. On March 11, 2020, this virus was labeled by the World Health Organization as a "pandemic", thus underlining how the potential impact of this event could be serious on citizens of every country all around the world.

From companies' points of view, this event completely disrupted much of the way of doing business as they were used to before the spread of the pandemic. In fact, managers have to worry about the possibility that many of their employees can become seriously ill at the same moment, thus causing a lack of staff personnel. But unfortunately is not just a matter of that, because, as in the aforementioned case of the 9/11 attacks, what can lead to significant interruptions in the supply chain are also the new policies implemented by the various governments as response for this specific emergency, adding in this way further perturbations beyond the adverse event itself. In this regard, it is indeed relevant to underlie that the spread of the COVID-19 pandemic has had serious consequences for every company and every sector worldwide and with an unprecedented scale, prompting governments and organizations to implement drastic measures in order to contain the proliferation of the virus. This has inevitably impacted the supply chain and forced consequently companies to review their plans and activities to address these changes.

Examples of these government measures against the spread of the virus are lasting and widespread lockdowns and the diffused restrictions on the movement of people and goods. The first, among other consequences, have also led in many cases to temporary closure of factories with consequent production shortages, while the latter have led to the lack of some transport options (including air and cargo), doubling the average delivery times of companies globally and giving rise to the need to reorganize transit priorities to meet urgent requests.

These, however, are not the only challenges that this pandemic has posed to global supply chains. In fact, there have been sudden and unexpected changes in demand, as the COVID-19 crisis has significantly affected the consumer purchases. During the first phase of lockdown, in fact, consumers have stocked up large stocks of basic necessities with the fear of potential problems in the supply of goods. In the second phase, on the other hand, various factors such as remote work, lower consumer purchasing power and prevention and safety measures caused a sharp drop in demand for certain products and services. This has led to sectors such as fashion to suffer significant drops in demand, while some other categories, such as that of personal care products, have seen growth never seen before. As a result of this consumer trend, some companies have decided to convert their production to meet the demand for personal protective equipment and medical supplies.

Furthermore, the drop-in demand, regardless of the typology of product sold, was mainly recorded through the traditional channels, i.e. physical stores. Consequently, the importance of buying on the internet has grown enormously, as in recent months the most marked change in consumer purchasing habits has been the transition from in-person purchases to e-commerce. The pandemic has therefore highlighted the need to rethink traditional supply chain models, in order to optimally face unprecedented market challenges and opportunities and to be able to meet the needs that have emerged with this "New normal", also preparing to be ready to face future crises.

1.3.4 Significant Economic Events

This category of destructive events is inextricably linked to the economic crises that have occurred over the years, which have always been followed by great repercussions in global supply chains. Impossible to start parsing this event group without naming the global economic crisis of 2008, that was a financial crisis characterized by enormous problems related to liquidity and solvency, both at the level of banks and States, and also by a lack of credit for businesses. Its origins seem to derive from the deflation of price bubbles, including the well-known American housing bubble, and from the significant losses suffered by financial institutions caused by the subprime loans crisis. This financial crisis has spread globally, causing a drastic drop in stock market prices and the bankruptcy of several financial institutions. The States therefore had to intervene to save many banks, thus causing a public debt crisis, as happened for example in Iceland and Ireland. It has also caused a recession that affects the entire planet, which has heavily committed public finances to solve this crisis, ending up further widening the public deficit in many countries, let alone the significant and widespread effects it has had on many organizations of various sizes all around the world. Unfortunately, this was not the first and only financial crisis that has created serious widespread problems, as the history has recorded many financial crisis starting from the one occurred in 1637 called the "tulip bubble", considered the first financial crisis triggered by the use of financial instruments for speculative purposes and that ended up by involving the entire European economic system. Moreover, it can be also remembered the Asian crisis of 1997 which ended up devastating the economies of many countries located in the Southeast Asian region, as also happened later in 2002 with the global collapse of financial markets.

Many of these economic crises have been, and still are, very difficult to predict. Nevertheless, more localized events and trends may turn out to be more predictable and some of them also may be a consequence of disruptive actions of various types. In fact, a huge problem to take into account is that an economic crisis can be also triggered by a disruptive event belonging to another category among those listed in this section or by other major changes.

1.3.5 Disruptive Governmental or Political Changes

Government changes that take place in a specific country can have enormous repercussions not only on local companies but also internationally, especially if they occur in key nations such as the United States. They can also significantly affect some, or even all, existing industries and even ending up by triggering ripple effects along supply chains worldwide.

In this regard, the elections that took place in 2016 of US President Donald J. Trump can be mentioned as an emblematic case of this kind of disruptive event. This is because, since his designation, the economic policies put in place by this Republican Party exponent have been consistent with his conservatism approach. Similarly as Regan did before him, in fact, Donald Trump focused his attention on massive tax cuts, thus offering an important fiscal stimulus to the American citizens and companies, then he increased also the public spending and the deregulation, for example by dismantling Obama's environmental measures, leading in this way companies to be forced to comply with less stringent ecological standards.

Furthermore, this president stood out for his strong protectionist approach and his rejection for free trade. These latter points have particularly affected global supply chain operations depending specifically on cross-border trade with the United States or on the free movement of goods and raw materials across its borders. In fact, President Trump has always denigrated pre-existing trade agreements and the US trade deficit in particular with China and other trading partners. Moreover, since his election, he has always shown a marked propensity towards the erection of trade barriers aimed at making difficult to import goods into the United States.

While this summary of the major policies enacted during Donald Trump's tenure is short and concise, it is in any case able to illustrate emblematically how a single government change can impact supply chains involving companies from different countries, which, in this specific case, were suddenly forced to deal with the protectionist approach that was implemented by this US president.

Another recent case of political change that has had significant consequences on supply chains is the 2021 coup in Myanmar, carried out by the Burmese armed forces on the morning of February 1 to overthrow the regularly elected government of Aung San Suu Kyi, who was arrested along with other leaders of the ruling party.

In the days following the coup, peaceful demonstrations followed in Myanmar, which however were severely repressed by the police and which led to the declaration of martial law in a large part of the country. National civil turmoil erupted resulting in delays in major container terminals, with drivers and customs personnel joining the protests. Moreover, daily demonstrations against the present regime, arrests of both protesters and journalists, curfews, Internet blackouts, disruption of banking systems and factory closures were combined to further overturn supply chains. The main port is congested and full, with import and export cargoes pending and shipping companies suspending cargo bookings and closed local offices. Not only air and sea connections are limited, but due to roadblocks also for trucks the transportation of goods within the country is challenging and Myanmar's factories operate with limited staff, resulting in further production and delivery delays.

This coup is therefore a disruptive event that has consequences not only on companies based in Myanmar, but also on the international ones. The famous Sweden's giant fashion retailer H&M, for instance, not only suffered for the aforementioned delays in production and deliveries, but was so shocked by the huge use of force against protesters in Myanmar to decide to pause placing its orders in the country at least for the moment. And this is not the only company that is thinking to punish directly or indirectly the shaming behavior of the illegitimate government in Myanmar.

1.3.6 International Geo-Political Changes

While probably not the first source of disruptive events that comes to mind, international affairs, and especially international relations among and between countries, could also heavily impact the normal flow of materials and information along supply chains. In fact, many stipulated treaties, international agreements and general relations can directly or indirectly influence many industries and companies belonging to the involved states and beyond. The impact of these events can be also significant, especially if some part of the supply chain ends up stalling or if a radical change occurs hitting them.

US-China relations, which have long been fraught with arduous challenges and full of uncertainty, can be taken as an example. As the recent summits between the two countries have pointed out, their relationship will be defined on the basis of a series of different fronts, ranging mainly from trade, to environmental issues and to potential threats to financial stability, also including an investigation into the outbreak of the Covid-19 pandemic.

Yet the aforementioned coup in Myanmar, in which the internal protest movement is further strengthened and more repressions are likely, increasing in this way the risk of economic collapse, represents the first foreign policy challenge for President Biden and will eventually take over the strategic position of his new administration. The future of Myanmar is therefore evidently poised and, in trying to understand if the international community can really help to reverse the situation, it is also necessary to keep in mind that in this context is China that has more power than any other international actor. However, even the latter is not omnipotent: it is trying to protect itself, waiting to see how events will unfold and trying to remain the party that everyone else needs. It is evident, however, how the Burmese military needs China's support both for the economy and to acquire a minimum of legitimacy, despite the fact that Myanmar citizens are particularly wary and tired of Chinese influence. The country, for example, is seen increasingly as a safe haven for many Chinese illicit industries. China relies on Myanmar also for crucial imports, so it is very unlikely that it will tolerate the failure of this state of growing strategic importance. On the other side, the goal of the US government is certainly to restore democracy in the country, protecting and supporting dialogue between different groups opposed to military rule, promoting dignity for the victims of the most heinous violations of human rights. The long-term future of Myanmar therefore depends on many elements in which the complex relationship between the United States and China will surely play a central role.

These delicate international relations with an uncertain outcome bring with them an equally uncertain destiny for all the supply chains that have to do with the abovementioned countries, whose may only try to be ready as much as possible for any eventual sudden disruptions along their networks.

1.3.7 New Technology – Technological Development

Even a sudden technological change could have huge consequences on some supply chains. For example, it could suddenly make a product or system obsolete, sometimes also resulting in an obligation to redesign them from the beginning, or even changing completely the way logistics functions are conceived now, thus putting many companies in difficulty.

However, it must be emphasized that a technological breakthrough could also end in a positive way for some companies, for example by leading to a dramatic improvement in their results or significantly reducing costs in some parts of the supply chain, as may be the introduction of new cheaper and stronger materials.

It is absolutely certain that many disruptive new technologies will be introduced in the near future and that they will eventually affect many sectors and companies. Some of these technological evolutions that will involve supply chains are actually foreseeable already now (such as, for example, the massive increase in the use of artificial intelligence in production phases and the possibility of increasingly use of 3-D printing with its potential future impact on logistics) while others will arrive unexpectedly in the future, resulting in an advantage for some companies while others will prove to be extremely vulnerable.

1.3.8 Industry or Market Changes or Disruptions

In all sectors and markets, events that may be considered as disruptive occur on a regular basis. Popular examples of this type of changes include large acquisitions or also mergers, declarations of bankruptcies, drafting of major contracts, new partnerships, corporate reorganizations or restructurings.

An interesting case could be for example that of the Walt Disney Corporation which acquired Marvel Entertainment in 2009 for more than 4 billion dollars. While from an outside observer's point of view, this just seems more entertainment, with Disney seeing its collection of iconic characters vastly expanding even more than before, within this field instead the problem arisen consequently was very great. In fact, we can think about all the stakeholders who deal with the related software or video games, or videos and films, or even other related products and services, who have experienced a real turning point in that sector following that acquisition.

Looking at the issue of these specific strategic decisions from a more general point of view, the companies around the world that are attracted by the idea of a merger or of an acquisition are uncountable, regardless of their size and the specific sector in which they operate. Their main motivations for this attractiveness derive from different objectives which, depending obviously on the individual case, are aimed at an expected increase in revenues, at the possibility of penetrating new markets, at obtaining a reduction in their overall costs, at increasing their ability to protect the market from new entrants, etc. Nonetheless, when considering a merger or an acquisition, companies sometimes overlook and underestimate the likely consequences that these strategic decisions may have on the supply chain, although they can also result to be very significant in terms of cost as well as of service levels.

For this reason, it would be preferable that the strategic decisions preceding these corporate transformations also take into account the problems related to the creation of new value for all the stakeholders belonging to the new supply chain. This is in order to take care of making the new supply chain more efficient than the current one, as well as potential problems related to the newly formed system and the optimization of new supply chains, gaining in this way more positive than potentially negative effects from this event.

1.3.9 Legal & Regulatory Changes

Finally, even a new legislation enacted or the arising of a legal problem can create a widespread disruptive effect on companies and even on entire sectors. In particular, when these regulations result somehow linked to trade, they will likely end up hitting also supply chains. In fact, changes to certain laws can impact companies and shareholders belonging to the same supply chain and can also hit possibly their business and profits.

If, for example, increasing environmental regulations at international level are taken into account, it can be seen how these changes can impact hugely the supply chain by for instance cutting a link from the route or by prohibiting a specific travel area, forcing companies that are found unprepared to find a quick alternative for that.

Import and export regulations may be a threat for supply networks in the same way. A case in point is the Brexit issue, with the UK and the European Union reaching an agreement on 24 December 2020 avoiding in this way the disruptive results of a no-deal and signing a temporary EU-UK Trade and Cooperation Agreement (TCA) which will define their relationships in the future. This TCA agreement does contain some significant free trade agreements, but it still affects the supply chain sector. In fact, no tariffs or quotas will be imposed on goods imported and exported between the UK and the EU but this is only applicable to goods that prove to satisfy the rules of origin of the aforementioned agreement. In other words, this only affects goods that come from the UK or the EU. The companies that will be charged import duties in the end are those that ship from a third country, such as China or the United States. From these considerations, it follows that companies will have to evaluate their supply chains in a more meticulous way, understanding the origin of each part of their products and what are their financial implications. And is not only a matter of that, because despite this lack of tariffs, firms will still be required to complete additional customs documents and declarations when they decide to trade across the UK and European borders. The reason is that there has been no mutual recognition of standards and guarantees among them, risking in this way to end up causing additional delays in the freight transport process and potentially even rapidly increasing costs. From this point of view it seems inevitable to think that the disruptive event represented by this agreement will bring enormous inconvenience to supply chains in any case, notwithstanding it is officially portrayed as a free trade pact.

1.4 Impacts and effects of Supply Chain disruptions

When it comes to supply chain impact, it must be taken into account that it is only possible to do this in an approximate way as most companies have found it very difficult to measure precisely what the effects of disruptions in their supply chain have been. Moreover, the

empirical evidence remains very limited, although many surveys and case studies have been done and analyzed over the years attempting to quantify the impact of disruptions.
Consequently, it is also difficult to find a general rule to quantify the severity of the impact, as the repercussions are highly individual for each company even if taking into account the same disruptive event. This is because the impact is determined by many different factors, depending for instance on the type of industry and the sector in which the individual enterprise operates, on where is its specific location, on the length of its supply chain, on the relative impact that a certain event had on its supply chain partners, etc.

Trying to analyze the question broadly, however, it can be argued that the impact on supply chain of disruptive events commonly includes a decrease in sales and/or an increase in costs, from which many companies are destined to never recover.

A decrease in sales can occur due to the failure to satisfy the demand of the final customer. This can happen as a result of prolonged unavailability of the requested product, of orders that have only been partially fulfilled in terms of quantity and of late deliveries. These complications inevitably lead to complaints from many customers, to serious damages to both the image and the reputation of the brand and the consequent loss of many customers.

The financial consequences of a disruption can therefore be described as lower-level of sales, a dropping in revenues and a reduction in the market share, compared to the previous period.

As mentioned above, higher-than-average costs can also occur for a company due to a variety of factors related to the disruption. Some of these impacting elements may be, for instance, the cost of using alternative means of transport to deliver the products, higher administrative costs for the management of back orders, costs needed to reschedule production following out of stock of some resources, or costs to be incurred due to lower productivity. Companies may also incur additional costs due to penalties for violation of contracts and failure to comply with the legal or regulatory requirements required by local and international authorities.

Overall, the decrease in sales and the increase in costs in the end lead to an even huge loss of profitability and a drop in the value of the company.

A final consideration is that the impact caused by an event can affect any logistics function belonging to supply chain, starting with the supplier flow (both materials and information), warehousing, distribution or transportation. After hitting one of them, the impact then could spread along the entire supply chain, sometimes also giving rise to one of two effects that will be analyzed below. In fact, also due to the aforementioned problem of the wide geographical diversification and the large number of levels and stakeholders often involved, a problem localized in a specific layer of the supply chain could turn out to be not only a local problem, but to a broader one, ending up affecting many, or even all, segments of the supply chain and the final customer. Therefore, perturbations originating in a specific point of the network have the potential to be transferred also to the preceding and the following levels of a supply chain with probable amplification effects.

1.4.1 The Bullwhip effect

The bullwhip effect is doubtless the most known supply chain amplification effect and relates to operational dynamics. This effect is mainly caused by sudden changes in customer demand that can end up propagating through the entire supply chain, amplifying in dimensions as the change passes to adjacent levels, as is shown in Figure 3. The motivation behind the choice of this particular name is precisely because a small change in demand may be enough to cause a massive snap along the entire supply chain, indicating that among its partners there is a lack of synchronization causing sudden oscillations in the orders.

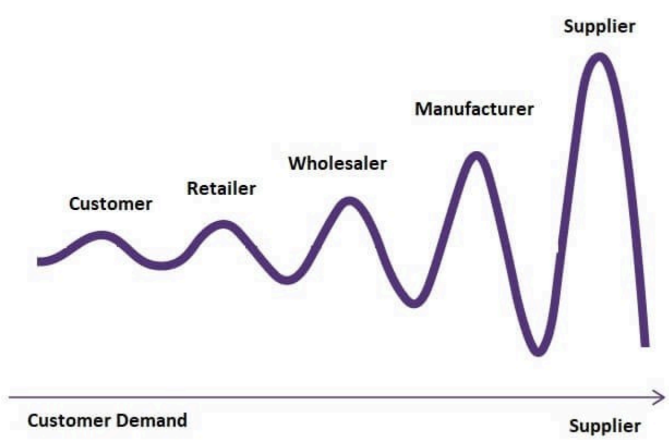


Figure 3: A simply representation of the Bullwhip effect along supply chain.

The bullwhip effect interested a lot of scholars and it was widely studied in the literature especially over the past decades with regards to operational risks linked to the aforementioned

high probability and low impact events (that in this document are called common disruptions), such as sudden fluctuations in customer demand. In fact, the major factors that may trigger this effect can be found for instance in batch ordering, games of shortages, promotions and a lack of transparency in information related to demand, as well as events such as Covid-19 pandemic which led to sudden changes in consumer purchases.
However, it is important to highlight the fact that the bullwhip effect is effective in describing only one type of disruption, the one that may occur on the demand side.
For a more detailed discussion about this phenomenon, the next chapter will be more comprehensive.

1.4.2 The Ripple effect

As has been stressed several times, the fact that supply chains have become increasingly complex and interdependent even on a global level makes them more vulnerable to any adverse events that can therefore create disruptions that in turn may originate a sort of snowball or domino effect, affecting seriously all related supply chain tiers. This type of propagation that amplifies the impact of disruptions is widely referred to in the literature as ripple effect.
This kind of effect is related mainly to the structure dynamics and can be caused by any kind of disruption in supply chains and not just common ones as the bullwhip effect.
In fact, the ripple effect takes into account the fact that a disruption can occur both upstream, due to interruptions on the supply side (such as lack of production or a supply failure, problems with poor product quality, sudden limitations of resources) and downstream, originate instead from unexpected demand or financial, legal and regulatory changes in the markets of reference.
An example of an upstream interruption can be for instance the case of a hypothetical supplier who has already produced some components with very damaging properties for the environment, which are however supplied to the next level of the supply chain and then to the level still late. Here, such harmful component would have to be first suspended and then recalled, resulting thereby in delays for the entire supply chain of the final product.
What should be emphasized is that the ripple effect is able even to describe the effects of the amplification and propagation along the supply chain of very rare adverse events, whose

consequences may be also much more critical than those of the bullwhip effect. The frequency of disruption linked to these events, which previously referred to with the term black swans, is usually much lower, but the impact on companies' performance is much higher than that of the previous analyzed effect.

In fact, the ripple effect often has a massive impact on the performance of the entire supply chain, on its capacity to deliver the product to the final customer and, consequently, on the survival of its related network of firms.

In Tab 2 the concepts that have been analyzed in the last subsections are summarized and schematized.

Feature	Ripple-Effect	Bullwhip-Effect
Risks	Disruptions (e.g., a plant explosion)	Operational (e.g., demand fluctuation)
Affected areas	Structures and critical parameters (like lead-time and inventory)	Critical parameters like lost sales
Recovery	Middle- and long-term; coordination efforts and investments	Short-term coordination to balance demand and supply
Affected Performance	Output performance like annual revenues	Current performance like daily stock-out/overage costs

Tab 2: Ripple effect and Bullwhip effect. Ivanov, D., Dolgui, A. and Sokolov, B. (2015)

CHAPTER 2: Inventory Management Systems comparison

In the previous chapter, it was explained in detail how vast and heterogeneous is the collections of events that may affect companies and the normal functioning of related supply chains even with very serious effects, since, depending on the case, the impact of these phenomena on a single firm may have repercussions also on the rest of their supply network.

Moreover, a clear distinction has been proposed between high likelihood - low impact events (commonly called operational risks) which can be predicted and handled quite efficiently by the risk managers also thanks to the use of the aforementioned decision support systems, and low likelihood - high impact events, which are the focus of this analysis and are usually instead trickier to deal with.

Furthermore, it was illustrated that often there is also a function within companies, called disruption management, that deals specifically with understanding what may be the most effective way to react in the moments following the impact on the organization of any type of adverse event, in order to recover as quickly as possible from the shock experienced.

In this way, it was then highlighted how these topics have been extensively studied in the existing literature.

On the other hand, what is less taken into consideration by scholars of the subject, and which instead constitutes the center of attention of this thesis, are the consequences related to the choice made regarding the type of inventory management system adopted by the company. In fact, the evidence points out how this may be a very crucial factor having a huge impact on the ability of an organization to respond more or less promptly than the others when a disruptive event hits its supply chain, even if it is obviously impossible to propose a magic comprehensive recipe able to fully avoid the unpleasant effects of these phenomena on any type of business.

Nonetheless, in the course of this chapter it will instead be emphasized which are those likely outcomes in which a company may incur when it is facing negative impact events, differing due to the specific inventory system chosen.

The purpose of this section is therefore simply to highlight some aspects that are sometimes not considered enough in this adoption, thus allowing companies to choose this key aspect of their

business model more consciously, taking also into account the robustness and resilience to adverse events that one approach can provide more than another.
Undoubtedly, in any case the selection of the approach to inventory management of a given company should be made bearing also in mind many other factors, including for example the product or service it deals with, the industry to which it belongs, the convenience from the economic side, the reference markets and the prevalent culture of its country of origin. In this regard, it also seems important to underline that this research is conducted with specific reference to the supply chains of manufacturing companies, as the functioning of the service ones is different under many aspects that will not be taken into account in these circumstances.
To achieve the aforementioned goal, in the following sections three different types of inventory management systems will be deeply examined, composing a non-exhaustive list that analyzes two opposite approaches, the MRP and the lean production, and one that can be considered as an intermediate between them, the innovative DDMRP. In this chapter, they will be described in their major strengths and weaknesses, referring in particular to their influence in the recovery ability after a disruptive event of companies that adopted them. Finally, a brief summary of the key points that emerged from the comparison between them will be proposed.
It should be noticed that, starting from now, only low likelihood - high impact events will be indicated in the discussion with the name of disruptive events, which are the ones that even the best supply chain risk managers struggle to predict concerning both their arrival and consequences.
Before starting this analysis, it seems also fundamental to propose a general definition about the topic dealing with the techniques used to manage inventory inside a company.
In this specific section of the present chapter it will also be emphasized the reason why the choice of the most suitable inventory management system for every single company is inevitably one of the key decisions that result very crucial to obtain a successful corporation business model. In fact, both the advantages and costs of maintaining an inventory inside the company will be emphasized, highlighting in this way that even a just-in-time approach actually needs to keep an inventory, and that what changes is only the logic behind it.

2.1. Inventory Management: definition and general considerations

Inventory is a term that basically indicates the stock of each resource and item that is used within a firm in its production processes. From the organization point of view, it may also be seen as invested money, since it can be essentially assimilated to it. (Jacobs & Chase, 2020)

Inventory management can be concisely described as a set of activities carried out within a company with the common aim to minimize the inventory costs, while maintaining an adequate supply of goods able to satisfy customer needs.

Since a company's inventory investments represent a significant part of its total fixed assets, inventory decisions inevitably have a great impact on physical distribution costs and the level of service provided to the customers. In particular, when a company does not have adequate stocks is unavoidable that stock outages occur, resulting almost surely in a huge loss of customers and consequently in a decrease in its turnover; the other way round, when a company has excess stocks or a low turnover of the same, automatically costs increase, as do the risks of product obsolescence, as well as those related to the storage of goods in the warehouse.

Inventory management is then a process that includes the processing of raw materials with the production of products and then the ordering, storage and sale of the finished article.

Knowing when to replenish inventory, how much to buy or produce, what price to pay and therefore at what price to sell result then to be a very complex process for the company.

Small businesses track their inventory manually by determining the quantities to be reordered that are at risk of breaking using an Excel spreadsheet. Larger companies, on the other hand, use specialized software for inventory management.

It can therefore be asserted that almost all the companies keep the inventory, even if according to the different approach chosen a different scheme of warehouse is required, and when it is well managed it brings different advantages to the company.

In fact, as pointed out by Jacobs and Chase (2020) it may serve to various purposes and the main reasons for keeping it can be summarized as follows:

1. To maintain the flexibility in operations. In fact, supplying materials to a work center permits it to be independent in its operations. Furthermore, a high degree of

independence of the workstations is desirable also when it comes to the assembly lines. In concrete, shall be taken into account that the time necessary to complete identical operations will vary from unit to unit, it follows that it is very useful to have a multiple part cushion within each workstation so that shorter run times potentially might compensate for the longer ones. In this manner, the average output can be reasonably stable.

2. To match up with variations in product demand. In case the demand for a given product was precisely known, it would be feasible to produce an amount of the product to precisely meet that demand. However, this is not usually the case, as demand typically is not fully known and consequently it results in convenience to keep a safety stock in order to be able to absorb the possible variation.
3. To permit adaptability in the production planning. An inventory stock mitigates the pressure exerted on the production system in order to get goods out as quickly as possible. This allows for longer lead times, enabling a smoother flow in the production scheduling and the production of larger batches that may permit lower cost operation.
4. To provide an internal insurance for any variation in the delivery times of the materials. This point is strictly linked to the topic of disruptive events impacting the supply chain. In fact, when the material needed for production is ordered from a seller, there are a number of reasons why even long delays can occur. For example, there may be a normal alteration of the expected shipping times, or an unexpected employee strike may occur at the seller's plant or the same may occur at one of the shipping companies, or yet another cause of arrears may be a shortage of materials in the seller's warehouse, or again it may happen that an order is lost or that a shipment is made of wrong or defective material.
5. To exploit the economic dimension of the purchase order. This is because placing an order entails various related costs. Consequently, making orders larger as possible means the less need to put more frequently smaller orders of the same material. In addition, expedition costs usually favor bigger orders, since the larger the dispatching is, the lower the unit cost will result.

In any case, despite each of the above reasons, it is still necessary to take into account that there is an evident trade-off, since keeping the inventory is expensive and consequently large quantities of it in general are undesirable. Large amounts of inventory may also cause long cycle times, which are undesirable in the same way.

In this regard, at the beginning of this section it was highlighted that the aim of inventory management is also to minimize the inventory related costs, which shall be taken into account whenever a decision is made affecting its size. According to Jacobs and Chase (2020), the main costs associated with it can be summarized as:

1. Holding costs. Also known as carrying costs, this wide category embraces costs of various types, as the ones incurred for storage and handling, or the insurance related ones, or those linked to theft and breakdowns, or even the ones that arose due to obsolescence, depreciation or taxes. Also the opportunity cost of capital shall be taken into account. Clearly, if the aggregate holding costs turn out to be very high, they will naturally tend to favor policies involving low inventory levels and frequent restocking.
2. Setup costs, commonly also called production change costs. In order to fabricate each differing product there is the necessity to obtain the materials needed, the preparation of specific equipment setups is required, along with the compilation of the proper documents, planning the appropriate loading of times and materials and the organization of the displacement of the stock of the previously used material. One of today's biggest challenges is trying to decrease these setup costs, thereby allowing smaller batch sizes. In fact, if there were no costs or waste of time in switching from one product to another, many small batches would be produced. In this way, it would be possible to reduce the inventory levels, resulting in cost savings.
3. Ordering costs. This cost category refers to the administrative and managerial costs linked to the preparation of the purchase or production order. Ordering costs involve all the even small details associated with these operations, including for instance the accurate count of the items and the exact calculation of the quantities to order. In addition, among them also the costs associated with the maintenance of the track orders system are included.
4. Shortage costs. In the moment in which the lot availability of a particular item is out of stock, if an order was placed for that item it must wait until the stock is refilled up or the order is canceled. The latter situation, related to the case in which the demand is not

satisfied and the order is therefore canceled by the customer, is commonly named stock out. On the other hand, a backorder occurs in the event that the order is completed at a later time behind schedule, thus in the moment in which the inventory of the item is restocked. There is clearly a tradeoff between maintaining inventory to meet demand and the costs that may result from stock outs or backorders. This is a balance that many times result difficult to achieve because it may not be possible to assess lost earnings, the repercussions of customer loss, or penalties for backorders. In fact, the assumed cost of scarcity is often little more than a mere assumption, even if it is generally possible to identify at least a likely range of those costs.

Determining the right quantity to order from suppliers or even establishing the optimal dimension of the lots submitted to the company's manufacturing facilities requires seeking for the minimum total cost that results from the summed effects of the four cost categories just outlined. Furthermore, also the timing of the orders is a relevant element that can affect the cost of inventory.

In order to choose which inventory management logic is most suitable for a given organization, it is also necessary to take into consideration a fundamental characteristic of demand, which is linked to whether demand is related to a product per se or whether it is derived from a final product.

The term independent demand is used to indicate the demand for different products that are not related to each other in any way. This type of demand is then triggered by external sources and in order to determine the right quantity to produce of these independent items the companies have to address to many of their internal departments as market research and sales, which will make predictions based on various methods like forecasting procedures of surveys to customers. In any case, the independent demand for items requires that extra units have to be kept in inventory, as it remains still uncertain. As regards the dependent demand, in this case the requirement of any element is a direct consequence of the requirement of one or more other elements, that are usually represented by a higher-level element of which it is a part. This type of demand creates fewer problems to be computed, since it does not have to be predicted but is calculated based on how many pieces of the high-level product in which it is used are required.

So, in choosing the logic of the inventory, it is necessary also to take into account what type of demand the company is used to dealing with. (Jacobs and Chase, 2020)

After all these considerations it emerged how, for all companies, a correctly managed inventory is a very crucial factor and it has a key value in improving the efficiency and the operation of any organization. In fact, as was already pointed out, an effective inventory management helps companies to reduce costs, optimize production, provide better customer service, avoid losses due to theft, deterioration and returns. Moreover, it provides information on a company's financial situation, customer behavior and preferences, product and business opportunities, current trends and future trends.

Shifting instead the attention to the related concept of business model, it can be seen that, even if it is a notion increasingly widespread in many disciplines, it anyway keeps on being criticized for being confusing and still too vague, and for the lack of consensus about its precise definition and on what its compositional elements are. In fact, in its most basic and crude definition, a business model can be described as the way the company makes money, but then there are countless ways to go deeper in this issue and delimitate this term.

Without entering into details and expounding on the vast number of definitions that have been proposed in this regard and their nuances, the following is a proposal that can be considered broadly acceptable: "*A business model describes the value logic of an organization in terms of how it creates and captures customer value*." (Fielt, 2013)

After this definition, it is natural to derive that the concept of business model is also linked to the one of inventory management system, since even at the core of the latter there is ultimately the goal of creating value for the consumers by providing them the higher level of service as possible, at optimizing the same time the resources used to achieve it.

In this sense, it can therefore be affirmed that by managing well their inventory companies contribute to improve their overall business strategy, increasing their profits and minimizing the losses.

At this point it seems appropriate to introduce what are the inventory management techniques that are practically used by companies. In fact, a wide variety of types of approaches that can help organizations in managing efficiently their inventory exist, but to reach the prefixed purpose of this thesis only three techniques will be analyzed, despite the full awareness that they are not the only existing ones.

Indeed, there is no presumption of being able to examine in detail each inventory management method, as it must be also taken into account that many micro categories of them are modeled according to the specific characteristics of the company in an idiosyncratic way. Therefore, these variants should be cataloged and analyzed separately from the other bigger groups, requiring too much effort for a little yield as the needed data are not openly available.

In the following sections, will then analyze the two most antithetical among these approaches, which may be seen as emblematic exponents of completely different philosophies regarding inventory management.

In the real world, between these two methods there is an infinity of nuances, which tend towards one or the other of them, depending on the individual case as previously highlighted. This consideration then brought out how important it is to underline and to keep in mind that this is a purely theoretical analysis and that then usually a real company does not adopt these methods in their purest and most rigid version as will be stressed in chapter, but they instead are often influenced at least in part by the other existing ones.

Exactly in the virtual half between these two inventory management systems we can identify a new technique that is becoming more and more popular in modern companies. It will be analyzed last, so that similarities and differences with respect to the previous two will emerge more spontaneously in the reader.

An analysis based more on real world events will instead be carried out in the third chapter, in which two examples of contemporary case studies will be exposed and then examined in the light of what really happened, making further considerations about what could have gone in a quite different way.

2.2. Lean Production and Pull system

In the 1970s and 1980s the well-known slowing down of economic growth and the new computer revolution pushed many industries to try to renew themselves, making an effort to introduce new methods of job which prove to be efficient in that environment. It is in this context that in Japan was implemented the model of the lean factory (and the related concept of lean production). This new method was initially tested in the automotive industry which was a widespread business field in that country, and more specifically by the Toyota company that may be considered the pioneer of this approach. In fact, it is in those factories that the globally known Toyota Production System was developed, a new working method that is also known with the name of Toyotism. This is an approach of organizing production that derives from a different, and in some respects alternative, philosophy to the one of mass production, which implies series and usually large-scale production based on the assembly line. (Jacobs & Chase, 2020)

In particular, there are three men that are remembered as the creators and developers of this system. They were Sakichi Toyoda, Kiichiro Toyoda and especially the engineer Taiichi Ono, who perfected the system between 1948 and 1975.

As mentioned above, this new approach was born mainly as a response to the serious conditions in which Toyota, and the entire Japanese industry at large, found itself after the devastation linked to the Second World War, that had left the citizens and the economy of this country inexorably on its knees. Then this system, implemented out of necessity but which later proved to be very successful, is responsible for making Toyota the company we know today, i.e. a leading manufacturer and producer in the automotive field at worldwide level that is expected to continue to be a global leader also in the future. (Valenti, 2017)

The great novelty of this system lay in an overall rethinking of the organization of productive activities, by reversing the traditional approach to product manufacture. Thinking backwards, so planning the production flow no longer from upstream to downstream (that is from the first production phases to final assembly), implies to start instead moving from market demands and then going back to production. This concept is the basis of what is commonly called the pull

system. In this way, it is possible to use only the necessary parts at the time when they are needed, avoiding waste and reducing stocks, giving rise to the idea of a lean factory.
Before moving on to analyze the concept more in depth, it may be useful to start by introducing a simple but accurate definition of the topic: "*Lean production is an integrated set of activities designed to achieve production using minimal inventories of raw materials, work-in-process, and finished goods. Parts arrive at the next workstation "just-in-time" and are completed and move through the process quickly. Lean is also based on the logic that nothing will be produced until it is needed*." (Jacobs & Chase, 2020, p.398)
The essence of this type of approach is then that the need for production is generated only by the actual demand for that item. Accordingly, in the moment in which a product is sold, the mechanism behind this logic implies that the market pulls a replacement from the final assembly, that more generally can be seen as the last position in the system. Therefore, an order to the factory production line is triggered, involving in this way that a worker has to replace the taken unit by pulling another one from an upstream station in the production flow. This last upstream station ends up pulling from the next station further upstream, following a process that continues in this manner until the raw materials are released. The process linked to this pull system needs to run smoothly, and to allow it the lean manufacturing requires not only high-quality levels at every step of such process, but also strong supplier relationships and a sufficiently foreseeable demand for the final product are required. This type of logic can therefore be applied not only to individual companies but also to their supply chains at large.

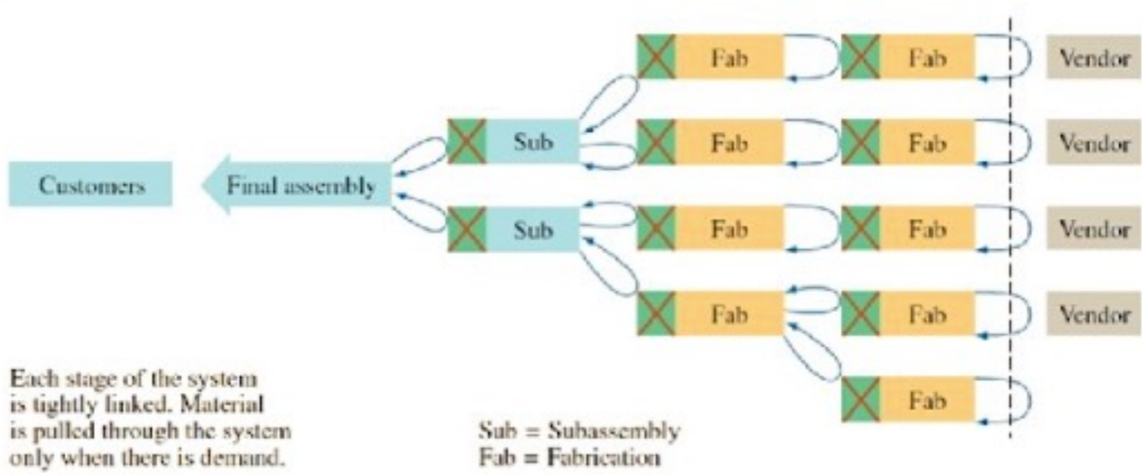


Figure 4: Lean Production Pull System (Jacobs F.R. and Chase R.B., 2020)

In Figure 4 this kind of process is explained schematically.

This revolutionary line of thinking then follows a Just-In-Time (also commonly known by the acronym JIT) approach to manufacturing production, according to which all the above described activities, which make up the flow inside the factory, are carried out using a minimum inventory of parts that arrive and are produced exactly when they are required and never before that moment. This is in clear contrast to approaches Just-In-Case, that rely on extra material and items in case anything goes wrong.

Moreover, the JIT philosophy is also coupled often with the Total Quality Control (TQC) approach, which aggressively tries to remove the causes of manufacturing defects smoothing the flow of the production process.

It is also relevant to introduce the Kanban concept, that is a lean production technique that makes Pull flow of materials possible. By traducing this term from Japanese, it emerges that Kan means "visual", while Ban means "signal". In fact, Kanban is based on physical colored cards that consent to the production, purchase or movement of materials.

The objective of kanban is to avoid overproduction, which is the waste with the greatest impact on the performance of a production system. The kanban is an operational method to circulate information in a systematic way within the company and between the company and suppliers, eliminating the need for complex systems of production planning. The Kanban is configured as a square card that contains the information needed in the production system. Consequently, it permits to automatically manage the daily work orders, allowing managers to deal with more critical issues and develop system improvements.

According to James P. Womack and Daniel T. Jones, who founded the renowned Lean Enterprise Institute (LEI) in 1997, five key lean principles have to be recognized: define value, value stream mapping, creation of the flow, establish and use a pull system, and pursue perfection. These concepts are briefly summarized in Figure 5 and they will be in-depth analyzed below.

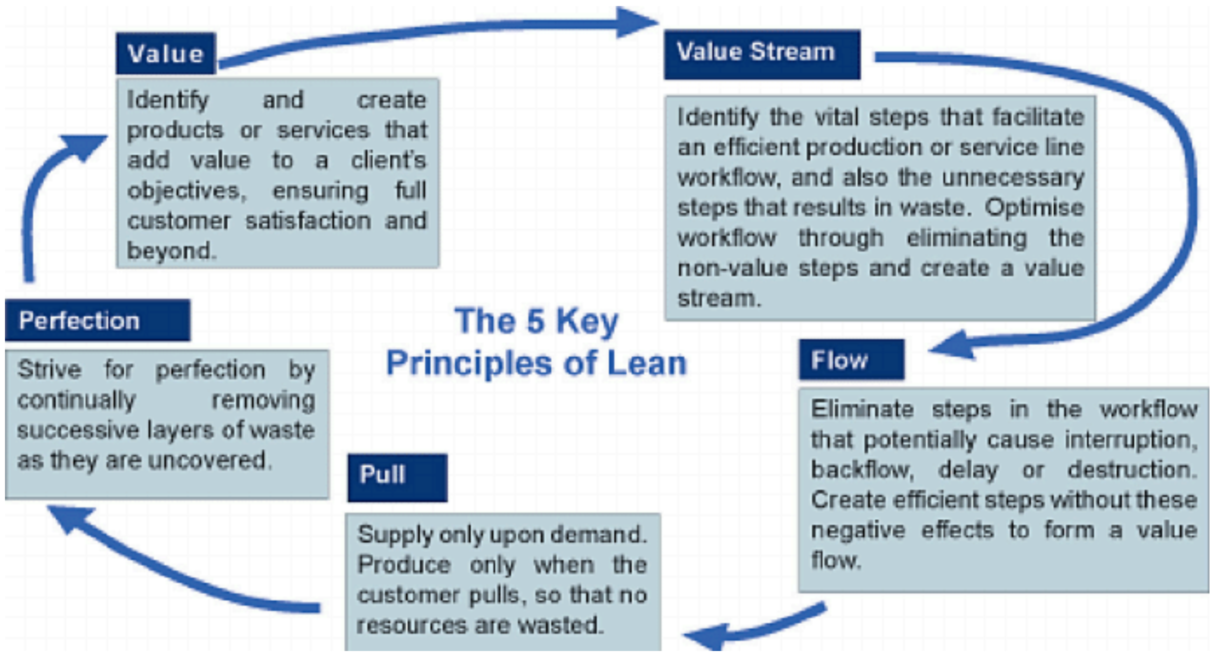


Figure 5: The five key principles of Lean Production

1. Define value. The first essential thing to remember when approaching this method is that lean manufacturing principles specifically aim to add value to the end customer. Value is therefore always defined by the customer's needs for a specific company product, so it is important to be able to understand what customers value in terms of their needs, what they really want, what they are willing to pay for and what will make them satisfied. But it is also possible that consumers themselves may not be able to articulate exactly what they want, which is especially common when developing new products or with innovative technology. Over the years, many techniques such as interviews, detailed surveys, and demographic information have been developed trying to help uncover what exactly customers find valuable.
2. Value Stream Mapping. The second key word in lean, once the value is determined, is undoubtedly the identification and subsequent mapping of the value stream in the workflow. According to this principle, the final aim is to use the previously mentioned customer value as a benchmark and then to pinpoint activities that are related with these values. In this way are also identified all the other areas, which are then considered as not adding value to the final customer and consequently are seen as waste. This waste can be further divided into two different categories: the non-value additive but needed activities

and the non-value additive and nonessential ones. The former should be reduced as greatly as possible while the latter are pure wasteful processes and should be eliminated at all. From this point of view, value stream mapping can also be identified as a re-configuring of production processes and is undoubtedly a useful exercise that also leads to a better comprehension of the entire functioning of the company's business.

3. Creation of the flow. The following step, after eliminating waste from the value stream, is to assure that the residual activities (the value-adding ones) flows without any breaks, bottlenecks or delays, hence in a smooth way. In order to achieve this goal there are many strategies that may be implemented, as for instance approaches that imply the reengineering of these steps of production, the redistribution of the existing workload, or the creation of departments with cross-functional tasks. Nevertheless, this may result in one of the biggest hurdles to surmount for lean programs.
4. Establish Pull System. Undoubtedly, inventory in a manufacturing facility is one of the major sources of waste. In this regard, it is recalled that the ultimate purpose of a pull-based system is to reduce inventory and the work-in-progress at minimum, and at the same time assuring that the materials and information needed are at hand, enabling a workflow as smoothly as possible. Then a pull system enables Just-In-Time production and delivery, with products manufactured only when they are required and exactly in the demanded quantity. In this way, by working backwards through the manufacturing system and following the value stream, it is more likely to satisfy customers with the produced items. That is because with a flow that has been improved, the time to market (also known as time to customer) can be drastically reduced and the outputs do not need any more to be assembled ahead or the materials stored up, that have also to be gathered in expensive inventory that needs to be well managed. The result of a pull system is then money savings for both the supplier or manufacturer and the end customer.
5. Pursue perfection. Waste is contained and reduced through the accomplishment of the first four stages outlined above. The fifth and final step, however, is perhaps the most important one. In this way, continuous process improvement (also called Kaizen in the Japanese philosophy) and lean thinking have become an essential part of corporate

culture. Every employee should be then involved in this pursuit of perfection while producing or delivering products that meet and satisfy the customer needs. Only in this way the unnecessary sources of waste can increasingly be uncovered and identified, leading then in their subsequent elimination from the production process.

It appears evident from the above characteristics that a lean manufacturing operation is not very easy and straightforward to implement. To this end, during the years many software programs have been developed to help organizations to pursue this approach by planning and scheduling production and then supporting managers to identify areas of production that need improvement and those that represent potential waste. It is therefore the learning process originally introduced by the Japanese, aimed to reduce or improve unnecessary movements, unessential production steps and inventory surplus, which is integrated with the modern technologies offered by today's world.

What continues to remain unchanged even after 50 years are the core beliefs embodied in the touchstone for lean production, the Toyota Production System. In fact, this approach was modeled around two values that are at the core of Japanese culture. The first is the already widely cited elimination of waste, intended as anything that is not absolutely crucial and essential within the production process. The categories of waste that must be eliminated from the supply chain are typically seven: movement waste, waste resulting from overproduction, waste linked to excessive inventory, process waste, transport waste, waste resulting from excessively long waiting times and waste caused by product defects. In order to avoid this last type of waste, it is necessary to improve the quality of the products and the only cost-effective way to upgrade this aspect is to develop robust process capabilities. Process quality, indeed, is primarily identified with quality at the source, which ensures that consistent and uniform products are produced the first time yet. In fact, producing right away with quality means avoiding spending time and money on unsatisfied customers. Furthermore, it should be emphasized that quality does not mean producing only the best, but rather consistently manufacturing products that give customers value for their money.

The second cardinal principle of the Toyota Production System, that is still prominent in lean factories today, is respect for people. Indeed, traditionally, Japanese culture has struggled to

provide lifetime employment for those positions that are permanent and to keep the same payroll standard even when business circumstances worsen.
One-third of Japan's total workforce is made up of permanent workers, who have job certainty and consequently they have then the tendency to be more flexible and willing to remain with a certain company and do whatever they can to support a business in reaching its goals. Then workers are encouraged to increase their productivity, because they know that if the company performs well this will benefit them, as they will receive a bonus. Managers view employees not as human machines, but as a valuable asset, leaving them free to concentrate on the most important jobs while repetitive and routine tasks are performed extensively by robots. It's not just about the workers, however, as Japanese companies typically rely heavily on a network of small business suppliers. They have long-term relationships with these subcontractor networks, made up of their suppliers and their customers.
As has just been mentioned, the lean manufacturing philosophy is based not only on just-in-time production planning, but also on “autonomation”, which in Japan is referred to as Jidoka. The concept of jidoka, typical of the Toyota Production System, indicates a particular type of intelligent automation with a "human touch" aimed at minimizing defects by interacting with the production cycle.
As Sakichi Toyoda, founder of the group, said, the purpose of any downtime must in fact be "to stop production so that production doesn't have to stop anymore", i.e. to implement interventions aimed at systematically eliminating defects at source.
Each workstation must be adequately equipped to be able to suspend activities when the slightest unforeseen event occurs, and the operator must immediately stop production to remedy the problem.
In the face of the wide range of problems that can arise, the worker should exercise independent judgment by stopping the machine whenever compliance is compromised. Therefore, it is clear that in this way the automation of the production process is strictly combined with the autonomy of the operator, who has the power to stop the flow when necessary.
At this point it has to be remembered that in order to make just-in-time production possible, it is of primary importance to produce products that conform the first time, reducing in this way waste

and rework. On the other hand, it is also highlighted that by keeping stock levels to a minimum as prescribed by the lean philosophy, there is no stock to draw on in the event of persistent quality issues. Adopting jidoka-based strategies in such situations is therefore essential to achieving objectives in terms of saleable production volume and compliance yield.

Until now, only the benefits of a Lean approach to production have been explained, which is then a method able to satisfy consumers and at the same time avoid unnecessary waste of resources as much as possible. But as with all things, there is also more than one downside.

The first consideration to do is that the JIT approach has been typically used when the same items are made one after another, as it gives its best when it is applied to repetitive and standardized manufacturing. So, it is a method effective only when it is applied in certain types of industry and in a stable context, therefore a company cannot arbitrarily choose to become lean without taking into consideration those factors.

In addition, considering the fact that inventories are reduced to a minimum to contain the related costs as much as possible, this consequently implies that there is also very little room for errors and rework of defective products. In this way then it is still emphasized how important quality is in the lean production approach. It remains, however, that unexpected errors can always occur also in this context, and in these circumstances a lean factory may find itself in difficulty more than other companies in the same situation, ending up losing profits and with unsatisfied customers.

Looking instead to a larger perspective, for lean production to work smoothly it is also fundamental that the suppliers are themselves involved in the lean process. In fact, waste can be reduced along the whole value stream, starting from raw materials to final products. But in the case in which a certain company is lean but its suppliers are not, it is likely there will still be some sort of waste. From this point of view, the creation of lean processes over the whole product supply chain is then the optimal situation to be actually consistent at all with that philosophy and avoid also hiding waste along the chain as much as possible.

In addition to this, the suppliers of a lean company also have an even more important role. In fact, the production process of an item depends a lot on the suppliers and if the stock is not delivered on time, the entire production schedule can be delayed with significant consequences. As will be discussed in the next section, in standard inventory-based production models, companies often place large orders for materials from suppliers, and many products can be manufactured from a single shipment. When production runs out of the first shipment of raw materials, a new order of the same type is then placed, creating in this way a convenient time buffer. Instead, JIT manufacturing means companies need suppliers willing to satisfy orders with different characteristics compared to the previous ones. In fact, those orders are smaller and more frequent on very short notice, and this ends up often with the choice of local suppliers in order to reduce both shipping time and costs.

Moreover, by minimizing inventories it is possible to drastically reduce the cost of keeping and managing items, a very positive factor in the case in which the environment in which the company operates is stable. But without inventories or stocks of materials, any supply chain related problem (such as those mentioned in the first chapter) can result in delivery delays and angry customers. For instance, if the price of raw materials suddenly increases due to problems with material procurement, or even paucity and shortages, or if political upsets or natural disasters occur, it may represent a serious threat to a company's ability to effectively serve its customers as it was used to. In fact, there are inevitably uncertainties that an organization cannot control, which may lead to a sudden change in demand and often also to a disruption in the supply chain, to which JIT production was not prepared to respond with already stocked and available products and materials. Thus, among the major risks associated with this type of approach are undoubtedly stock-outs and the risk of sudden supply breakdowns of critical production inputs.

In addition, there is another reason why JIT production is not the most efficient way to deal with unforeseen events, linked to the fact that it relies entirely on existing orders. It naturally follows that a company using this strategy may result in being badly equipped to handle a sudden increase in demand for a product, despite JIT being a very responsive method of production. Lack of spare inventory may indeed mean customers have to wait for the organization to receive raw materials and supplies and produce the item. Also in this scenario, the likely results are prolonged delays, unsatisfied customers, and there is also the possibility of loss of part or the entire order if there are problems in the supply chain.

A further factor to consider is that with this approach the incapacity to meet large orders in a timely manner is very likely and it often results in loss of profits for the company. Furthermore, are other few hidden costs linked to the JIT strategy that are just as critical and have to be considered. In fact, as has been pointed out above, manufacturing products for sale in smaller batches imply that for each shipment of raw materials the expenses are lower, but it can ultimately result in more costs for the company. This is because firms that have high levels of production can benefit from economies of scale, which means that the average cost of producing each item actually decreases as the quantity of production increases. This is in part because large bulk purchases from vendors are often accompanied by generous quantity-based discounts. As a result, it's common that companies using the JIT manufacturing strategy may pay more per item because they have to place smaller and more frequent orders that are not qualified for such discounts. And on top of that, the additional delivery and shipping charges that are linked to more frequent orders may also have a major impact on the bottom line.

In conclusion, it represents a quite risky inventory management approach and there are many existent potential downsides and trade-offs in adopting this approach and there is frequently a price to pay to be a lean company. Often this cost is linked to the dissatisfaction of customers in the moment in which unlikely disruptive events occur. Like all unpleasant downsides, however, there are also steps that can be taken to minimize the possibility of their occurrence, that will be outlined in the third chapter, in which two case studies related to lean production will be examined in depth.

2.3. Material Requirements Planning and Push system

A completely different method of inventory control than the one previously outlined is the Material Requirements Planning (commonly referred to by its acronym MRP), in which manufacturers order inventory after considering their sales forecasts.

The MRP system at its time has revolutionized the industrial world by allowing for a new planning approach that has been relatively quickly adopted primarily in many large manufacturing companies around the world, but it is used extensively by smaller companies as well. They may

decide to apply this method for production planning and order issuing whether by means of a management software such as SAP, that is one among the most famous and efficient ones.
Over the decades, this method has undergone a logical progression that has led to the integration of other elements, but the information system underlying the original version of the MRP has remained essentially unchanged. Indeed, this is an approach that was conceived in the 1950s, a period when computers were beginning to spread. These new devices allowed firms to make quick and complex calculations regarding what and how much they need to buy and produce at any time given a specific demand input, overcoming the limits linked to the information processing tools used until that moment. Then in the 1980, with the successive additional incorporation into this system of also the cost accounting, this method took the name of Manufacturing Resources Planning (the also called MRP II).
MRP II has then evolved into Enterprise Resource Planning (abbreviated in ERP) in 1990, which is a management software that can integrate all relevant business processes and all functions present within a company, from inventory management, to finance, sales, purchasing, accounting, etc. It therefore integrates all business activities into a single system, which has an essential function in supporting management. Thanks to this software, data coming from multiple parts of the company are collected centrally in common databases.
Also in this case, before going to examine in detail each part of this methodology, a definition of MRP is proposed coming from the APICS Dictionary that sees this system as "*A set of techniques that uses bill of material data, inventory data, and the master production schedule to calculate requirements for materials. It makes recommendations to release replenishment orders for material. Further, because it is time-phased, it makes recommendations to reschedule open orders when due dates and need dates are not in phase. Time-phased MRP begins with the items listed on the MPS and determines (1) the quantity of all components and materials required to fabricate those items and (2) the date that the components and material are required. Time-phased MRP is accomplished by exploding the bill of material, adjusting for inventory quantities on hand or on order, and offsetting the net requirements by the appropriate lead times*."
So basically, the Material Requirement Planning system can essentially be seen as a computing hub consisting of different elements that are all required in order to make the MRP program run.

The planning time horizon is generally two or even three months, discretized according to weekly time buckets.

The main input to this process is the Master Production Schedule (MPS), the production planning document which generally contains all the relevant information about end products to assembly and that is in charge of feeding the demand signals to the MRP. The latter in turn is responsible for analyzing the organization's current inventory records, taking into account both which is at hand and what is on order, as well as the structure of the specific product (which is called bill of materials or even BOM). Based on this data, and taking into account the related production and supply lead time, it then creates a synchronized list of supply orders of raw materials and semi-finished products, which have requirements of date and quantity that determine the elements of that plan of synchronization. These requirements are then entered into a production execution system that converts each of them into different types of orders also in relation to the lot sizing policies defined for each product. In fact, they may be alternatively translated into orders of transfer to distribution sites, of production to be scheduled on the shop floor, or even purchase orders to be transmitted to suppliers. This calculation is usually made daily, according to a rolling horizon policy. The MRP process therefore determines a new production plan every day, taking into account various factors such as possible variations in demand forecasts, or different requirements due to unforeseen events and, more generally, new visibility on customer demand for finished products that the passage of time entails.

In Figure 6 is visually described the planning method just explained above.

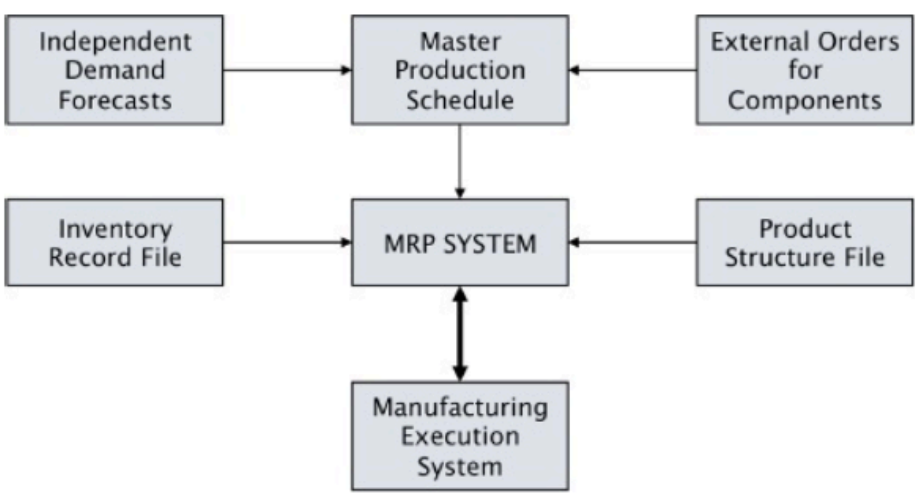


Figure 6: Conventional planning schema (Ptak, C.A. and Smith, C., 2016)

From this brief explanation of the base functioning of the MRP it can be easily understood why it has been considered an innovation in the field of planning. In fact, thanks to it, for the first time it has been possible to calculate which was the requirement on the basis of what was already in the warehouse in contrast with what was instead necessary, obtaining a net result of temporal phases. It appears clear from this perspective that, although it can be argued that MRP is a huge inventory-based system when compared to lean manufacturing, even in this case the goal is to minimize inventory as much as possible while avoiding unnecessary waste of resources.

A further significant development related to the advent of MRP is also its ability to calculate even more easily the dependent demand for an item using the BOM of its parent part, thus making it necessary to forecast only the dependent demand of the parent part and not also of the component parts.

Then, the type of system for inventory control exposed in this section inevitably involves some sort of forecasting of the inventory, in order to be able to produce enough items to meet the expected customer demand of final products.

It is commonly known as Push system, that appears diametrically opposite to the one explained in the previous paragraph that was instead dedicated to the Pull approach to inventory, which kicks off the production process only in the moment in which an order from the customer had been received. Between the major advantages of adopting a push approach there are both the ability to respond promptly to sudden changes in customer demand because demand predictions are yet embedded in the system as an integral part and the fact that production rates at all levels of the network are accurately planned for many periods into the future.

However, as was also pointed out by Joe Orlicky (1975), one of the founding fathers of MRP, even this system suffers from many imperfections as it may be simply the best method that could be implemented at the time. In a nutshell, in fact, this solution is optimally applicable only under the circumstances in which it was devised, so limited by the assumptions on the basis of which it was originally structured. The three assumptions on which the MRP logic is based are:

- The variability of customer demand is not taken into account at all: both customer orders and the demand forecast are actually considered in the same way, as if the demand forecast were not affected by any kind of error. On the base of both types of demand the explosion of the requirements on the whole BOM happens therefore unconditionally.

- In the base form of MRP, both production and procurement lead times are considered to be unaffected by any type of variability.
- The capacity of the resources available to the company is considered infinite. In fact, on the basis of the quantities of finished products to be produced, the MRP calculates the production orders of the components needed to satisfy them without taking into account the production capacity constraints (whereas this is not the case with MRP II).

Moreover, the last two aspects are connected, since the net requirement of a material is always calculated starting from the lead times, but since they are considered as free from variability, what is not considered is that they could be longer than estimated. In the case in which this inconvenience is happening, after the daily recalculation of the MRP the new quantity to produce could turn out to be greater than the production capacity needed in order to respect the order in the required times.

This aspect is not however taken in consideration from the MRP, therefore making necessary to consider whether these assumptions on which it is based are still acceptable and realistic today, because if the conditions had changed obviously would not make sense the willingness to continue to use a technique in a short-sighted way, neglecting that the present context of application is a world dominated by variability. In fact, as Chad and Debra Smith (2013) pointed out, today's boundary conditions are quite different than they were sixty years ago, and the characteristic features of what the authors call the “New Normal” may now be distinguished:

- The complexity of supply chains has increased. In fact, there has been a shift from primarily linear and vertically integrated structures to branched and disaggregated structures.
- due to the exponential population growth, the volumes of material required (and therefore processed) are physiologically increased.
- Both the heterogeneity and complexity of the variety of products offered by companies in any industry have significantly increased.

- Consumer preferences change very rapidly, especially due to technological advancements that occurred in recent years. This has led to a drastic reduction in product life cycles and to a customer demand forecasting significantly less accurate, as the demand is much more variable.
- Consumers can now find everything they want and at the lowest possible price, while also demanding reduced waiting times. This because of the increase of the players to the inside of the markets, that has therefore increased the competition, and of the reduction of the informative asymmetry between company and consumer due to the spread of Internet, which has carried to a reduction of the times of tolerance of the customer.
- As a result of increased demand variability and shorter product life cycles the pressure to minimize inventory on hand has significantly increased.

Consequently, because of this widespread variability and of the unpredictable fluctuation in demand, orders calculated by traditional MRP result inevitably inaccurate.

This phenomenon is called "nervousness" of the MRP and is the reason why the personnel of many firms using this approach usually rely on spreadsheets in parallel to it. In fact, although programs such as Excel are easily subjected to human errors, if managers stick only to what the MRP calculates they might have to redo or modify what they did the previous day, since this program alters the outcome of every day planning due to the fact that it is based on inaccurate calculations.

Also the bullwhip effect, discussed at the end of the first chapter, is a phenomenon whose occurrence is another direct consequence of the uncertainty and fluctuation of demand.

In fact, a small variation in customer demand can be crucial to upstream component supply as it is progressively amplified (Ptak and Smith, 2016).

In this way, therefore, an information bullwhip effect propagates due to disorganization and lack of communication, as inaccurate information in the final step of the supply chain ends up having serious repercussions on the initial levels.

In addition, there is the bullwhip effect based on the flow of materials, which propagates from initial to final layers. In this case, a stock out of a raw material upstream in the supply chain can generate stock outs on different finished products.

In general, it can be seen that the longer the supply chain, the more severe the damage caused by the bullwhip effect, even if it is in any case physiologically present in every logistic supply chain with its twofold nature, which is reported visually in Figure 7.

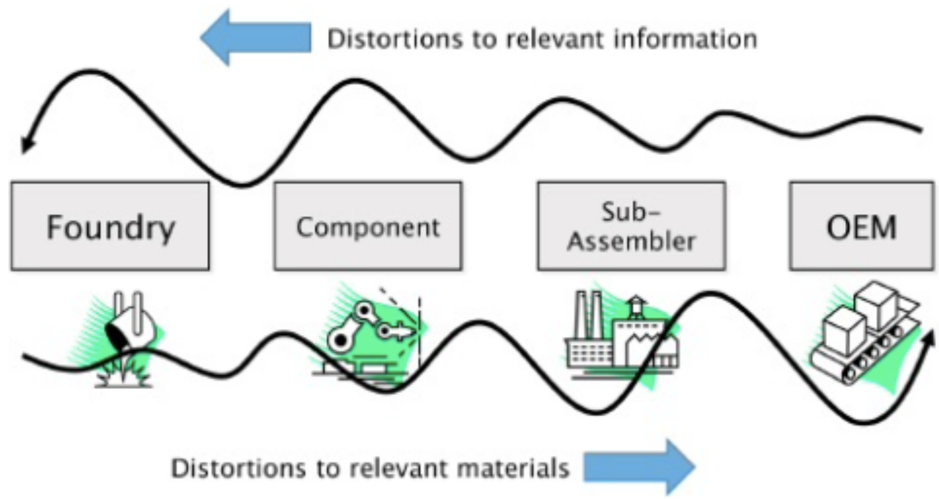


Figure 7: The twofold nature of bullwhip effect in supply chain (C.A. Ptak and C. Smith, 2016)

However, the method with which the orders are generated can in part contribute to contain its effects and MRP is particularly unsuitable for this purpose, since it provides an algorithmic and total dependence between the orders generated along the entire supply chain.

The consequence of this phenomenon on the levels of stock generated is commonly called bimodal distribution of inventory, of which the fluctuations of the customer demand generating oscillations of the orders that are calculated from the explosion of the BOM are responsible. It is a situation in which the inventory levels of a company fluctuate between situations of overstock and situations at risk of stock out. This concept is graphically represented in Figure 8.

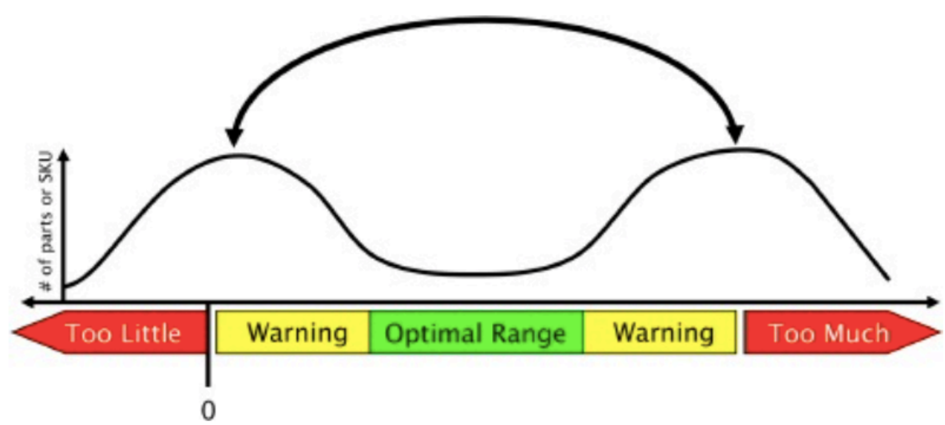


Figure 8: The bimodal distribution of inventory (C.A. Ptak and C. Smith, 2016)

The optimal area of the inventory, the central one in the above representation, is the one in which the warehouse costs are minimized without risking running into stock out situations, which however is only rarely reached by real companies, as was observed by a study carried out by the Demand Driven Institute from 2011 to 2014.

At the beginning of this chapter it has already been pointed out that an excessive level of stock is not economically viable and that a too low level of inventory is on the other hand a huge risk for the company.

It has then to be highlighted that the MRP method, to carry out the explosion of the BOM, is obliged to take into account not only the actual orders of the customers but also the demand forecasts, despite the disastrous impact of the variability and the lack of accuracy that the latter entails. This is especially true in the presence of long lead times, since if only the actual demand is considered it would be mathematically impossible to react to any of its changes. In this context of uncertainty, it then naturally follows that the phenomena of nervousness and the propagation of the bullwhip effect are further fed.

After these considerations, it can easily be guessed what happens when a sudden disruption hits a company using the MRP method.

In fact, the impact of one of those events on a company's manufacturing capabilities will be enormous, as without stable and reliable inputs from the other internal business functions, from consumers, and from supply partners, interruptions in the supply chain resulting from ongoing uncertainty threaten the effectiveness of an MRP system in being able to do what it was designed to do.

2.4. A hybrid and innovative approach: the DDMRP

As has been stressed in the previous section, the MRP system has the merit of being able to connect the various phases of the production process in order to accurately plan where, when and how much material is required to satisfy the final demand.

However, this virtue is also a huge flaw when this dependence ends up amplifying and accumulating distortions in the flow of materials and information along the supply chain.

In 2011 was then developed a modern alternative to the traditional planning methods using the MRP system. In this year C.A. Ptak and C. Smith founded the Demand Driven Institute and that was published by the same "*Orlicky's Material Requirements Planning*" in its third edition. It is on this occasion that Demand Driven Material Requirements Planning (DDMRP) made its appearance, presenting itself as an innovative inventory management system.

Basically, this new demand-driven approach shifts the focus to demand and real flows, such as the methods commonly referred to as "position, protect, and pull," abandoning a logic called "push and promote" that is based instead on supply and operating costs.

As can be seen in Figure 9, the DDMRP relies on many different conventional methods, merging some of the most important features of each of them, despite the fact that they normally are in conflict with each other. In fact, it takes cues from both MRP and its close relative DRP but it also takes insights from Lean production, the Theory of Constraints and the Six Sigma. The final ingredient is innovative features unique to DDMRP that make this harmonious fusion possible.

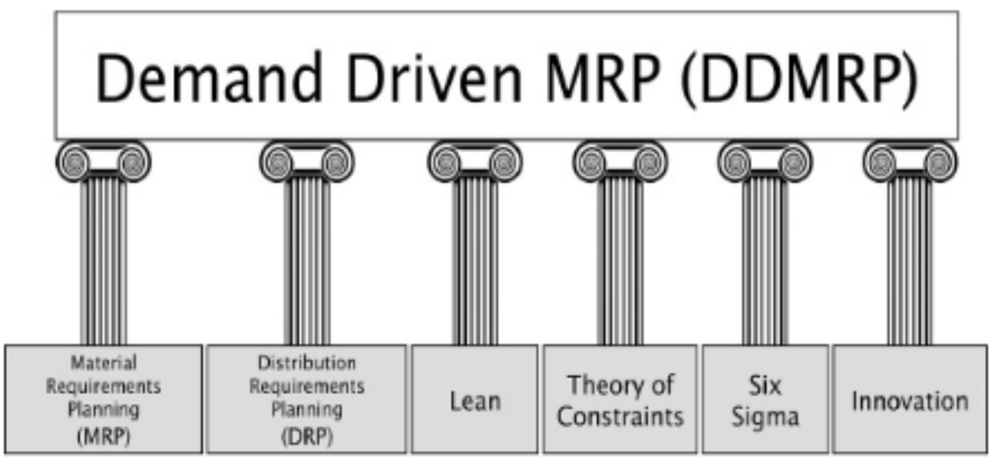


Figure 9: The methodological foundation of DDMRP (C.A. Ptak and C. Smith, 2016)

Before analyzing the components of this new approach, it has to be noticed that the variability that characterizes the real world can never be completely eliminated in any way and the best that can be done in this regard is to try to minimize it as much as possible, by accepting its inevitable existence and trying to manage it effectively.

In fact, the only effective way to counteract the aforementioned bullwhip effect and the nervousness of the system is not to eliminate variability but rather to somehow stop the transmission of variability along the supply chain.

The decoupling technique can be seen as a functional solution of this problem. Indeed, paraphrasing the definition provided by the APICS dictionary, this concept may be basically described as a method able to create independence between the various layers of supply and demand, placing stocks of materials between operations along the supply chain. In this way, it is reached the objective to avoid as much as possible that eventual fluctuations in the supply of materials or in the customers demand affect respectively the successive or the previous activities along the manufacturing system.

The result is the disconnection between the various steps that compose the process, which has the positive effect of isolating any adverse events that affect a single stage, preventing them from spreading throughout the supply chain.

This is specifically obtained through the use of decoupling points, which are positioned through the production process with the aim to disconnect each entity from what happens before and after it. Determining where they will be placed is a decision that hugely affects the extent to which the overall system will be effective, so this choice is very crucial.

Figure 10 illustrates the benefits resulting from the use of decoupling points, which are able to protect each other by absorbing at one time the variability associated with both supply and demand, as can be observed from the component positioned in the center of the figure. In fact, the decoupling of the purchased component, positioned in the left part of the figure, protects the next step from long lead times and accumulations of variability in the supply, while the latter is also protected from the demand variability thanks to the decoupling point positioned in correspondence of the end item.

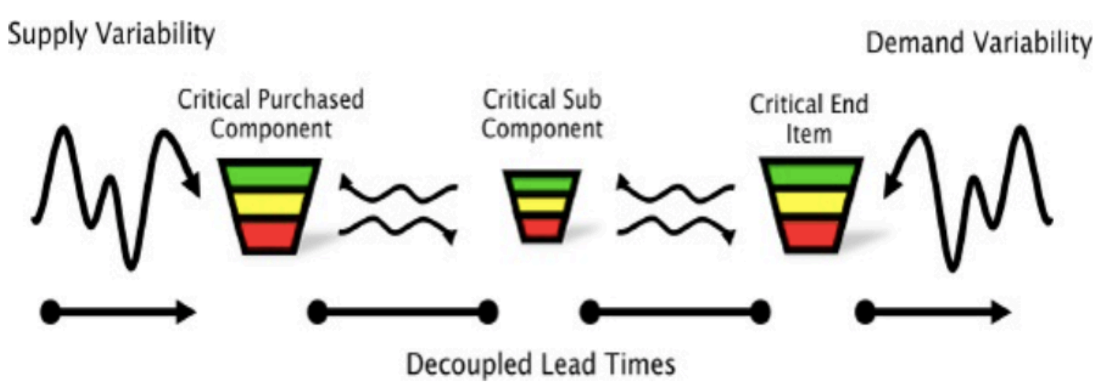


Figure 10: The benefits of tiers of decoupling points (C.A. Ptak and C. Smith, 2016)

To ensure an adequate level of protection able to sufficiently absorb the variability from both directions, there is then the need to keep a certain amount of inventory in these decoupling points. It is commonly referred to as “buffer” and it is projected to decouple demand from supply, providing to consumers a safe stock of the desired item while also allowing demand orders to be aggregated, creating an efficient signal for suppliers of that kind of item, definitively more realistic than the MRP ones.

Hence, thanks to the presence of these strategic stocks of material, it is possible to create a certain level of independence between the various stages that compose the supply chain. In this way, each step may be planned and executed according to its independent horizon.

The use of buffers is then at the base of the DDMRP method, thanks to which it is possible to limit satisfactorily the diffusion in both directions of the variability along the supply chain avoiding its accumulation, obtaining also a reduction of the lead time throughout their compression.

But this is not the only feature of the DDMRP, as the components of this logic are essentially five and they operate sequentially as can be seen in Figure 11.

The Position (1) and Protect (2 and 3) phases are responsible for setting before the starting and then the evolving configuration of this model. Strategic inventory positioning, as was discussed above, is a critical decision impacting the overall strategy. It is the phase in which will be decided what are the tactical places in which the decoupling points will be settled. The second component of the DDMRP is called buffer profiles and levels. This is the step in which those decoupling points are carefully examined and it is determined the appropriate amount of protection to be provided to them.

The next stage, represented by dynamic adjustments, has the task of defining the manner in which this level of protection changes depending on various impacting factors, such as market-related changes or future known events, which cause it to move up or down with respect to the previous situation.

In contrast, the Pull phase (4 and 5) of the DDMRP represents the definition of the planning and execution of the system, i.e., the operational aspects. Demand-driven planning can be viewed as the process through which the needed supply orders are created and executed, which includes purchasing, manufacturing, or inventory transfer as the situation demands. The last step is called visible and collaborative execution and is the procedure by which this method handles open supply orders.

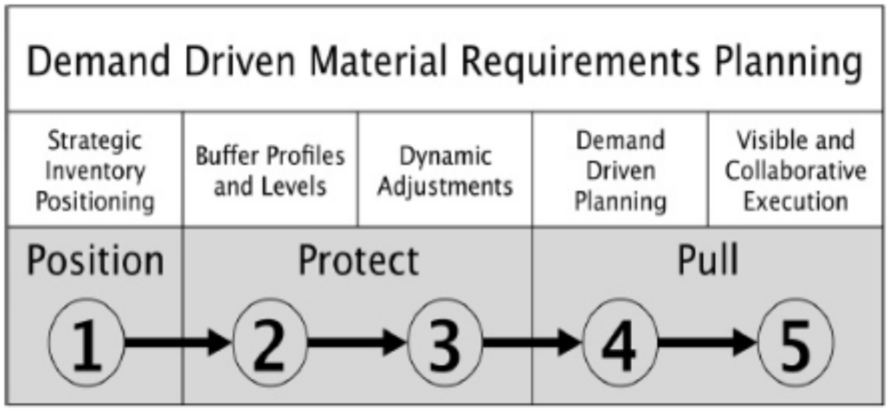


Figure 11: The five components of DDMRP (C.A. Ptak and C. Smith, 2016)

After this brief introduction to this innovative method, it is necessary to move on to the central issue of this analysis. In this regard, it can be noted that the DDMRP is able to remedy the biggest flaw of MRP, as it is able to stop the transmission of variability along the supply chain, thus promoting the flow of both materials and information. In addition, it is equipped with larger inventories than those of lean production.

In light of these two theoretical considerations, one is therefore naturally led to believe that the DDMRP is more able than the other approaches to respond to sudden disruptive events. However, what is necessary to keep in mind is that better than others do not mean optimally, as even this logic has limitations and suffers from the negative impact of these unpredictable phenomena. Being a recently developed method moreover it is difficult to affirm with data to the hand which are in the specific one these limits and in which degree it suffers in these uncomfortable situations, however it can be reasonably assumed that (at least from a theoretical point of view) it is an optimal candidate as a resilient and robust inventory management method with respect to impacting negative events, at least more than the others analyzed previously.

Further considerations will be made in the last chapter, where with the use of Matlab software it will attempted to overcome the scarcity of data available for this analysis, simulating what might be the likely reaction of the DDMRP system when it is put under stress, investigating in particular what happens when a highly-destructive phenomenon hits a company that has chosen to adopt this specific approach.

2.5. To sum up

This final section offers a visual summary of the functioning of the three inventory management methods analyzed in this chapter (Figure 12).

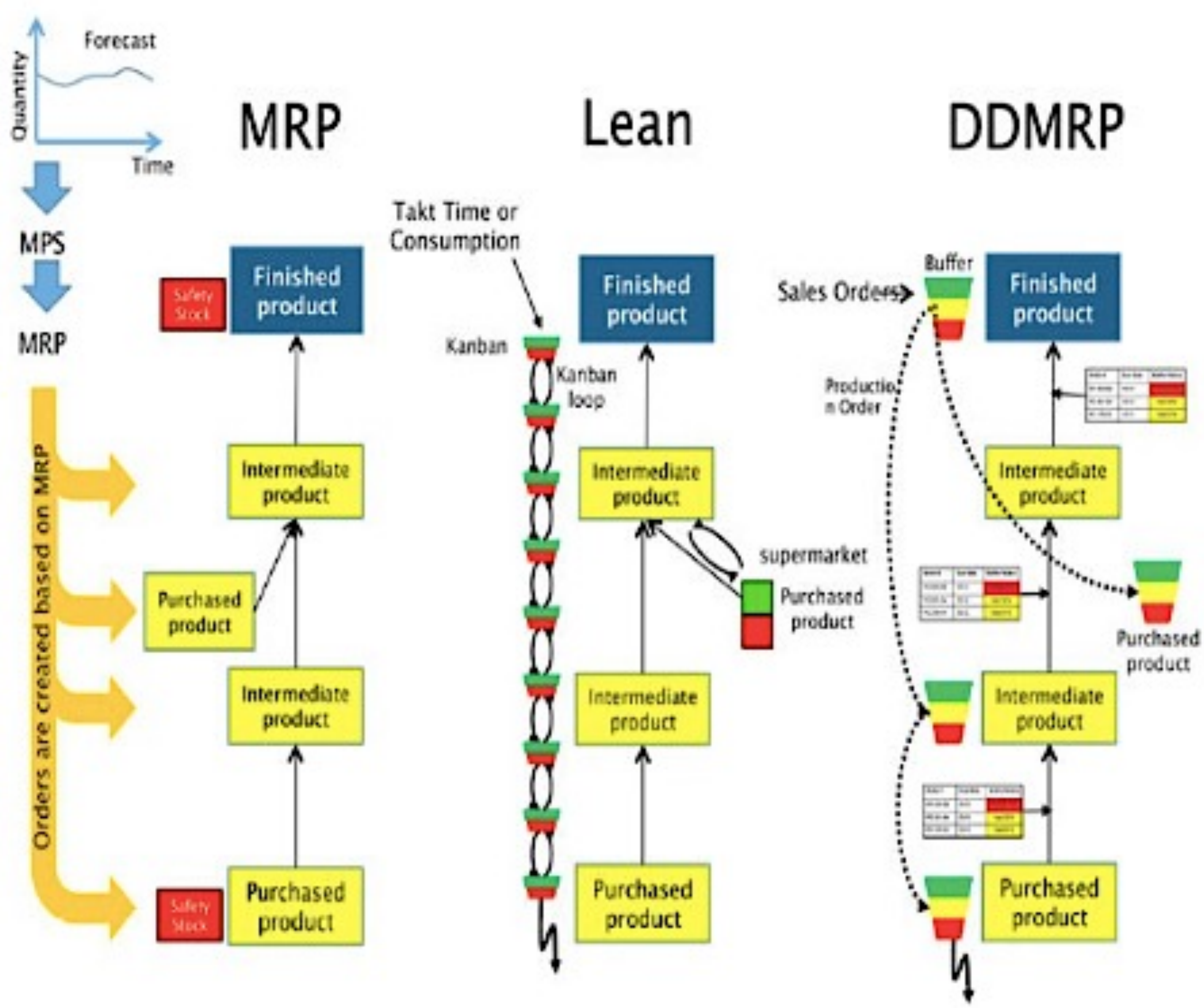


Figure 12: MRP, Lean and DDMRP (C.A. Ptak and C. Smith, 2016)

During this exposure, it aroused what the biggest limitations and weaknesses of each approach are, leaving an open question regarding DDMRP as it is an innovative method for which only few data is available.
In any case, it also emerged how an effective inventory management system is essential regardless of the type of industry in which a specific company operate, because each of them may be a victim of a sudden disruptive event and in that circumstances it is needed more than ever an improved supply chain management able to overcome as fast as possible the emerged difficulties.
In the following chapter two contemporary real cases will then be examined in order to analyze this topic not only from a theoretical point of view but also from a practical one, with the aim to understand if the conclusions reached can be similar from both perspectives.
However, before proceeding to this analysis, it is necessary to make some considerations regarding the terminology used in the present chapter.
The starting point is a useful paper written by Hopp and Spearman (2004), which explains how the basic associations "lean production - MTO - pull system" and the one " MRP - MTS - push system" turns out to be indeed too oversimplified, as the matter is actually more complex. According to the two authors in fact the pull system is a too wide concept to be reduced only to the kanban idea, because the latter was simply the first manifestation of this type of system. In the same way, the push system has been widely equated as synonymous of MRP, although they do not indicate the same concept.
The authors also pointed out that there are two different applications of the term "pull," which can be used at either a strategic or tactical level. One way to establish strategic pull is for example to define a takt time to adjust the plant output to be equivalent to demand, a logic that could therefore also be similar to the one of MRP and of push systems in general.
What instead differentiates the tactical pull, which can be connected to the kanban and not to other systems considered push like the MRP, is the placement of limits to the work-in-process (called also WIP, indicating goods partially finished waiting for their completion) thus allowing the system to never exceed its capacity. In fact, a tactical pull system does not keep on adding new

orders to the system over a given inventory threshold, even in the case that forecasts turn out to be wrong or demand rise exponentially.

To clarify the concept, the authors have therefore provided an additional definition in this regard: *"A pull production system is one that explicitly limits the amount of work in process that can be in the system. By default, this implies that a push production system is one that has no explicit limit on the amount of work in process that can be in the system."* (Hopp and Spearman, 2004, p. 142)

This is clearly a theoretical definition of the concepts in their purest form, inasmuch as they also point out that "*However, in the real world there are no pure push or pure pull systems […] Indeed, there is presumably some limit on WIP for every system […] The distinction, however, is that the WIP limit in practical pull systems is explicitly stated and is generally small. Any WIP limit in a practical push system is implicit, large, and usually comes into play too late (i.e., after WIP is out of control)*." (Hopp and Spearman, 2004, p. 143)

According to the definition given by the two authors, is then still possible to connect the MRP to a push system and the classic kanban to a pull system, as in the first case releases are done based on a master production schedule with no consideration of system state and consequently there are no a priori WIP limits, while in the second case the amount of kanban cards is a fixed constraint on the WIP. Note, however, that if the MRP method was designed using a WIP restraint, it would be configured as a pull system and no longer as a push system.

Regarding instead the association of the concepts of Make-To-Stock (MTS), Make-To-Order (MTO) e Make-To-Forecast (MTF) to the inventory management methods, Hopp and argue that these notions are orthogonal to the distinction between pull and push, in as much as they are strategic decisions that should be independently made and not a priori associated with either one of these systems. In fact, each of them, when combined alternately with a pull or push system, leads the company to obtain a variety of results that are more or less efficient depending on the environment and the different contexts.

Despite being aware, therefore, of the existence of these considerations emphasizing how it is a mistake to careless link with each other the terms "lean production - MTO - pull system" and " MRP - MTS - push system", it has been decided to use this association anyway.

Specifically, it was deliberately chosen to adopt the meanings that are more commonly used in the vast literature dealing with these concepts in order to be more widely understood by a wider public, although being conscious of the existing misunderstandings in this regard.

CHAPTER 3: From theory to real contemporary Lean case studies

The previous chapter has evidenced which are the strength and weakness points of the most popular methods of inventory management systems, dwelling in particular on which could be presumably their difficulties in facing unexpected catastrophic events hitting the supply chain of the companies that have adopted them.

Based on the analysis carried out in the preceding chapter, which focuses mainly on the theoretical and literary point of view, it can be expected that the Lean approach is more easily exposed to the risks of supply chain interruptions and bottlenecks, it is more likely affected by lead times getting longer and even it is more prone to be impacted by supply related threats.

In particular, it has been underlined how the Lean production method, although being very efficient mainly in terms of costs in stable contexts, in the case in which the situation turns out to be more challenging than the predicted one it may end up seriously exposing to several risks the companies using it.

This is the main focus of this chapter, which dwells on the analysis of two emblematic cases, contemporary to the moment in which this document is written, trying to expose in practical and not just in purely theoretical terms what may be the drawbacks for companies that have decided to implement the logic of Lean production in their supply chain. In fact, it has already been stressed how up to this point of the discussion the topic has been investigated only from a literary perspective, while in the present section an attempt will be made to understand if what is derived from theory can also be deduced by examining real world events, while in the next section it will be proposed a more analytical analysis with the use of a schematized model.

Specifically, in this chapter it will be investigated if in this type of problematic situation the companies that have generally operated according to an approach "just-in-time" turn out to be particularly penalized in the moment in which one shock happens, since they may be found substantially unprepared.

The reason why it has been decided to concentrate the attention on this type of inventory management system and not on case studies with companies using an MRP approach is therefore just because from the analysis of the previous chapter it appears that the former is more disadvantaged than the latter in this kind of adverse situation.

Once again, the objective of this analysis is not to decide in absolute terms which is the optimal inventory management methodology to adopt for any type of company, since the implementation of each of the systems mentioned has both pros and cons depending on the specific case, and there is no one totally and unquestionably "better" than the others. The dynamics that will be therefore the object of this investigation are not all those possible and imaginable tied to the corporate context, rather the focus of this study will be instead exclusively on the company dimensions that appear as closely linked to the problems that can arise in relation to inventory management in case of adverse situations occurrence. These dynamics can be then basically summarized in two main problems: sudden supply shortages and longer delivery times (which indicate the duration between when an order is placed and when it is actually processed), resulting in customer dissatisfaction problems. As it has already been said, it can be thought that these issues mainly concern a context in which a just-in-time logic is implemented, since it can be intuited from the theory that Lean industries may be more prone to these two specific problems than industries that use the MRP method in their inventory management, reason why in this chapter a focus on real cases related to the former and not to the latter is proposed.

Of course, this would not suggest that companies adopting an MRP methodology do not hurt when one of these disruptive events hits their supply chain, but rather that they experience this disruption differently (and likely less severely) than those companies that have instead opted for a Lean approach in their manufacturing process.

Going into the specifics of the two contemporary cases considered, it will be shown how they are clearly different from each other, as the issues and events that created them are completely dissimilar situations. Despite this, what they have in common is that they both affect one of the manufacturing sectors that has traditionally used a just-in-time approach in their production, the automotive industry. This inventory management system methodology has allowed this sector over the decades to significantly cut costs in their mass production process, consequently permitting them to lower their selling prices and then offer their products to a wider range of consumers. This result has been achieved also thanks to the exploitation of increasingly long

global supply chains, which have enabled them to purchase from the most convenient suppliers of the various necessary components, even though they are located overseas.
But this mechanism has demonstrated its weaknesses in recent times, as relying on distant cheaper suppliers without having built substantial warehouses of stocks has ended up becoming a vulnerability in these times of great uncertainty, leading many companies operating in this sector to a significant crisis.
In the course of this chapter it will be analyzed in detail how the shortage of chip supply has become a crucial problem for the whole world of electronics and consequently also the automotive one, even concerning the governments of the most powerful nations that have recognized the magnitude of the issue.
It will then be taken into consideration how the announcement of Brexit has profoundly shaken the industries operating in the United Kingdom, once again affecting in particular car manufacturers who used to be supplied abroad with critical components and sell their end products all over Europe.

3.1. The global problem of chip supply shortage

A humble little object like a chip, an invention dating back more than six decades, has drawn global attention in recent times, quickly moving from being an exclusive of powerful computers to being the most crucial component of modern consumer electronics.
Chips are indeed built and sold to be integrated inside an increasingly wider range of devices, as the Chart 1 points out, thus making clear why the demand for semiconductors (materials fundamental for their manufacturing) is rising worldwide. This explanatory chart is taken from a Bloomberg article and was constructed based on data derived from a IDC report, the world's leading company specializing in market research in the ICT and digital innovation sectors.

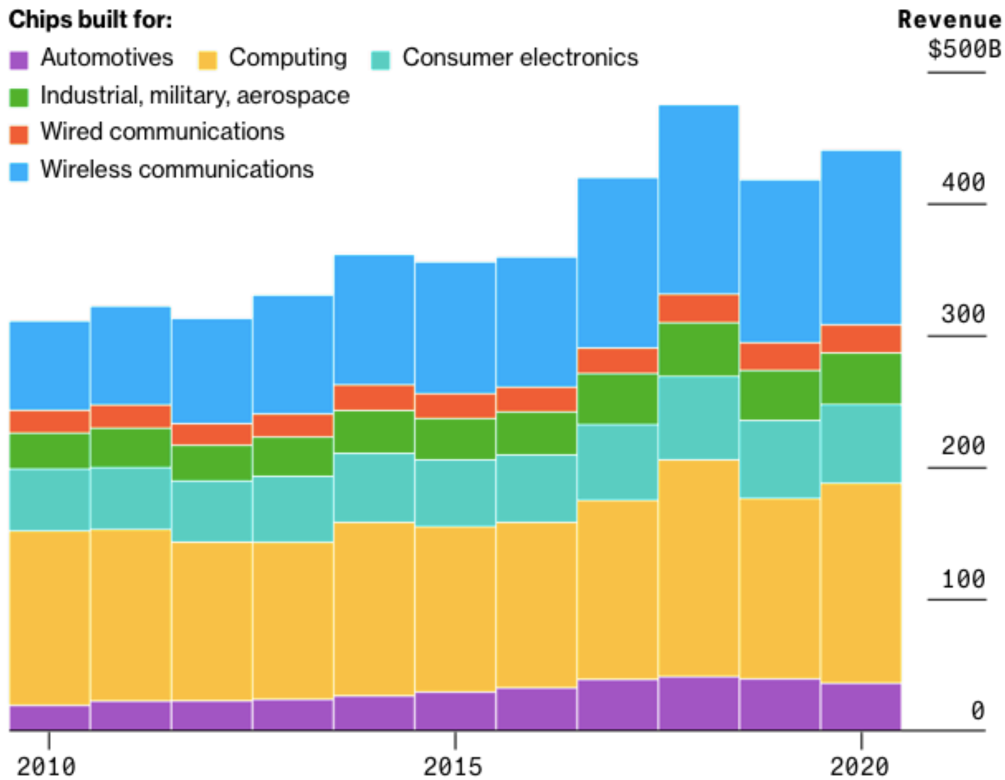


Chart 1: Manufacturing sectors using chips over last decade. (Bloomberg, 2021)

At the time this document is being written, the world is experiencing a huge and unprecedented shock related to the short-term supply of these essential components, a shortage that has created (and will keep creating in the near future) countless disruptions in this industry.

Before starting to analyze the current situation, in the following subsection it will be exposed a useful brief description of what specifically chips are, how they are composed and why they have proven so crucial to so many industries globally.

3.1.1. The chip: a critical element in modern electronics

Ranging from many everyday and common objects such as telephones, household appliances, televisions and computers to highly secret military devices, they all have one thing in common: their working is made possible by miniaturized silicon based chips.

A silicon chip is basically a set of electronic microcircuits, which can perform many different functions depending on the way their fundamental electronic components such as transistors, diodes, resistors, etc., are arranged. Nowadays the integrated circuits, the one informally called “chips”, are composed of billions of nanoscaled active components which cooperate to perform all sorts of electronic processes.

The starting point for building an IC (“Integrated Circuit”) is a tiny circular slice of extrinsic semiconductor material, called wafer, which is cut off from a bigger piece of monocrystalline silicon. To enhance even more the semiconductor behaviour of silicon, different types of chemical impurities are added to the latter (mainly boron and phosphorus), through a doping process that aims to create the active zones of the various devices. Basically, the chip is the substrate that contains the elements (active or passive) that make up the circuit (for further explanations consult Franssila, 2010)

Silicon is one of the most abundant elements on earth, and can be found, with impurities, in common sand.

From the purified molten sand, silicon crystals are obtained that eventually resemble big and elongated cylinders. These are then sliced to obtain thin wafers, on which miniaturized images of very complex and structured electronic circuits are firstly lithographed then etched and deposited in successive layers. The modern manufacturing process for the interconnection layers, the so-called “damascene process” (developed by IBM in the 90s) also requires the usage of cobalt to interface the active layer with this latter one.

The current trend in this area is to try to design smaller and smaller chips while maintaining or even exceeding the power of current configurations. The use of IC eliminates the manual labor and the soldering that would be required to fabricate complex electronic devices, making the final product less expensive, more reliable, and, most importantly, smaller. The cost of making integrated circuits has reduced significantly over time due to increasingly efficient and automated technologies and strong economies of scale, and they have become relatively low-cost components.

Moreover, the manufacturing cost of an integrated circuit varies very little as its complexity increases, so it is, in proportion, very economical to develop even very complex circuits.

The silicon integrated circuit thus qualifies as the basic element of electronics, now increasingly common, valuable and practical.

There are various kinds of chips that are currently manufactured by semiconductor companies. They are usually grouped in two main manners: the most common way to divide the semiconductors is by functionality, while sometimes they are instead classified in terms of what ICs are used in their manufacture.
When their functionality is considered, four further categories can be identified:

- Memory chips. This first type of chip is used for the storage of data and programs, on both data storage devices and computers. Even within this category, different types may be further distinguished. Time-limited workspaces are provided by RAM (random access memory) chips, while information is stored in a permanent manner by flash memory chips, unless being deleted. ROM and PROM chips (Programmable Read-Only Memory and Programmable Read-Only Memory, respectively) are created specifically for the purpose of being non-changeable, while both EPROM (Erasable Programmable Read-Only Memory) and EEPROM (Electrically Erasable Read-Only Memory) can be modified.
- Microprocessors. This category of chips is the one related to devices that contain one or more CPUs (central processing units), such as smartphones, personal computers, and computer servers. In mobile phones, the chip architecture that is typically used is ARM, while 32- and 64-bit microprocessors relying on x86, SPARC and POWER architectures are used in servers and personal computers. Instead, lower-powered 8-, 16-, and 24-bit microprocessors usually can be found in items such as automobiles and various toys.
- Graphic Processing Units. GPU is a type of microprocessor able to effectively render the graphics for displays used in electronic devices. Since 1999, the GPU has been known to consumers due to its use in both modern video and video games, providing very smooth graphics than those provided by CPUs, which up to that time were used to handle graphics rendering. Moreover, the performance of a computer can be increased when a GPU, which cannot run many calculations at the same time, is used in conjunction with a CPU, as in this way it is possible to accelerate the elaboration speed of the applications.
- Commodity ICs. These are standard and very simple chips, produced in large batches and typically used to perform repetitive processing routines, usually employed in single-use devices.

If, on the other hand, chips are divided according to the types of integrated circuits they use, the main categories are analog, digital and mixed. The majority of today's computer processors employ digital chips, which typically involve a combination of transistors and logic gates. Digital chips have replaced almost all analog chips, which were more noise prone and susceptible to voltage variations, increasing the likelihood of causing errors. Finally, mixed-circuit semiconductors are generally defined as digital chips with embedded technology designed to work with both analog and digital circuits.

3.1.2. Chip industry market structure influences the shortage

As was anticipated at the beginning of this section, a worldwide chip shortage is currently being experienced, impacting many manufacturing industries. The severity of the situation is also increasing further in the last period, with the demand for chips continuing to exceed the supply capability. According to a Gartner analyst, A. Priestley, the impact of the chip shortage will be suffered by millions of people worldwide, as the average person will not be able to get an item they want or will get it at a higher price.

The world's leading chipmaker, Taiwan Semiconductor Manufacturing Company (TSMC), recently asked its international customer base to accept a price increase, necessary to finance the investments required to meet the "structural and fundamental increase" in global demand for microchips. For this year, the Taiwanese company has already announced a record increase in capital spending, amounting to $28 billion.

Susquehanna Financial Group (SFG) collected industry distributor data highlighting how lead times recorded in February 2021 have lengthened to 15 weeks on average. This is the first time such long lead times have been noticed since their data collection began, four years ago, in 2017. In addition, Broadcom Inc. (a global tech leader which is involved in the entire supply chain, then considered as a crucial indicator for the industry) reported average lead times of 12.2 weeks in February 2020, while a year later this number has almost doubled, extending to 22.2 weeks.

Chart 2, published by Bloomberg in 2021, shows average statistics calculated from data provided to SFG by four different distributors, pointing out how in early 2021 lead times for chips far exceeded the other major peak of strong demand that was instead recorded in 2018. The result of the latter was a disastrous surge in double orders, and it is not so implausible that also the present spike will turn out this way.

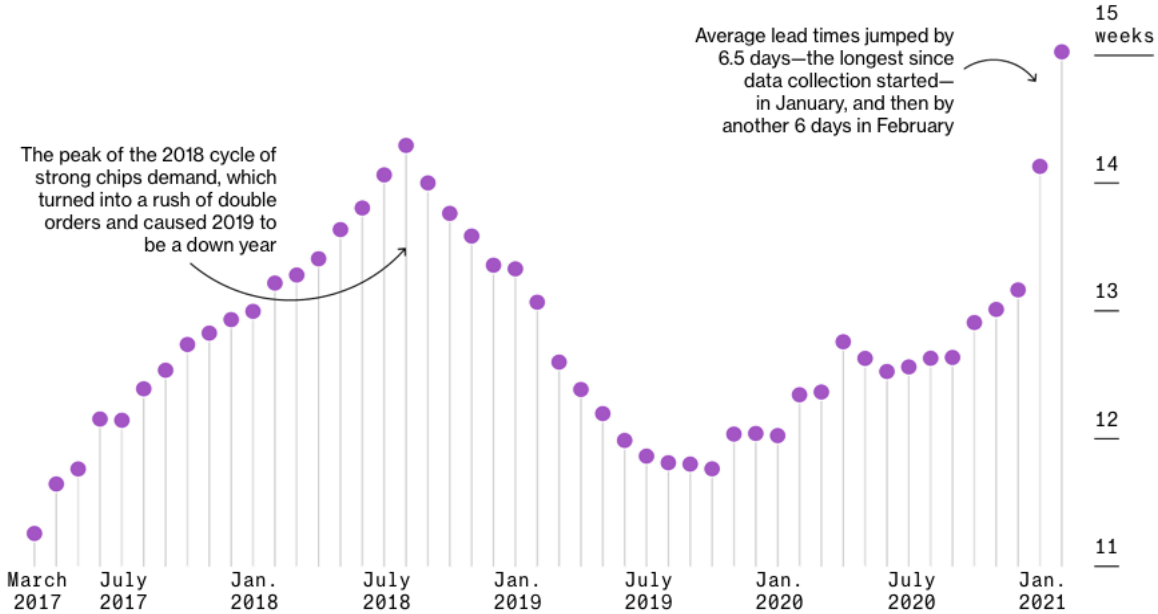


Chart 2: Average lead times calculated on data from four different distributors. (Bloomberg, 2021)

It is a crisis that has alerted not only the world of the electronics industry but also the political one, worrying in particular American, European and Chinese governments, connoting this industry as an important strategic asset for the future in light of today's chip shortage and the ongoing race for technological supremacy.

The key bottlenecks in this complex scenario are the so-called foundries, which are advanced factories responsible for the production and the realization of many large electronics companies' projects. In fact, numerous big-name firms, such as Nvidia, Qualcomm or Apple, are now "fabless" meaning that they just design the technology and the chips that underpin their products, while the actual manufacturing is delegated to these foundries and now only very few of them account for most global chip production.

Approximately 91% of the total chip manufacturing is then estimated to be located in Asia, specifically in Taiwan and South Korea. It is right here that TSMC and Samsung Electronics Company have their headquarters. These two industry giants, in addition to being Asia's two largest chipmakers, are also responsible for producing most of the world's most advanced silicon.

Globalfoundries based in California and United Microelectronics Corp. based in Taiwan are their direct competitors, responsible however for a much smaller share of production.

An overview of how the foundry business is dominated by Asia-based companies is shown in Chart 3, constructed by Bloomberg (2021) from TrendForce data.

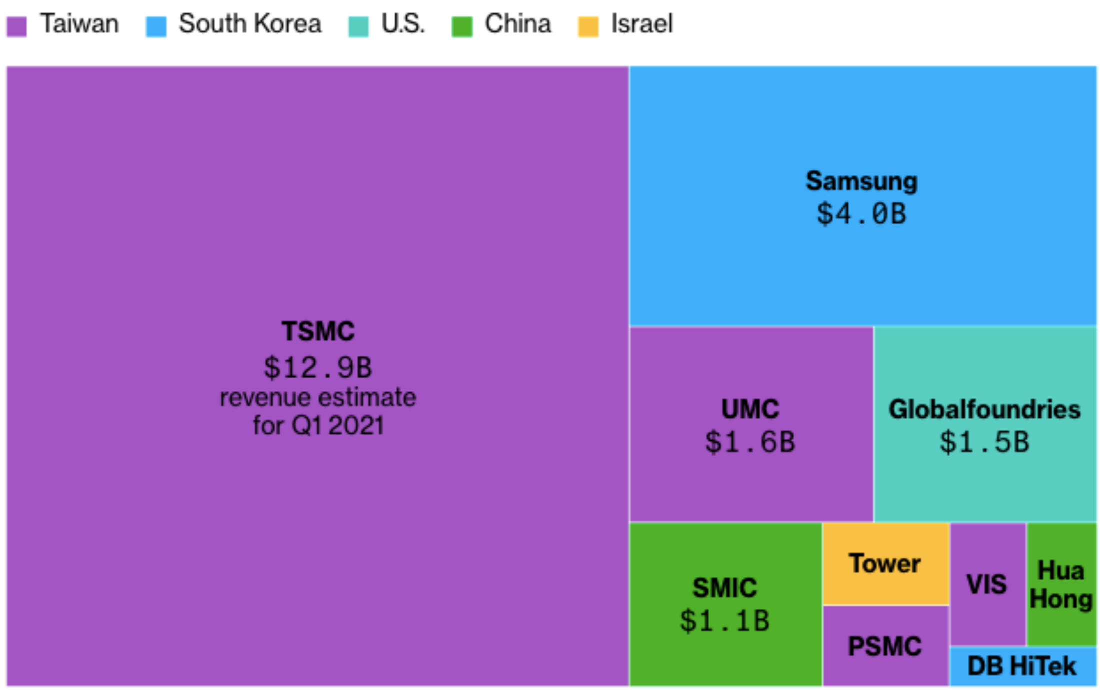


Chart 3: The foundry business dominated by Asian companies. (Bloomberg, 2021)

However, when looking at revenue, U.S.-based Intel Corp. is the largest chipmaker. At the beginning of 2021, it announced that it is developing a $20 billion plan that would allow it to expand its foundry business producing more also for other American semiconductors companies outsourcing their chip manufacturing. Intel is not indeed a fabless company like many of its direct competitors, but it designs and manufactures its own chips, also selling them to other companies in order to get additional profits by keeping its manufacturing plants occupied, which cost several billion dollars to be built.

With regard to the success of the aforementioned new plan, which would enable the U.S. to gain independence in the chip business, only the future will tell to what extent it is achievable. What is instead certain nowadays is that in 2018 this company deployed all its R&D forces to try to get smaller and smaller chips, announcing that it would develop new 10nm chips that would outperform the previous 14nm chips. It was sensational news at the time, but it turned out to be too ambitious and even ended up being harmful for Intel. The company's CEO, Brian Krzanich, has in retrospect explained that in 2018 Intel did not yet dispose of the EUV (Extreme UltraViolet) lithography process, which was the main reason why the release of 10nm chips was delayed for a long time. In fact, in order to obtain transistors smaller than those that were already feasible, more efficient lithographic processes in terms of resolution were required. This is because the physical limit to enable this type of production is indeed the phenomenon of electromagnetic diffraction, therefore smaller wavelengths result necessary.

The fact that Intel's efforts were all concentrated around the development of this new product has actually negatively affected even the normal production of the company's existing chips, leading to a reduction in its overall manufacturing activity. This has impacted not only the company but also every external PC manufacturer that used to purchase chips from Intel. The typical production logic of these companies is the just-in-time, which is the reason why they were forced to switch to other chip foundries for their supply, in order to avoid stopping their own production due to their empty warehouses.

As a result of these missteps, Intel's influence in the chip business has slightly diminished, further strengthening the one of TSMC and Samsung accordingly.

Since the beginning of 2021, all eyes are then mostly on the latter two companies, as they proved to not have the capacity to meet all the existing demand for their products during this time frame even if they are already manufacturing chips as fast as they could. The natural consequence of it is the aforementioned bottleneck, that is bound to not be solved before several quarters. According to the most pessimists, it may extend into next year (or even the next one yet) before being resolved.

Nonetheless, despite the huge efforts of the arch-rival Samsung, TSMC is undoubtedly, and in every respect, the undisputed leader in this field. It is the largest company in Taiwan, churning out millions of wafers a year that are purchased by major customers in an impressive array of industries. This incredible achievement has been made possible by the billions of dollars it has invested over the past three decades to keep itself at the forefront of this industry's technology, striving to perfect its craft as a chipmaker.

Twenty-five percent of all of TSMC's business comes from Apple, as revealed by Bloomberg's estimates of its supply chain, which is also the most prestigious customer for whom it produces chips directly.

TSMC also produces chips for fabless chip designers and for many other semiconductor firms. In addition to the already mentioned Qualcomm and Nvidia, it is in fact also the main supplier for AMD, Broadcom and Texas Instruments. But that is not all, as TSMC's importance increases further when the critical role it plays in the entire semiconductor supply chain is considered at large, since the aforementioned companies in turn are in charge to supply the world's largest consumer electronics, communications equipment and cars components companies.

The nub of the issue is exactly this form of industry oligopoly.

In fact, as has been pointed out so far, this advanced manufacturing has become over time centralized in the hands of fewer players, making the chips an increasingly critical product. This is referred to as an oligopoly because the cost of keeping up with technological advances has increased exponentially, especially in the last decade, making the business of semiconductor manufacturing an exclusive field within the reach of a few companies, precluding in this way the arrival of new entrants. At the same time, existing players have also had to increase their capital expenditures projected for 2021, such as TSMC and Samsung, which are investing hundreds of billions of dollars in order to remain competitive.

Moreover, Samsung was the first major company to warn of the consequences of this crisis, pointing out that it is a "serious imbalance" at a global level and that its appliance and television production is being seriously hit by this semiconductors shortage, encountering difficulties especially in the manufacturing of products equipped with displays. The managers of this tech giant have therefore decided to react to this critical situation by assigning the remaining available components to their products following an order of priority and urgency. One example is that the company recently announced that the launch of the latest model of the popular Galaxy range, the new Galaxy Note smartphone, could skip for this reason and thus be postponed to no earlier than 2022. The danger is to end up in a situation like the one of Sony, which has launched its new gaming console (creating a lot of hype) the famous PlayStation 5, disappointing those who would like to buy it because due to the lack of chips, it is very difficult to get it (Griffin, 2021).

However, despite the fact that the first alarm bells started ringing months ago, even today many companies that are at least partially affected remain reluctant to admit publicly that they are in trouble, hoping to somehow get out of this situation without having to cancel their customers' orders.

3.1.3. The automotive industry in the eye of the storm

Although, as mentioned above, the sectors hit by this crisis are countless, the business undoubtedly most affected worldwide is the automotive industry. In a moment in which modern cars demand is already high, the new vehicle availability has been impacted, as much as their deliveries across the worldwide industry.

This is mainly due to the fact that modern automobiles growingly rely on electronics, consequently also on semiconductors. In fact cars, which were in the past made largely only of mechanical parts, in recent years have become increasingly intelligent thanks to the development of technology, which entails a massive use of chips.

This is a trend destined to keep on growing in the coming years.

According to a recent Deloitte report, automotive electronics (which include a huge variety of internal car devices, such as displays or in-vehicle systems) are expected to account for 45% of the cost of manufacturing a car by 2030. Also by 2030, it is estimated that the cost of semiconductor-based components used in these electronic devices will rise to $600, up from $475 in 2020.

Well-known international companies such as Volkswagen, Ford and Jaguar Land Rover have already closed some factories, laid off employees and slashed the production of vehicles. In addition, this limited supply of electronic components, according to Bloomberg (2021), is leading some automakers to leave out high-end features that were normally included in some car models before the crisis. One example comes from Renault, which is no longer placing an oversized digital screen behind the steering wheel of some models, as it was used to doing.

At the beginning of May 2021, TSMC stated to be confident that they will be able to reach automotive demand by June, although many experts say that would be a far too optimistic timeline, considering how vast the chip shortage issue is in this sector. Moreover, the automotive industry is not the highest priority of the foundries, as only 3% of TSMC’s 2020 sales were from car chips, while the electronics companies account for a bigger sales share, as the 48% recorded in the same year for smartphones.

This problem was also exacerbated by the fact that the automotive industry tends to use not so advanced chips as high-tech companies, continuing to prefer the ones produced by older manufacturing processes. Chip makers, on the other hand, are moving in the opposite direction, no longer investing in the capacity of older processes but moving toward the production of more and more advanced chips.

It should also be noted that automakers typically employ just-in-time inventory logic in their manufacturing processes, which means they avoid stocking extra parts needed to be more cost-effective.

Relying on a lean manufacturing approach has therefore allowed them to realize huge cost savings, but they have at the same time exposed themselves to the supply risk. Indeed, this method is brilliant when things are going well, but in the case of disruptive events, such as this widespread chip shortage, this philosophy might actually show what its Achilles heel is.

Poor inventory planning which, as noted in the previous chapter, is a crucial factor for any manufacturing company and could therefore be a further reason why automakers were hit first by this crisis.

It is estimated that the industry is set to lose over $61 billion in sales this year alone due to their misstep which also led them to underestimate the consumption of vehicles and thus the amount of chips they needed.

According to SEMI data, which focused on analyzing the upper side of the supply chain, chip manufacturing capacity has kept pace with sales growth in recent years.

They also pointed out that semiconductor demand has generally been on par with disposable manufacturing resources, as buyers are taking capacity as soon as it is brought available online. But in recent times the market's insatiable appetite has remained dissatisfied, as the world's biggest chip makers are not able to manufacture these products fast enough to fulfill the market's insatiable appetite.

Moreover, low-end chips are produced from 200-millimeter wafers, the supply shortage of which has been particularly reported by industry experts. The problem related to this scarcity is especially relevant as these chips are the ones used in displays integrated circuits that are required in a broad range of industries, including the already mentioned automotive and widely used gadgets.

In two recent statements, TSMC executives said that their customers in many industries have decided to start accumulating more inventory than usual as safeguard against future adverse events, but it may be too late to make up for the 2021 production delays. In fact, companies operating in a wide range of industries are all trying to buy as many chips as possible to continue to manufacture their products and recover the pace of production that they had before the crisis, thus leading to a further increase in demand for chips that is bound to remain unsatisfied for a period not so short. Moreover, due to the fact that the stockpiles of many firms are being boosted, this is causing chips to be even more difficult for other companies to obtain.

Unfortunately, the troubles and challenges are not finished here, as most consumer products have extensive supply chains, and the impact of chip shortages in some areas has yet to begin to be seen. Furthermore, other parts of the supply chain may also emerge as new bottlenecks.

For instance, a further monopoly can be glimpsed in the hands of ASML Holding NV, a Dutch-based company that over the years has concentrated in its hands the production of modern photolithography equipment needed to reproduce the advanced chip patterns on the wafer.

That for chemicals required in semiconductor production is also a market increasingly dominated by a few Japanese companies, including Shin-Etsu Chemical Co.

In addition, Synopsys Inc. and Cadence Design Systems Inc. are two U.S. multinationals that lead the industry in automation software used for electronic design, without which manufacturing cannot begin.

Politicians around the advanced world are the most worried, particularly the United States and Europe, and have been urging Taiwanese authorities to aid them in solving the global chip crisis. They are at the same time pushing for the development of national chip manufacturing facilities, but governments cannot actually do so quickly to address the current chip emergency, since it

takes years to build a completely new production facility and start running it in a smooth way, regardless of where they decide to locate it.
In one of the following subsections it will be explained how one European company in particular had the foresight (combined also with a good dose of luck) to develop in advance a strategy based on the construction of a plant for the production of chips that would be able to reduce the dependence on Asian suppliers.
But before doing it, it will be examined what combination of factors has led to this complex situation of chip shortages, in order to complete this overview on the issue.

3.1.4. A blend of causes, one result

Generally, shortages of goods in a market are due to a significant increase in demand, a supply shock, or a combination of both, as in this case in which the outcome cannot be attributed to one single factor.
Some of the causes of this semiconductor shortage crisis, which so far has had enormous consequences worldwide and is expected to have further implications in the near future, have already been mentioned in the previous subsections, but they are not the only ones affecting this complex situation.
Listed below are the six most likely causes that have led to this ongoing shock, although this is certainly not an exhaustive list as there may be other hidden factors not yet evident at the time this analysis is conducted.

1. Intel's missteps.

   As was previously mentioned, in 2018, Intel, the world's biggest producer of x86 CPUs for computers, faced a chip shortage due to delays and issues in developing their new 10nm chips, which in turn affected its usual manufacturing of 14nm chips. Not even time to recover from this shortfall that last year this company ended up making another false move by delaying the release of its new 7nm chips as well. The sum of this multinational company's recent faux pas have caused more and more PC producers, a traditional just-in-time industry, were forced to purchase the needed CPUs from the Intel direct competitor AMD, the second company in the world in the manufacture of microprocessors with x86 architecture, thus putting pressure on its supply capacity. As opposed to Intel, which produces its chips with its own in-house foundry, AMD is accustomed to outsourcing the manufacturing of the majority of its chips to TSMC, which as noted above is the world's most cutting-edge chip foundry. So AMD's unexpected rise in demand led to greater pressure on TSMC's facilities, putting its production capacity under further strain already before the pandemic.

2. The fluctuating price of memory chips.

   In the period between 2017 and 2018, then in parallel to what was described in the previous point, the price of memory chips increased substantially, only to fall as much during 2019 and early 2020 due to weak demand from the smartphone and PC markets. This led the largest DRAM and NAND chip makers (Samsung, Micron Technology, and SK Hynix to name a few) to reduce the amount of product being manufactured, right in the run-up to the pandemic during which the demand for chips will increase dramatically.

3. The Covid-19 outbreak related crisis.

   As highlighted by the previous two points, this was already a shaky market when the pandemic began at the beginning of 2020. In addition to this, as the pandemic began to spread worldwide, there was a disruption, albeit temporary, in global semiconductor shipments. At the same time, due to the forced spread of remote work and online learning, as well as other trends related to staying at home, global demand for new PCs and mobile devices rose dramatically compared to the previous years.

   After the disruptions they initially suffered, however, most chip manufacturers were able to recover, and in response to growing demand also memory chip manufacturers quickly increased their production. In addition, it has to be noticed that TSMC's more advanced facilities based in Taiwan were not highly affected and they never experienced a closure as many other foundries.

   But even so, the chip industry still was not able to satisfy the market's appetite. In the last 12 months TSMC's factories have already been operating at their over 100% utilization and the company recently announced that it is planning to spend $100 billion over the next three years to further expand its facilities. Moreover, according to Intel, to solve the global chip shortage would require immense investments, and even so it is set to last for another two years.

4. Tailwinds persisting.

Over the past few decades, it has been noted that global demand for chips has usually followed a cyclical pattern. However, the rise of new technologies, such as 5G networks cloud services, is fueling a sort of "supercycle" of chip upgrades, which could take much more time than a typical cycle.

It has already been mentioned how modern connected devices, such as cars and smartphones, require an increasing number of more and more complex chips for their production and how these electronic components represent increasingly a large portion of the total costs of the final product.

Even before the pandemic, many chip manufacturers had predicted that this supercycle would eventually increase demand and consequently their sales. But due to the crisis related to the spread of Covid-19, many of these trends already in place ended up accelerating rapidly. The temporary interruption of shipments has also further increased the pressure on the supply chain, leading to the global chip shortage dragging on.

5. The current technological war.

Another pressing issue nowadays is the prolonged technology war between the U.S. and China, which has intensified with President Donald Trump and is still ongoing with President Joe Biden. Huawei and SMIC, as well as several other large Chinese companies, have already been sanctioned by the U.S., though not without national security concerns. Those penalties are aggravating China's shortage of advanced chips, but they are also pushing the Chinese government to attempt to reduce its overall reliance on overseas technologies by aggressively investing in its domestic chipmakers. This trend could end up causing the U.S. and Chinese markets to become disorderly.

6. An independence hard to earn.

The Biden government recently suggested investing more than fifty billion dollars to boost the U.S. chip industry, but it is not likely that this new money will be able to quickly fix the present chip scarcity. This is because most of the global semiconductor market still relies on the Asian companies mentioned above, which are therefore more important than most of the American chip makers who still remain dependent on these overseas suppliers, with their supply chain that has repeatedly proven in recent times to be fragile and prone to disruptions.

7. Rising raw material prices.

Almost all raw materials have become unavailable and very expensive at this time, as a result of the combined effect of three factors: real, financial and logistical.

The first factor is linked to the fact that in the first months of the pandemic, due to the closure of many production plants, the values of raw material prices fell by 20-30%. China immediately took advantage of this to build up stocks, also benefiting from the fact that it had restarted four months earlier. But immediately afterwards, prices began to rise again because all countries started up again suddenly, with the warehouses of companies empty due to the just-in-time organization to which many are used since they do not accumulate stocks in order to be more efficient and therefore now need to be filled from scratch.

The causes linked with financial markets are also relevant because raw materials have become an interesting investment thanks to their pricing in dollars, a weak currency at this time, so they are convenient for those who buy them in other currencies.

In addition, transportation costs have also increased dramatically.

The Dry Baltic Index, an index summarizing sea freight charges for products such as minerals, has recorded a peak of +605% in the last year. The introduction of the new regulation approved by the International Maritime Organization is one of the most significant causes, which requires all ships to lower the sulphur content of fuel oil from 3.5% in January 2020 to 0.5%. This change has led to the scrapping of some ships and renovating of others, including container ships and bulk carriers transporting goods overseas, and the cost has been passed on in prices. (Gabanelli and Querzè, 2021)

There are also some raw materials that are proving to be necessary in unprecedented quantities, indispensable to the digital revolution underway in the production system.

In particular, copper, lithium, silicon, cobalt prices are involved which, as mentioned earlier in the chapter, are materials used in the production of chips and are also essential components of new car batteries. Chart 4, elaborated by Professor Achille Fornasini, University of Brescia, on Lme (London metal exchange) data, provides a useful overview of the situation of the rising prices of such raw materials.

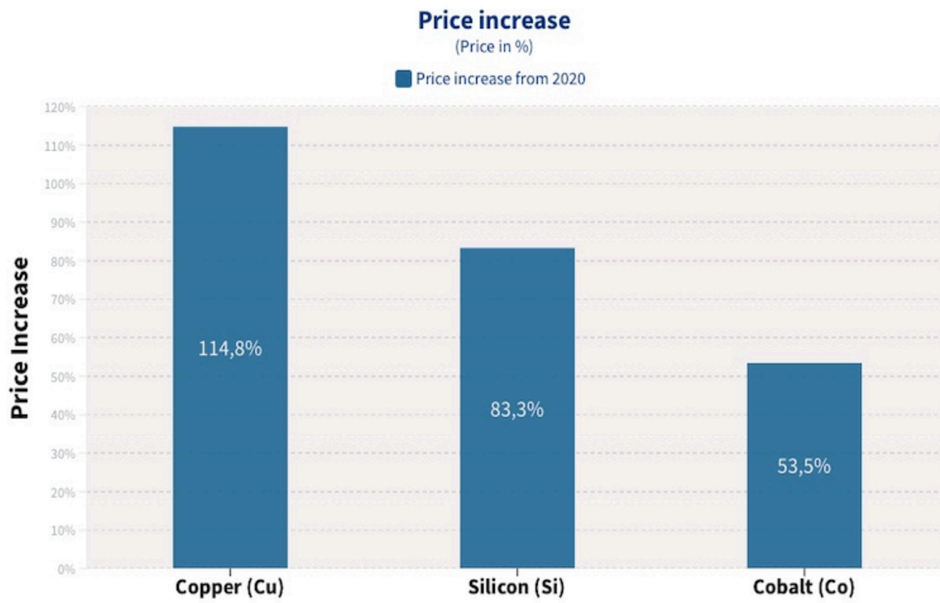


Chart 4: The rise in prices (data in percentage) from 2020, Professor A. Fornasini, University of Brescia (2021)

Naturally, these are only a part of the causes that have led to this situation of global imbalance, as many other factors involved in this undesired outcome may have been overlooked in this analysis, given the complexity of the IT sector and its related markets, and others may still have to come out and explicit manifest themselves.

In fact, this non-exhaustive list of causes does not consider further challenges that will probably have to be addressed in the future.

On the other hand, it should also be taken into account that sometimes not all bad things come to worst, as the case of SMIC, China's largest foundry, is proving. It is a chip manufacturer not able to produce the most cutting-edge components like TSMC and Samsung, as its technology is far behind rivals. This is because, as was anticipated above, the U.S. government has sanctioned SMIC and added it to an export blacklist known as the Entity List, which restricts U.S. companies from exporting technology to this Chinese company, a move that has hurt SMIC's ability to produce the most advanced chips. In fact, TSMC, Samsung and SMIC rely on machinery and software from U.S. and European companies to produce chips, but if SMIC has no access to these tools, it becomes extremely hard for it to catch up with its rivals. But SMIC is still able to produce semiconductors based on older technology, which could work to its advantage since, as already pointed out, cars and other products don't require cutting-edge chips and this is a market that the company's competitors do not find very attractive. "*Every cloud has a silver lining*" states the famous saying emphasizing the fact that every unpleasant situation may have positive spin-offs, which seems fitting in this case where the Chinese chipmaker could end up being therefore a beneficiary of the global chip shortage.

3.1.5. The Infineon case: foresight and serendipity

This complicated and difficult context is therefore pushing several nations to think about how to increase the number of chips they are able to produce on their own.
It has already been mentioned how the US, the second biggest chip producer, is attempting to invest in this industry, promoting R&D and taking steps towards reshoring some important phases of semiconductor manufacturing, trying to reduce their supply dependence from Asia also by sanctioning and penalizing their companies operating in this industry.
Not only the U.S. administration, but also the European one is planning to support local manufacturing of high-tech equipment with specific aid, with the aim to make it more cost-effective for their companies operating in the industry to settle back in their home country, and not just keep on relying on outsourcing to the Asian continent. Last December, in fact, ministers from 17 EU member states signed a joint declaration sealing their commitment to combine the efforts to improve this critical industry. With these statements they have then decided to join forces to invest in the hitherto mainly Asian-led industry of processors and semiconductor technologies. In fact, Europe currently relies almost exclusively on chips produced abroad, a dependence that until the advent of the Covid-19 pandemic did not seem so worrisome but is now very penalizing and a great source of vulnerabilities.
At the beginning of the year, Germany said that total joint EU investments in this sector could amount to up to 50 billion euros and Germany's prime minister for the economy, Peter Altmaier,

is further pushing to expand state aid for companies operating in this sector to enhance their manufacturing capability, with the full approval of the chip firms with the largest presence in the country, GlobalFoundries and Infineon Technologies. A spokesperson for the latter company stressed that rapid action by member states is essential, as this plan could make a significant contribution to boosting Europe's overall economic competitiveness and its geopolitical robustness.

Infineon is a German company that has faced many challenges during this turbulent period, as it has always outsourced part of its production to Asian manufacturers. But thanks to foresighted management and improvement of its inventory, it has not suffered in this context as much as many of its direct European competitors.

But it is not only this that makes this company interesting for this analysis.

In February 2021, Infineon also declared that its future plans specifically include expanding its manufacturing capacity to help tackle global chip supply shortages, thereby moving closer to its goal of meeting its customers' long-term needs.

Indeed, since the end of 2017 this chip company had announced its expansion into Austria. Despite the penalizing situation linked to the pandemic, CEO Reinhard Ploss stated that the Villach production site in any case will become fully operational as planned by 2021 (optimistically by the end of summer) bringing a breath of fresh air to the European market. In fact, the Austrian plant is expected to be able to produce enough power semiconductors annually to equip the drivetrains of 25 million electric vehicles. Ploss added that the construction of an additional plant in Dresden is also scheduled to begin soon, which will allow the company to control production at this site and the 1.6 billion of euro plant in Villach as if they were one single plant, in an effort to gain greater flexibility.

The upcoming construction of the new, completely automated high-tech chip factory in Villach that will be dedicated to producing 300-mm thin wafers, seems to be perfectly timed in light of the chip shortage problem, even if, as was reported above, this was a decision made by Infineon's managers years ago, so long before they knew what the present circumstances would be.

What is important, however, is not whether this decision was the result of a fluke or a series of very forward-looking decisions by the company, but the result that this German enterprise will be able to achieve in the near future. In this way, in fact, Europe is taking a step towards greater independence from Asian countries with regard to the supply of semiconductors, allowing additional production capacity within the continent.

A strategy that, as previously mentioned, even the United States would like to adopt, but the construction of this type of production plants takes a long time regardless of the amount of capital invested, implying that the new American chip manufacturing facilities will be productive only after the storm of the semiconductor shortage has passed.

What should be taken into account is that Asia is not ready to throw the towel in this power struggle, as demonstrated by the recent news of the Chinese company Shenzen Invenland holdings that has tried to buy 70% of the Italian Lpe of Baranzate, in the Milan area, a company active in the development of epitaxial reactors used for the production of semiconductors.

But the Italian executive, led by former ECB president Mario Draghi, has opposed this transaction by exercising the "golden power" option over the Chinese company, thus vetoing the entire operation. Draghi's move has to be read as closely linked to the Biden administration's attempt to curb China's presence in an increasingly global strategic sector such as semimetals, as a reaction to the fact that the Asians have no intention of surrendering.

The future is then still uncertain and it is very difficult to predict which balance will be established in this sector under the crosshairs of the whole world and which country will become the leader of this strategic business. This notwithstanding, the new Infineon factory that will soon be operational will certainly bring some advantage to Europe, whose companies will finally be able to be more autonomous in the production of these crucial components. It provides then an excellent example not only how essential it is to keep at least a safety stock of materials, but also of how deciding to reshore a part of the business could be more costly due to the capital investment needed, but by shortening the supply chain it is possible to render lean factories work smoothly and with less fear of supply disruption, resulting in a more robust and resilient process.

3.2. How Brexit-related threats may turn into opportunities

The second real case subject of this thesis will now be analyzed, focusing on the Japanese car company Nissan and the complications that have arisen in relation to Brexit in the UK. Before starting the analysis of the specific case in hand, however, it is considered useful to define more thoroughly the context which is being referred to.

The term Brexit refers to the process of Britain leaving the European Union, which was initiated after the referendum on June 23, 2016.

To understand the historical context thanks to which this decision was arrived at, it is necessary to emphasize that since the very beginning the British conservative parties have never approved the contributions that the United Kingdom was forced to pay to the Union. But it was not only about this discontent.

In fact, this ill-feeling was compounded by the issue of immigration: the entry of European immigrants into the country monopolized any discussion about the referendum. The more rural UK, even in the areas where immigration was at its lowest, expressed concern about the foreign invasion, blamed for lowering minimum wages and putting pressure on public services.

However, without the political push, the referendum would not have taken place.

In February 2016, then Prime Minister of the United Kingdom and leader of the Conservative Party David Cameron negotiated a new deal with Brussels and decided to call the referendum for voters to decide whether or not the UK should remain in the Union. Cameron was an anti-European conservative who during the election campaign had pushed the issues of immigration, free trade and had spoken out against the power of the European Union.

After the announcement of the referendum, two factions were immediately and naturally created: the remain and the leave.

Although David Cameron had promised the referendum to the voters during his election campaign, he had declared himself pro-permanence, together with the other half of the Conservatives; on the other hand there was the side for the exit, headed by Boris Johnson and Nigel Farage.

Nowadays it is well-known how this situation came about, but what is not yet clear is what will be the long-term consequences of this decision that has shaken Europe and the whole world. The greatest risks in the period after the referendum until the end of 2020 were indeed both economic and political, as it was unclear whether the nation will continue to have its significant influence on global markets and Western society and whether companies will leave the country for more open legislation. If the answer to the latter issue was yes, the question will also shift to understanding what this migration of workers and capital will mean for the British economy, especially if an agreement could not be reached with Brussels. The following section will examine in detail what these threats were for companies operating in the UK and what has changed for them after the announcement that a soft Brexit was reached.

3.2.1. Side effects of the referendum: Brexit challenge on multinationals

As was already mentioned above, on June 23th 2016, after a tough election campaign, the British citizens made their decision: 51.9% of voters are in favor of leaving the European Union. The process for the UK's exit officially began on March 29th 2017, with the delivery of the letter in which Theresa May formally asks to leave the EU to European Council President Donald Tusk, initiating the Article 50 procedure, which provides for the possibility of leaving the Union.

This was followed by a series of negotiations, postponements, rejections, and negotiations again leading up to the date of January 31th 2020, the last day of the United Kingdom's official stay in the European Union.

The UK has dedicated a large part of 2020 especially to face challenges both on the national front, considering that in Scotland and Northern Ireland the electorate voted to remain in the EU, but also, and above all, on the international front, as a considerable amount of time has been dedicated to negotiate free trade treaties.

In fact, after the initial debate between the UK and the EU resulted in the withdrawal agreement that implemented the UK's exit, negotiations began for a permanent agreement governing trade and other relations between the EU and the UK after the end of the transition period.

This particular moment of changeover has emerged as the one of greatest concern for all stakeholders involved at least in part in this uncertain situation. This is also because the Brexit vote and its final outcome on EU and non-EU multinationals operating in the UK was expected to have adverse economic and financial prospects for the country.

These negative likely consequences could have been basically divided into three profound impacts: financial, economic and legal, and labor mobility.

The financial implications could be detrimental in the form of increased business and administrative costs, decreased foreign direct investment (FDI) into the UK, and fallout for a number of select sectors.

The economic and legal consequences of the vote were equally inevitable, putting a strain on the nation and its companies whose business operations are closely tied to other EU countries. Brexit could have caused increased trade costs for EU multinationals seeking to engage in international trade while operating in the UK. In addition, the economic effects of the Brexit vote could have potentially resulted in inflation and increased costs of imported goods for UK residents. Additional negative economic implications could result, such as volatility in the British pound and the economy in the short term.

In addition, a possible implication of leaving the EU is arguably a reduction of labor mobility and immigration, devastating British businesses through increased labor costs, further strained by the ageing population prevalent in most Western European economies.

Starting on June 23th 2016, these difficulties led to speculation that it was very likely that major multinationals would be led to opt out of their UK operations and move their headquarters and businesses to another European country.

When the agreement on the future relationship between the United Kingdom and the European Union arrived on December 24th 2020, those concerns were still not fully addressed. In fact, after almost a year of negotiations, missed and postponed deadlines, and when many had lost all hope, the last obstacles to compromise between London and Brussels have been removed, although there are still many uncertainties about the future.

Crucially, British Prime Minister Boris Johnson made concessions that finally unlocked the deal. In fact, the main British problem was to arrive at a “good” deal on Brexit, because a “bad” deal would have been worse than the “no” deal. A good agreement, according to the British, basically translated into the "take back control" that has excited the extremists since the referendum, implying keeping the reins on immigration, state aid, internal market and trade agreements with the rest of the world. However, there were concerns about a hard Brexit which, according to the

Chancellor of the Exchequer Rishi Sunak, would have had an even worse economic impact on the British economy than the pandemic, at a time when Prime Minister Johnson was still drawing criticism in the country for his handling of the Covid-19 emergency. It was probably too much even for Johnson, who finally made concessions that met Brussels' demands.

The importance of an agreement was also linked to the fact that the common interests between the EU and the UK go well beyond the strictly commercial sphere: they also concern security and collaboration in the field of intelligence, the fight against climate change, research as the one on vaccines for Covid-19. The no deal would have negatively marked the future relations also in these areas, a scenario that was better avoided in the interest of all.

The three points on which the EU and the UK were mainly discussing were fishing rights, state aid rules and the governance of the agreement. In any case, on January 1st 2021, the UK would have left the EU's single market and customs union. In concrete terms, this means that restrictions on the mobility of people with a visa system have taken over and that the British government will also have a free hand in applying trade agreements with non-EU countries, already finalized with 29 countries and regions of the world out of the 40 that were already part of agreements with the EU, but under the same conditions as before and not improved for the UK, and with Japan, with which the EU does not have a trade agreement. The EU and UK have therefore mainly negotiated a free trade agreement that would allow British goods to enter the European single market without any duties and quantitative constraints (while some customs requirements have, however, come into force with possible queues at customs), and vice versa for goods coming from EU countries and going to London.

Leaving aside the question of fishing, which is of little interest in this analysis, the other two points are then much more important.

The first concerns the level playing field, which in practice concerns Brussels' fear that in the future the UK may promote standards (for example in the environmental field) that are less stringent than those that the EU imposes on its own companies, with the result of unfair competition from London. This could also occur if the UK were to recognize more generous state aid to its companies than those of European countries (which must comply with EU rules), thus distorting competition once again. The agreement foresees that London can deviate from European regulations, but not to the point of damaging free and fair competition.

This is where the governance of the agreement comes into play, i.e. the procedures that are initiated if one of the two parties believes that the other has engaged in unfair behavior or refuses to respect the agreements. On the crucial issue of governance, Brussels would have obtained a particularly streamlined and fast 'arbitration' mechanism in case of future disagreements on the agreement and the possibility to apply 'sanctions' (e.g. in the form of duties) if the UK deviates from fair competition or fails to respect the agreements (and obviously vice versa).

The agreement reached therefore avoids putting trade between the UK and the 27 EU countries at risk. In fact, the UK exported 43% of its goods to the EU in 2019, and was therefore far more vulnerable to the lack of a trade deal than each individual European country. In the event of hard Brexit, World Trade Organization duties would have reverted to British goods bound for Europe. Although the average European duty would still have been less than 3% for all non-agricultural goods, however, for some products duties would have been much higher (for example, 10% on vehicles). In addition to the duties, it should also be remembered that a whole series of customs fulfilments and controls would have come into force (some of which will also come into force with the agreement).

In general, having reached an agreement is then a positive result, although it is not the best possible agreement for anyone, but at least it did not concretize the fears that initially arose as soon as the referendum result was announced.

However, negotiations have been protracted for far too long and the result is actually not wholly satisfactory. This is particularly true for some industry sectors and for all multinationals with subsidiaries or business interests in the UK, as in any case it will be difficult to avoid additional costs and increased bureaucracy arising directly from the split.

In fact, it is inevitable to note that the patience of many UK-based global companies has been severely tested during this period. As a result, not only tech giants but also automotive leaders have excluded the UK for their upcoming development projects. A notable example is Tesla, which has decided to build its forthcoming facility in Germany, or even Sony, which is instead relocating its European headquarters to the Netherlands.

This is mainly because it is the automotive and manufacturing industries that have had the hardest time since the Brexit was announced, as their significant physical supply chains will in any case at least partly be affected by this change, especially if their business model was founded with a just-in-time logic relying on the availability of foreign supply without any problems.
But now the context in which they operate has changed, bringing with it new challenges but also new opportunities. The case of Nissan is emblematic in this sense and will be presented in detail in the following subsection.

3.2.2. Nissan: a happy ending following initial fears

The case related to the car company Nissan and its facilities located in the UK has undergone several developments and twists and turns, particularly during the transition period after the Brexit vote. Even before the British referendum on the EU in 2016, the Japanese company had in fact warned that Brexit, particularly if it caused it to pay duties on exports, would force it to move production elsewhere. In fact, 80% of the cars that leave the local plant are sold in Europe.
After the Brexit victory in the referendum, Theresa May's government repeatedly reassured Nissan, like other UK-based car companies, that it would avoid extra costs as a result of leaving the EU, promising an agreement with Brussels that would avoid import-export tariffs or otherwise guarantee economic compensation.
Therefore Nissan, four months after the Brexit referendum, had announced that one of its models, the X Trail suv, would be started to be produced in Sunderland, in northern England, so with the prospect of new investments and new jobs shaping up as a move that had been viewed with optimism by the world of British industry and finance.
Nissan's Sunderland plant is in fact the company's largest plant in Europe. Founded as a screwdriver factory to produce the Bluebird in the mid-1980s, it now has an annual output of about 500.000 vehicles, which, as mentioned earlier, are almost all exported to European Union markets. In Sunderland, besides the Juke, models such as the Qashqai (the brand's best seller), the Note, the electric Leaf and the Infiniti Q30 are produced.

By the beginning of 2019, however, the company had second thoughts. In fact, Nissan announced that the X Trail would no longer be produced at the Sunderland plant in northern England, instead focusing its production in Japan.

The company in an official statement announced various reasons behind this radical decision, but Brexit was certainly the crucial one, as the persistent uncertainty linked mostly to the future of the UK's relationship with the European Union hinders car companies in planning their future.

For Sunderland, a town of 200.000 whose economy depends heavily on the Nissan plant, this was a troubling wake-up call, despite continuous reassurances that the decision would not cause any layoffs.

Summing up at the end of the year, Nissan has also recorded a very difficult year from the point of view of turnover at the Sunderland plant, which fell to £6.1bn compared to the previous £6.26bn and a drop in profits, which fell to £145.7m compared to the previous £149.6m.

There was also a drop in vehicle production numbers, which decreased from 487.000 in the previous year to a volume at the end of 2019 of 415.000. (Whitfield, 2019)

It has to be pointed out that in the 2016 referendum Sunderland voted overwhelmingly (61%) for Brexit, a direction also supported by the Labour employees at the Nissan plant. The reason behind this inclination was that the EU had been presented as the scapegoat for the economic backwardness of the north of England compared to the south of the country and for cuts in public assistance in the long years of austerity following the 2008 financial crisis. In addition, anti-immigration sentiments have also played a role in this scenario, despite the fact that the presence of European immigrants is only 5% in the local population. It was only in 2019 that Labour workers in Sunderland began to realize their mistake, as by voting for Brexit they ended up voting against their own interests.

In fact, the manufacturing plant gives work to more than 6.000 people, in addition to being responsible for a further 70.000 job positions in the whole supply chain throughout the North East of the country, which would have been at risk in the event that Nissan executives deemed the plant as no longer viable.

To make matters worse, the latter was not only a farfetched hypothesis. In fact, in the closing months of 2019 Nissan's European president Gianluca De Ficchy stated that a hard Brexit with no deal would likely undermine the sustainability of its European business model. Indeed, he argued that in the event that a 10% export tariff was introduced once the UK left the EU, what would happen in case the UK has to move to World Trade Organization (WTO) regulations, the Japanese company's operations would be compromised. While pronouncing these words he was in the Sunderland plant, even though De Ficchy was referring not only to that factory specifically but to Nissan's entire operations in Europe that would be at stake, such as also its plants setted in Spain and France.

The automotive industry is the UK's largest goods export sector, with eight out of ten UK-built cars being exported, mostly destined for the European market. In the specific case of Nissan, exported vehicles account for 70% of total production, thus explaining why De Ficchy was so concerned about having to bear 10% duties on the vehicles they export, also considering that around two thirds of the components needed to produce their cars come from the EU.

However, it is not the only UK-based carmaker warning about the impact of Brexit on their business, as also BMW and many others are scared not only by the cost of the tariffs they may have to incur but also by the potential future slowdown in production due to the new trade controls that would be introduced after Britain leaves the EU.

As noted above, this is an industry operating predominantly on a just-in-time model, moving components around the EU to build cars in factories across the 28-nation block, thus destined to greatly suffer in the event that additional costs and time in moving goods than those planned were added. In fact, delays in overseas supply would be disastrous for companies that rely on a Lean approach to their inventory, as if even one key part is missing from a vehicle it cannot be produced at all, leading to huge dissatisfaction among their customers and consequently to a significant loss of profits.

This explains why industry experts at the time described the situation as the beginning of the end for the UK automotive industry.

Reading the local newspapers in Sunderland, conflicting voices followed one another in the transition period after the Brexit announcement, in which rumors were followed by statements and denials from Nissan's chief operating officer Ashwani Gupta, while worried citizens could never clearly determine whether the company's manufacturing plant located in the city would continue to operate or would be closed.

The issue in fact was exclusively related to the outcome of the agreements between UK and EU, as Ashwani Gupta repeatedly stated that it was not their intention to close the facility, but that if they would not continue to operate with the tariffs they were used to, the business would not be sustainable.

As noted above, Nissan's Sunderland factory is the biggest automotive plant in the UK and one of the company's most important facilities outside Japan, producing three main models including the Juke, Qashqai and the electric Leaf.

Its closure would have been an enormous damage for all the workers employed in the factory, as well as a huge harm to the image of the whole of Great Britain, further enticing other large automotive companies to seek a new production site outside the nation, no longer a convenient location for their manufacturing processes.

Nissan therefore wanted to demonstrate a commitment to the UK, recognizing the importance of this manufacturing site and being aware of the rumors about its uncertain future that have circulated in recent years. Therefore, in 2019 the Japanese company announced that, despite having decided to move production of the new X-Trail to the Kyushu plant in Japan as it was previously mentioned, there is some news about its manufacturing in Sunderland.

In fact, they said they would invest over £400 million to start production in Sunderland of its new flagship Qashqai model, despite the threat of the introduction of new tariffs. However, these plans were disrupted by the spread of the pandemic, as production was scheduled to begin in October 2020 and then moved to April 2021. This gave Nissan more time to wait and decide how to proceed after the outcome of the UK-EU trade negotiations.

Before moving to analyze how the announcement of the reached agreement at the end of 2020, and therefore of a soft Brexit, has made the Japanese company and the entire automotive industry with business in England breathe a sigh of relief, it is interesting to mention what was reported in the Financial Times in February 2020.

In fact, in this period just prior to the massive spread of the pandemic, the newspaper reported that Nissan had come up with a plan in case of a hard Brexit. This project included the closure of the company's plants in Spain and France, allowing Nissan to withdraw from continental Europe in order to focus its efforts in the UK. The driving reason for this strategy would be the fact that through this move Nissan and its car production in Sunderland would gain a huge competitive advantage in the local market in Britain, as all other car manufacturers, for instance Volkswagen, would face huge tariffs in case they would want to keep importing cars into the country.

Nissan once again did not comment on this and neither confirmed nor denied such speculation, as it was waiting for the outcome in the Brexit negotiations before making any decisions involving its European production facilities.

As was previously anticipated, this long-awaited agreement between the UK and EU finally arrived in the closing days of 2020.

Following this news, Nissan gave an interview to the BBC stating that thanks to this new trade agreement the Sunderland plant of the Japanese car manufacturer has nothing more to fear, ensuring a brighter long-term future. In fact, not only the threat of the consequences of a no deal Brexit has been averted, but moreover this agreement ended up surprisingly turning into a new opportunity for Nissan.

Ashwani Gupta, in fact, said that the trade agreement has been very favorable for the Japanese company, as it has provided them with the opportunity to reshape the automotive sector in the nation where Nissan is the largest automaker. This is because an optimal competitive environment has now been created for their UK plant, with respect to both the internal and external national markets.

But the wave of optimism has not ended there. In fact, Ashwani Gupta also announced that their new production of the 62 kWh battery, used for the manufacturing of its Leaf electric cars, will be located in the Sunderland plant, thus putting an end to their importation. Indeed, until the beginning of 2021, only the 40 kWh batteries were made within the British plant, while the 62 kWh batteries of the top model were produced exclusively in Japan.

At the root of the strategy to transfer the production of powerful batteries to the UK is to ensure that in this way the cars produced by Nissan will comply with the new trade rules enshrined in the Brexit agreement. The treaties in fact provide that, in order to benefit from a zero tariff on

cars that are exported from Great Britain to Europe, it is required that at least 55% of the value of the entire car comes from or is derived from the UK or the EU.
As already mentioned, more than 70% of the cars produced in Sunderland are destined for export, particularly to the European market. Hence it is important for Nissan that its products are suitable for export without incurring border duties. Building all batteries within its Sunderland facility will allow it to meet this requirement and avoid any commercialization issues.
This means that the plant set in the English city, after initially being threatened by the Brexit announcement, will be earmarked to produce Nissan's new models in the years to come, also allowing the company to capitalize on the abundance of benefits that will come from producing electric vehicles, while also cutting the cost of transferring batteries from Japan. The decision to continue investing in this plant will also have positive repercussions on the economy of the area, both on the workers who will keep their jobs and an encouraging message for the British automotive industry at large. In fact, it should be noted that Nissan's renewed enthusiasm for its UK-based car production is far from shared by other carmakers, who are still hesitant about the future of their UK plants. In addition to the new rules to be complied with in order to avoid the application of duties on their cars, in fact, the rivals of the Japanese company will also have to deal with the new request of the British government, which has recently decreed a radical change towards the electric in the country, specifying that by 2030 no new petrol or diesel cars will be sold in the UK, and then gradually eliminate hybrids by 2030. Estimated costs for this change are around £4 billion in infrastructure costs, although it is likely to be much more.
The UK automotive sector is therefore still uncertain, as ironically they will have to wait and see which way Europe goes with electric cars. Indeed, being the UK's primary export market, the attractiveness of the sector and the likelihood of Nissan's rivals also investing in the country, depends on whether future electrification targets between the UK and EU are aligned.

3.3. Case studies takeaways

As has been mentioned at the beginning of the chapter, the focus was placed on two real cases related to Lean production because it is the inventory management system that ends up being more penalized in an uncertain environment full of disruptive events. In fact, the objective of this paper is not to take into consideration all the aspects linked to these business models, but only those connected with longer lead times and supply shortages.

As it is said therefore it is not less important to these purposes to focalize on the MRP and the DDMRP methods, as far as also they have some flaws when looked at in their complex but those related to the supply shortage and lead time are remarkably more important in the Lean production, that for its nature holds in its warehouses only the stocks tightly necessary to the production. While on the other hand, the issue of capital assets and risk of obsolescence, which are more typical of the MRP approach, are not relevant in this context where the focus is on which inventory method is most affected in a sudden negative event situation.

Obviously even MRP will have problems and will waver in these circumstances, as its forecasts and calculations will be completely wrong in these unpredicted situations, but the fact that at least in the early days after the shock can count on a quantity of inventory makes it more advantaged than a Lean factory. In fact, the latter can no longer produce even a single product in the event that there is a problem even in a small component, since, as mentioned above, the stocks that are kept in house are generally limited.

This weakness of Lean production, which ends up putting the entire production process under stress as soon as there is a problem, can also be seen in a positive light. This is because, by eliminating any margin for error, this philosophy forces managers to take immediate action to resolve any problem that interrupts the flow of production. The fact that a production process is put under stress means that many resources must be committed to solving the underlying problem, without being able to resort to temporary patches that naturally lead to issues that will never be fully resolved.

In this way, therefore, the company is forced to find a definitive solution that may be useful for the future, as for example Nissan has done with the decision to move battery production directly to the Sunderland plant.

Moreover, from this decision and also from the dynamics of the first case study, it emerges how crucial it can be to successfully break the increasingly long global supply chains, bringing back part of the production closer or finding nearer suppliers.

This is to decrease overseas dependence especially of essential components, as dislocating production makes it easier for companies to incur a disruptive event in at least one part of their supply chain.

The last but not the least observation regarding this issue, is that for every problem there is always a solution and taking cue from the DDMRP method it can be noticed like having an effective buffer of product stock would have been essential above all in these circumstances (without obviously falling in the opposite creating enormous wasteful warehouses) but a correct amount of supply and not scarce like generally that one of the Lean production can turn out essential in order to survive in turbulent environments.

CHAPTER 4: Modelling of the analyzed real case

As has been previously mentioned, this chapter will take the analysis one step further.
In fact, in the present section an analytical model connected to the first real case examined in the previous chapter will be proposed, focusing on a more detailed examination of the factors that have been identified as the most likely causes responsible for the current situation of worldwide microchip shortage. It has already been said that indeed this situation is not exclusively linked to a single triggering factor, but that there has been a chain of events that have followed one another until leading to this dramatic scenario.
The attempt to improve the understanding of this sequence of events in its most meaningful steps and the effort to grasp how the final outcome could have potentially changed in the case in which one or more of these triggers would have gone in another way represents a further useful deepening of the problem in question.
It has been chosen therefore to analyze these dynamics through the construction of a model, since thanks to this theoretical construct it is possible to represent the situation through a set of different alternatives and a series of logical and quantitative connections between them.
In this construction assumes great importance the simplification effort, as the process that led to the current microchips shortage is very complex and full of variables interacting and affecting each other repeatedly. In such a context, it is therefore necessary to carefully select which are the most relevant variables and their more significant relationships, since analyzing every single detail would be impossible and even not useful.
A model in general, in fact, has no pretensions to be an omnichomprehensive representation, as such expectations would be immediately invalidated by computational infeasibility and by incompleteness and scarcity of available data.
Therefore, the conclusions that can be drawn from the models will simply be reduced representations of the cases being analyzed. Nevertheless, appropriately built models have the potential to remove extraneous information and to isolate the relevant factors and relationships among them, thereby allowing a better understanding of the entire phenomenon.

Also the selection of which typology of model to adopt among the several existing ones is fundamental, inasmuch as it is necessary not only to choose accurately which variables and which relations between them represent, but also to choose carefully how to organize this information and how to represent it in a meaningful and effective way.

In this regard, before starting to examine the individual triggering factors, the following subsection will briefly present the method that was selected to represent as appropriately as possible the concatenation of events in question, in an attempt to facilitate the conceptualization of the case study.

Subsequently, the individual causes previously identified as the main culprits of the unfortunate situation will be considered in chronological order, and then brought together in a single chart to provide an understandable overall representation of the present scenario and the steps followed to achieve it.

Speculation will then be made according to a "what if" analysis, including thus considerations concerning how the outcome would have turned out in the event that one or more of these situations had been altered.

The final comparison will be made taking into account how the situation could have had a different outcome by connecting it to the perspective of the type of inventory management system chosen by a hypothetical company working in this field, specifically considering the antithetical lean production and MRP methods. It will therefore be attempted to investigate which between the two approaches hypothetically could have been assumed as the management method more advantageous to adopt both in respect of the events that have actually happened in the real world and in the hypothetical case in which the alternative scenarios supposed in the course of the chapter had been instead realized.

4.1. The methodology: the Decision Tree technique

To perform the analysis subject of this chapter, it has been chosen to use a widely known technique of schematization, the decision tree. It consists in a method that permits to obtain a clear and concise visualization of the evolution and succession of the events, allowing also to do some considerations in a reverse approach, starting from the estimated final results and then going back one step after the other in the analysis.

This approach is normally employed by managers when it is necessary to make decisions involving a sequence of actions on which also uncertain external events have an impact and where the probability of the occurrence of such situations is then unknown and it can only be estimated.

The basic structure of a decision tree is the one represented in Figure 13. As shown in the image, two types of branches are used in this kind of analysis: decision branches and chance (or probabilistic) branches. The former enables the assessment of alternative options by comparing them with each other, while the latter provides an indication of the probabilistic aspect of the outcome and each of them is associated with a given likelihood of occurrence. The point at which a decision-maker comes to a decision among the available alternative options is represented with a square node, while round nodes represent the point at which chance prevails. (Oakshott, 2009)

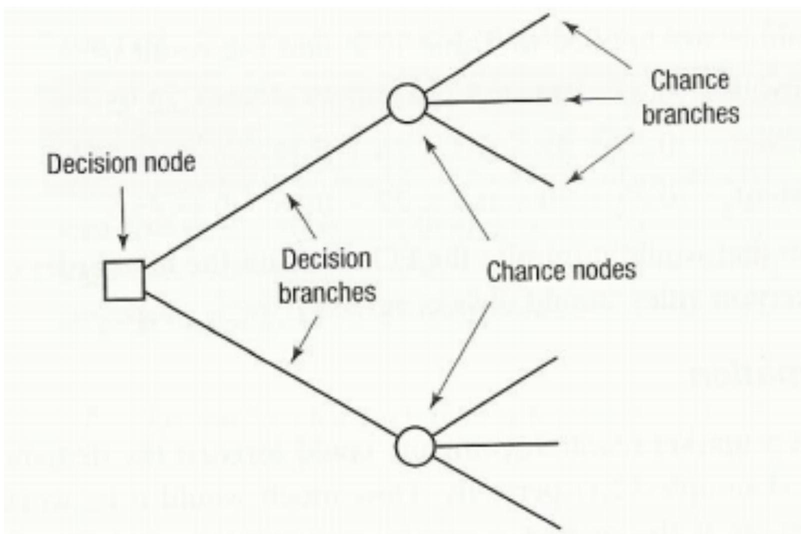


Figure 13: The basic structure of a decision tree. (Oakshott, L., 2009)

A decision tree is constructed starting from the left and proceeding to the right and specifically in the present analysis it was chosen to proceed in chronological order in the sequence of events. To evaluate the tree, it is instead necessary to proceed from right to left, according to a "roll back" approach.

Usually a decisional tree is therefore used for determining which is the more advantageous decision to take in the current time, keeping in mind the potential consequences of this choice in a future in which even uncertain events can happen with a certain probability. This decision is then facilitated by taking into account and by comparing the various possible outcomes that can be obtained depending on the various paths that the sequence of events may take.

In the particular application of the present chapter, however, it will not be taken in consideration a chain of events that could happen in the future, but one that has already occurred and has already been exposed in the third chapter.

The point of view that has been chosen to adopt in this modelling is the one of a hypothetical U.S. company that operates in the manufacturing field using also chips in its productive process, which through the employment of the decision tree will attempt to understand which inventory management system would have been better to choose in a previous moment before the beginning of this chain of events.

Specifically, the assessment will be operated retrospectively investigating which among lean production and MRP would have been more advantageous to have adopted for the company, and which would therefore have led it to be less affected by the lack of chips in the various alternative scenarios that have been constructed through the modelling.

In order to do that, the way in which the series of circumstances actually happened will be initially described, analyzing first two decision nodes that will be considered as independent from the choice that the company can operate, as they are decisions that have been taken from external actors but that subsequently had repercussions also on the internal affairs of the firm.

In a second time, two chance nodes will also be analyzed, which are representative instead of exogenous situations that have not been decided by anybody, but that have occurred with a certain probability.

In the meantime, the different paths that the story could have taken will also be described, then coming to establish which could have been the likely different outcomes of each of these alternative stories.

Only once this has been done, it will also consider the effects that would have occurred if either a lean or MRP approach had been chosen upstream, and what the implications of such a decision might have been on the final outcomes.

It should be noted that many of the data and probabilities that will be considered in this analysis were roughly collected and estimated, and therefore may not be fully aligned with the actual ones. This is because in many cases the data is not available to the public or it is very complicated to arrive at an accurate calculation of the probability of occurrence since there are several factors involved.

In any case, the purpose of this analysis is not to construct the scenarios in precise details, but rather to provide a useful and realistic schematization of the circumstances. Furthermore, the provenance of each data and each probability calculation in this chapter will be clarified, as well as the logic behind their selection.

4.2. Building up the model step by step

The first event in chronological order that can be considered as a trigger of the current crisis related to the shortage of chips is the technological cold war between the two biggest global economies, US and China.

It is in fact a conflict that has overwhelmed companies operating in the technology industry in both countries, going to affect the semiconductor market too. This is because of the block imposed by the Trump government on imports of major Chinese companies into the U.S. market and the restrictions placed on exports to China from American companies as well. The costs related to this decision are difficult to estimate, consisting in millions of dollars related to lost business and to search for replacement products.

Moreover, it is not only the lost profits that are of concern from a US perspective, as the loss of sales in the Chinese market will also affect the amount of R&D funding available to American chipmakers, thus hindering their production of cutting-edge chips.

In this regard, both previous and current U.S. officials argue that in the long run, these costs will be justified, as aggressive measures against imports of Chinese products are linked to protection against potential espionage that Beijing might implement primarily through telecommunications equipment. In addition, in this way it is also possible to make it difficult for Chinese chip companies to produce advanced products due to tight controls on US exports, offsetting the support that American officials believe the Chinese government offers to its chipmakers.

Furthermore, according to the US government, in the long run American companies will also have more money to invest in R&D as they will no longer be forced to lower their selling prices in order to compete with products made by the Chinese rivals.

But many US semiconductor companies still remain skeptical about that, as many Chinese electronics manufacturers have accounted for a large portion of their component sales for years, so penalizing exports to China does not appear as very beneficial from their perspective.

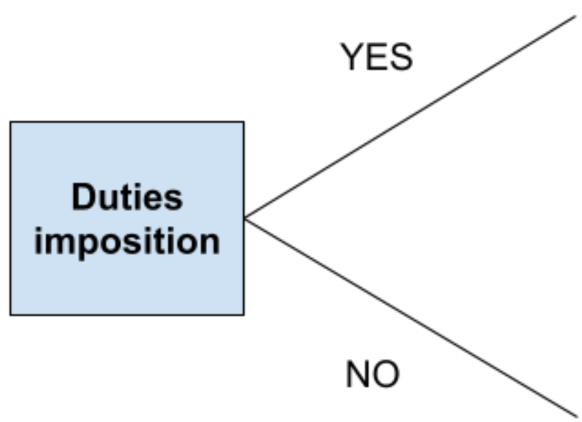
One example is Huawei Technologies Co., a Chinese company that, with its $123 billion in recorded sales in 2019, emerges as one of the largest manufacturers of electronic devices and it is also one of the biggest victims of US restrictions, as it was prevented from using the cutting-edge chips needed for its manufacturing process, made with American technology. However, what has not been taken into account is that pursuing the objective of hindering this Chinese company has ended up penalizing the American ones as well, since it is estimated that Huawei spends over 11 billion dollars a year in the purchase of components from the United States. (Woo, 2020)

Unfortunately, the restrictions have disadvantaged the US in another way as well, as by applying duties on goods entering the country they have also ended up raising the price of their own products. Indeed, when the United States under the leadership of Trump imposed a 25% tax on the import of semiconductors into the country from China, as well as other types of goods, it failed to consider that about 60% of these imported components are actually originally manufactured in the US. This is because most of the American companies operating in that field design and manufacture their semiconductors in the United States, and then ship the finished wafers overseas for the final step known as ATP (Assembly, Test and Packaging). This phase is relatively a low value one, as it accounts for about 10% of the total value of a chip, however, outsourcing it to foreign countries allows US chip companies to focus on the more important high value-added design and production phases. From this perspective, it is clear why US companies therefore end up paying duties on their own goods, with an estimated additional cost of over $750 million being incurred by US chip manufacturers since July 2018 due to tariffs paid on chip imports. Furthermore, semiconductors are the fifth most important exported goods from the

United States, since the country's chip companies sell 82% of their finished products abroad, thus resulting in a double disadvantage. (Semiconductor Industry Association, 2020)

Starting the construction of the decision tree therefore the first event that can be considered as influential on the crisis related to the semiconductor market, especially from an American company's point of view, was the introduction of tariffs on Chinese goods in 2018.

For this reason, it was opted to select a decision node as the first building block of the model (which will hence be denoted by a square node) corresponding with the moment when the US government led by President Trump was faced with the choice of whether or not to impose the 25% duties on Chinese imports. As can be observed from the image below, two branches depart from this point, indicating the two alternative options that could have been chosen in 2018. In the case in which it would have been decided to apply a tariff surcharge on goods entering in the US (as actually happened), the price of these ones would have increased by 25% due to the duties, while in the case in which it would not have been decided to apply them, the price of imported goods would have remained unchanged.



The second event that was identified in the previous chapter as one of the triggers for the chip shortage is the series of missteps made by Intel, America's largest chip designer and manufacturer. Its attempts to develop and launch production of smaller and smaller chips despite not having the required technology at the time to achieve this step and therefore produce a new, more advanced generation of chips, caused it to delay even its normal chip production during 2019, as all of the company's efforts were focused elsewhere. To simplify the model, this chapter will not consider that this drop in production resulted in Intel's customers switching to AMD, which in turn disproportionately increased the amount of chips it commissioned to TSMC at that time, adding further pressure on the production capacity of the latter company.

What is instead taken into account in this analysis is the fact that Intel's chip production has dramatically decreased during that period, consequently diminishing also the amount of chips available worldwide. Unfortunately, only the same company knows exactly how much has decreased its production due to this series of questionable strategic decisions and it has not publicly disclosed this information yet, therefore it is only possible to speculate which might have been such a reduction. For this purpose, it seems plausible to set a decrease of 50% of the total annual production of Intel chips during that period, an obviously fictitious but reasonable data.

It was then considered the percentage of Intel's market share in that year, specifically using data provided by T4, a platform that synthesizes the most relevant market research reports available online. Thus, as can be seen from Chart 5, Intel's sales share of the semiconductor market in 2019 was about 15.7%, confirming it as one of the most influential vendors in this industry.

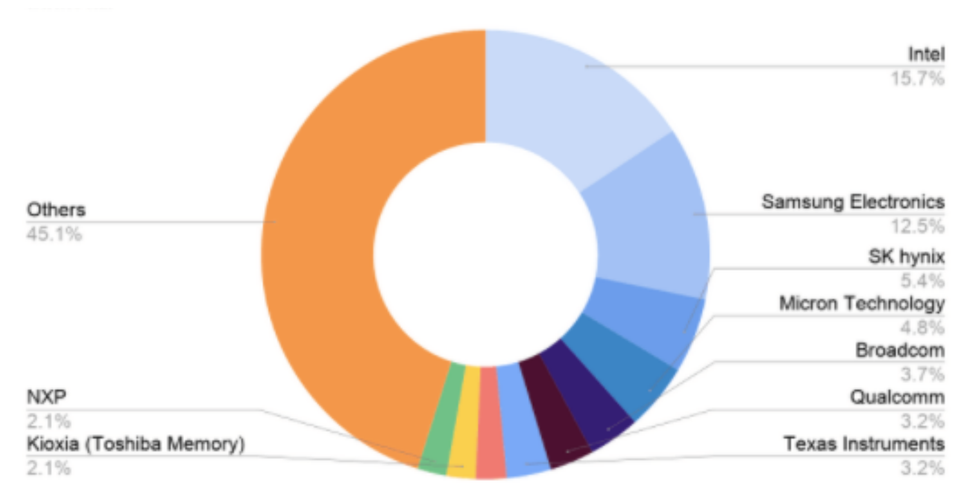
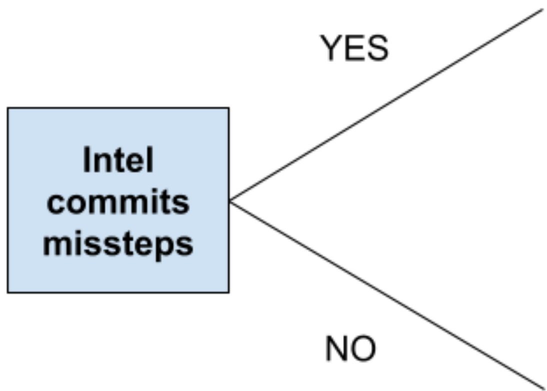


Chart 5: Global Semiconductor Market Revenue by Vendor. T4.ai (2019)

Therefore, taking into account also the hypothesis previously made, it may be assumed that the semiconductor supply in that specific year was reduced by approximately 7.85%, since Intel in that period potentially produced 50% of what it used to produce, by covering in a normal year the 15.7% of the total market.

As a result, it can be seen that a company that needs semiconductors in its production process has had less product available than usual, as the worldwide supply of this type of component has dropped to 92.15% compared to previous years.

The next step in the decision tree is therefore to construct an additional decision node, which indicates the moment in which the Intel managers have taken the crucial decision that will lead to the real course of events, in the hypothesis in which they choose to invest almost their entire efforts in the development of new products at the expense of the production of the usual ones. In the opposite case in which they would have decided to continue to produce the normal amount of chips without incurring in the well known series of missteps, they would have thus opted to follow the relative decision branch, leaving unchanged the amount of product supply in that year.



The third factor taken into consideration as influential on the scarce availability of chips is identified in the rising price of the required raw materials.

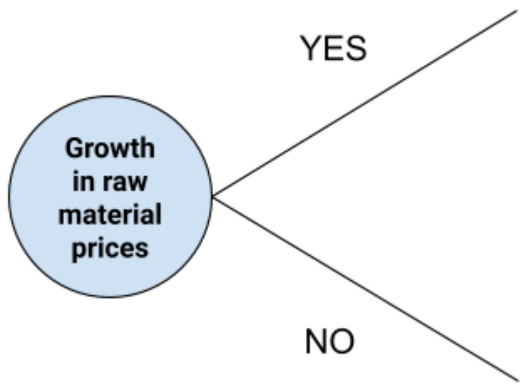
In order to simplify the model, it was chosen not to give much emphasis to the causes that led to this rise, since taking into account all the influential variables would be excessively complicated and of limited interest in the construction of the decision tree.

Instead, it was decided to consider this information as a free-standing fact, arbitrarily assuming that in a normal year the probability of a worldwide increase in the price of raw materials is about 20%.

It was also decided to take into consideration the data contained in the article dealing with the topic that has already been presented in the previous chapter, written by Gabanelli and Querzè (2021). This paper reports the percentage increase experienced by key raw materials since 2020, including those identified as most critical to chip manufacturing.

Specifically, copper has recorded an increase of 114.8%, silicon of 83.3% and cobalt of 53.3%. In order to obtain a unitary data which can be taken into consideration, it was decided to calculate an average of these three increments, thus establishing that the medium rate of increase in the price of raw materials used in the semiconductor production process is about 86.3%.

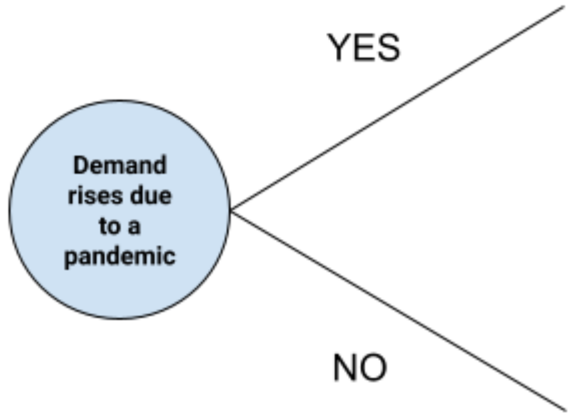
This situation is hence a random event and therefore can be described through a chance node, which is represented with a round node in the decision tree. Two chance branches extend from this node, the first of which describes the situation in which in a certain year the raw materials rise by an average of 86.3% with a probability of 20%, while the second branch indicates the case in which the price remains unchanged, with a probability of 80%.



The last trigger of the chip crisis that is taken into account in the construction of the decision tree is the increase in demand for electronic devices (and consequently for semiconductors) that has occurred due to the Covid-19 pandemic. In order to simplify the model, this factor alone was taken into account as an influential factor in the growth in demand for these products in 2020.

As it was reported by the World Semiconductor Trade Statistics organization, global semiconductor sales during 2020 were estimated to be $440.4 billion, thus registering a total growth of over 6.8% in comparison to the data recorded in 2019.

It was then attempted to estimate the probability that a pandemic will occur in any given year. In order to do this, it was considered the time periods that have been affected by a widespread disease from 1900 to current times.



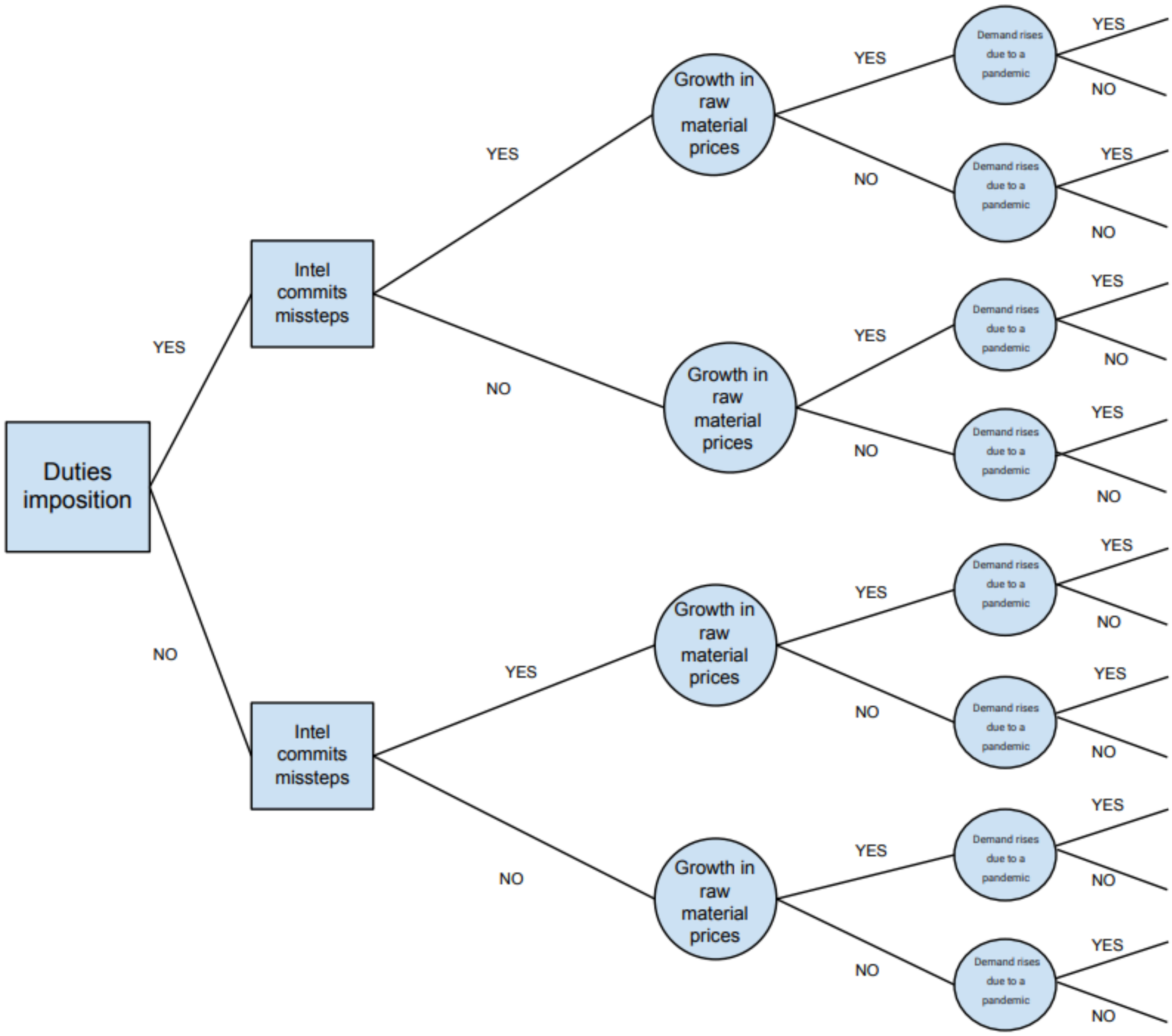
It should be noted that each outbreak had different mortality and spread impacts, but for purposes of this analysis this is not a relevant factor.

In particular, in this analysis were considered Spanish flu (1918-1919), Asian flu (1957-1958), Hong Kong flu (1968-1970), Swine flu (2009-2010), Ebola (2014-2016) and Covid-19 (2020-2021). (LePan, 2020)

From this data it emerges that approximately the number of years in which a disease has spread, causing several victims, is around 14 out of the 120 total years analyzed, resulting in a raw probability that in a specific year a pandemic may occur (regardless of the magnitude of the phenomenon) of about 11.67%.

With this information the construction of the decision tree has then been completed, adding a final chance node in which the demand for semiconductors increases by 6.8% in the event of a pandemic, occurring with a probability of 11.67%.

It is now possible to construct the entire model joining the various steps that have been explained in this section, thus obtaining a decision tree organized in chronological order from left to right as represented below.



The succession of events that actually took place in reality is the scenario that emerges as the absolute worst among all the possible ones that have resulted from the construction of this model, and it is individuated by the path of branches located higher than the others in the previous figure.

4.3. Introducing the decision about the inventory management system

It should be noted that up to this stage of the construction of the tree, only events on which a hypothetical American company operating in the sector could not have had any kind of influence have been taken into consideration.

In fact, despite the first two nodes being decisional, respectively indicating a political decision and a strategic business choice, they were in the hands of external actors and therefore could not be influenced by any manufacturing company that employs chips in its production process. This company has therefore merely experienced the consequences of decisions taken by others and of chance events that have occurred.

In this section, however, an additional decision node will be placed on the left side of the decision tree, assuming that the only type of choice a company could have made is upstream, at a time preceding 2018, deciding which inventory management system to adopt.

It was also assumed that although there are many different approaches as was described in the second chapter, the only available alternative was to choose between the antithetical methods of lean production and MRP.

In this way two additional alternative paths have been configured, doubling therefore the obtainable final results from the decisional tree.

In order to facilitate the comparison between the different inventory management systems, it has been decided to analyze the two decisions separately, investigating in the first instance how the final scenarios would have been configured in the case in which the company had chosen to adopt a lean approach and later considering how the circumstances would have changed if instead it had opted for the MRP method.

In this phase, the data and the percentages of probability that have been introduced in the previous section have been used, transferring the decision tree in Excel in order to obtain numerical results associated with the various resulting scenarios.

Using this program, it was no longer possible to maintain the shape distinction linked to the decision and chance nodes, but although they are not anymore represented by square and round nodes their underlying logic obviously remains the same.

4.3.1. The Lean production scenario

While beginning to analyze the way different event sequences would hypothetically have developed in the case in which a manufacturing company would have initially chosen to adopt a lean approach, it was further assumed that this type of method is associated with economic advantages compared to an MRP method.

In order to underline this difference, it has been chosen to associate to lean production an initial unit cost of 90 for each single chip employed in the manufacturing process, which will instead be considered equal to 100 in the case of the MRP method, since in the latter case there are also the additional costs of warehouse management to be included.

Below it is introduced how the decision tree is configured by considering only the lean scenario, including the data previously exposed.

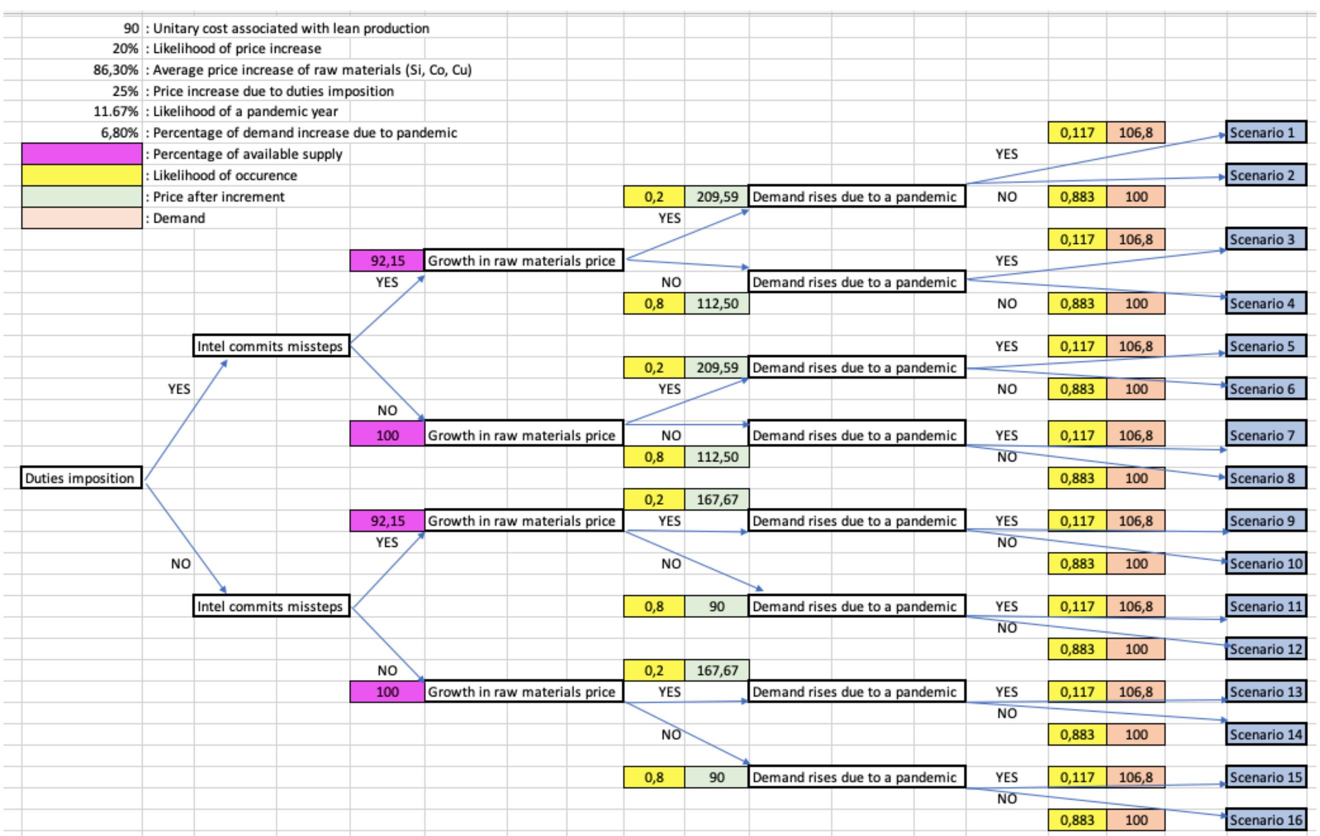


Figure 14: Decision tree if the company choose the lean production approach

Starting from the data obtained through this Excel sheet, a table summarizing the different results for each variable linked to any of the sixteen final scenarios was then constructed, adding also a column called "Price corrected" in which the final price was adjusted by considering the other two variables too.

This result was obtained through a basic function which has been used to correlate the three different kinds of information: *Price*(1+(Demand-Available supply)/100)*

In this way, it was therefore possible to compare how the final price varies depending on the degree to which the available supply is able to meet the demand for the product, since general microeconomic theory suggests that if there are fewer chips at disposal than those demanded by the market, their price will inevitably increase. On the contrary, if the demand equals the available supply, in a simple economic model there are no reasons for which the price should increase.

These types of considerations are well visible in the following table.

	Price corrected	Demand	Available supply	Price
Scenario 1	**240,29**	106,8	92,15	209,59
Scenario 2	**226,04**	100	92,15	209,59
Scenario 3	**128,98**	106,8	92,15	112,50
Scenario 4	**121,33**	100	92,15	112,50
Scenario 5	**223,84**	106,8	100	209,59
Scenario 6	**209,59**	100	100	209,59
Scenario 7	**120,15**	106,8	100	112,50
Scenario 8	**112,50**	100	100	112,50
Scenario 9	**192,23**	106,8	92,15	167,67
Scenario 10	**180,83**	100	92,15	167,67
Scenario 11	**103,19**	106,8	92,15	90
Scenario 12	**97,07**	100	92,15	90
Scenario 13	**179,07**	106,8	100	167,67
Scenario 14	**167,67**	100	100	167,67
Scenario 15	**96,12**	106,8	100	90
Scenario 16	**90**	100	100	90

Tab 3: Synthetic table showing the obtained results for each different lean scenario

As can be noticed from the table, the worst result is always the highest one, identified with the series of disruptive events that actually happened, while the best hypothesis is always the one in which the context had remained stable and none of these circumstances had come true.

It was then carried out also the calculation of the Net Present Value (N.P.V.), shown in the figure below, which is obtained by multiplying each price corrected by the corresponding probability that the event to which it refers happens, adding this result to the probability that the same event does not happen multiplied by the adjusted price to which it is linked. The results of these calculations are presented in the figure below, and from their comparison it clearly emerges, as could already be guessed from the previous table, the most influential event of all on the increase in the correct price with respect to the gap between supply and demand is the increase in the cost of raw materials needed for production.

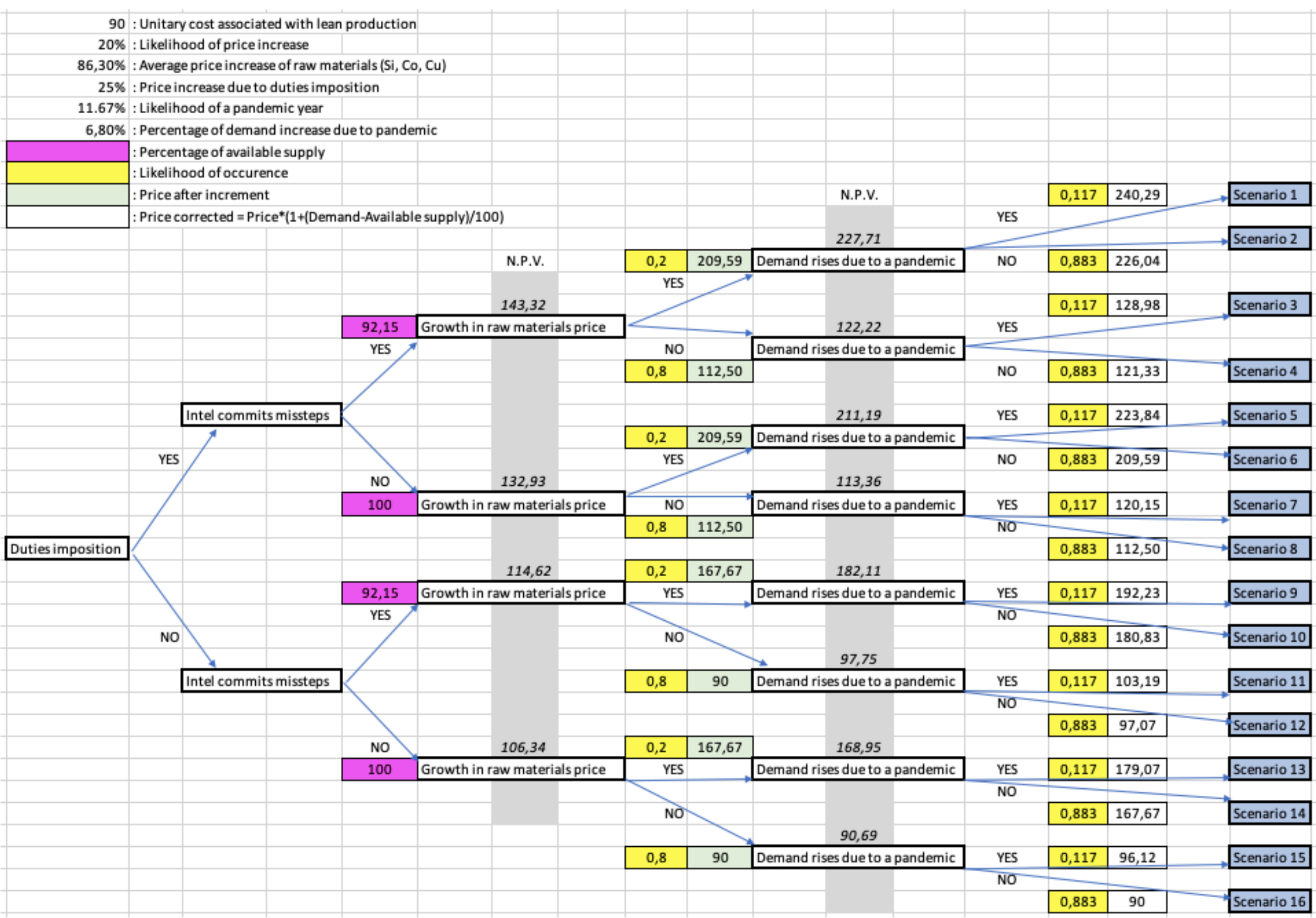


Figure 15: Calculation of N.P.V. in lean scenario, starting from the price corrected

It will now also analyze the case in which the hypothetical manufacturing company had instead decided to adopt an approach to MRP in order to manage its inventory before being confronted with the series of events described in the decision tree. From the comparison with the two various situations it will be therefore possible to extract further considerations.

4.3.2. The MRP scenario

Moving on to analyze the decision tree configuration in the case in which a company had initially decided to adopt an MRP logic in its production process, it should be remembered that in this instance the initial unit cost has been assumed to be higher than the one considered in the previous case.

This is because this type of approach is different from the just-in-time, in which some warehouses exist inside the company but they contain only the strictly necessary components in a specific moment. The MRP instead is a logic that relies on a determined availability of materials, naturally trying also in this case to avoid useless wastes but in any case holding greater quantities of stock in comparison to the ones of a company operating according to a lean approach. Therefore, it has been considered appropriate to fix a unit cost of 100 for each chip used in the production process, as in this situation further management costs related to the warehouse in which materials are stocked should also be taken into account.

A further assumption that differentiates this subsection from the previous one is that in this instance the case of Intel will not be taken into account in the construction of the decision tree. This manufacturer of chips is in fact one of the most famous multinationals nowadays to use a lean approach, as following this philosophy they have been able to significantly reduce the production time of their products, also enhancing the quality of finished products by increasing controls and reducing waste, thereby satisfying the final customer. Furthermore, in the technology industry, products are updated and changed at a very fast pace, and this type of approach has allowed Intel to easily stay up-to-date. (Lombardi, 2018) However, unfortunately,

it has also been observed that with this just-in-time approach, a series of missteps in corporate strategy is enough to slow down the entire production, significantly extending lead times.
The reason that underlies the choice to not include the decision node corresponding to the Intel issue is that this decision would have theoretically influenced significantly less companies running with an inventory management system of the MRP type, compared to those working with lean production.
It has already been mentioned that the PC manufacturers who were used to buying Intel's products were forced to switch their chip supplier after the well-known events and turn to AMD, as the former company's production was no longer able to meet their huge demand. This happened largely because in general also computer companies follow a lean approach in their production process, hence they had a critical need for components in that situation. Therefore, could not simply wait for Intel to return to its normal pace of chip production, as they had no stock of components to rely on such moments in their warehouses and would have to stop their production in case they did not get the necessary materials.
In this part of the analysis, however, it has been declared that a manufacturing company adopting an MRP approach in its productive process is being considered, thus on a theoretical level such a factory would not have been affected so much by Intel's drop in production, inasmuch as it had some stocks in its warehouse that allowed it to keep on producing in any case, despite the fact that the supply of components had decreased.
The part of the decisional tree linked to the choice to adopt a MRP inventory management system, built through the use of Excel and applying the aforementioned simplification with reference to the decision node about the strategic choice of Intel, is represented in the following figure.

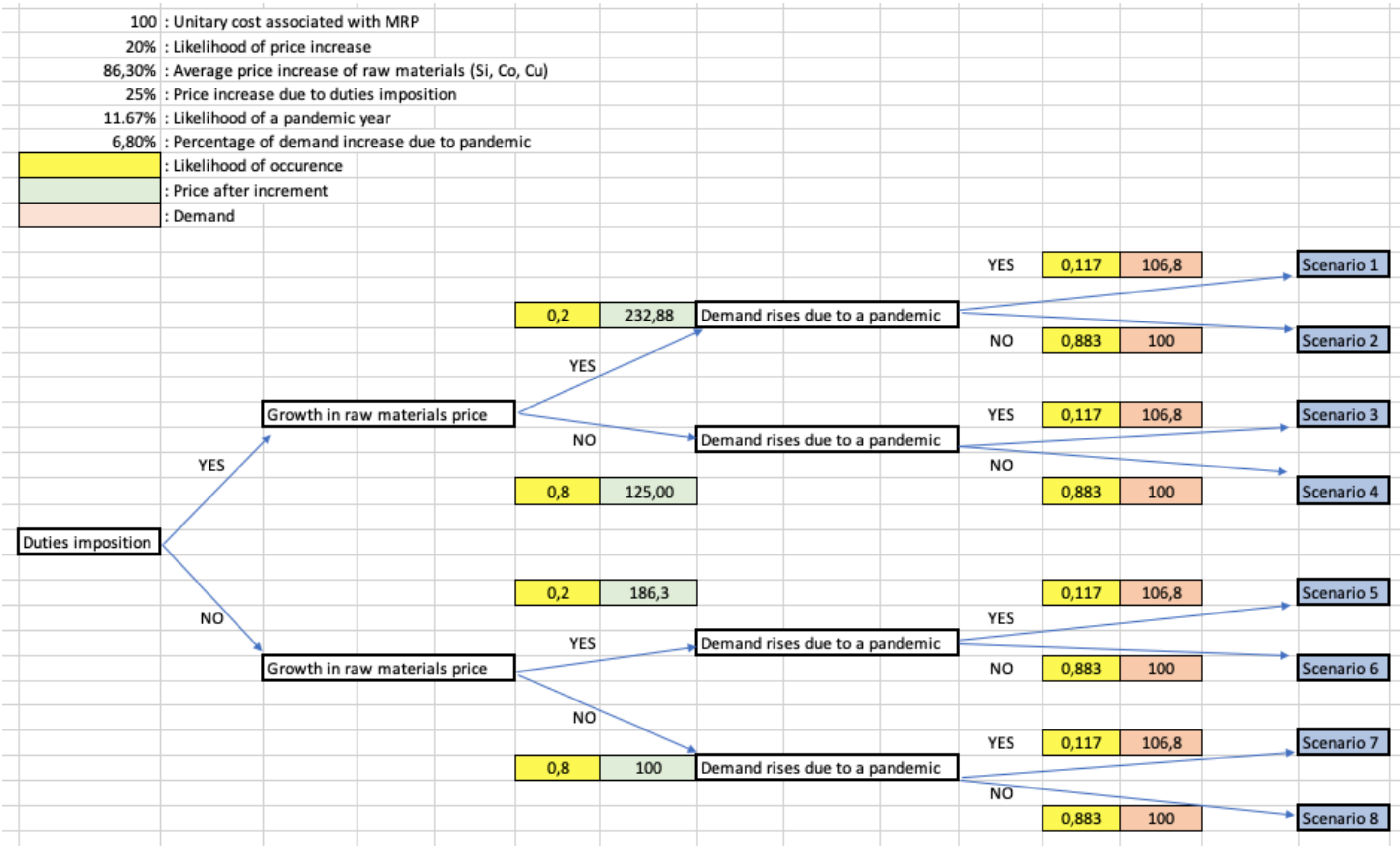


Figure 16: Decision tree if the company chose the MRP approach

Of course, the resulting scenarios under these circumstances are eight and no longer twelve, as a consequence of not having considered the decision node associated with the Intel strategy.

Even in this case, using the data obtained by means of this Excel sheet, a summary table of the different results for each variable linked to every final scenario has been constructed, adding also the column called "Price corrected" in which the final price has been adjusted taking into account the other two variables, demand and offer, by means of the same function exposed previously.

	Price corrected	Demand	Available supply	Price
Scenario 1	**248,71**	106,8	100	232,88
Scenario 2	**232,88**	100	100	232,88
Scenario 3	**133,50**	106,8	100	125,00
Scenario 4	**125,00**	100	100	125,00
Scenario 5	**198,97**	106,8	100	186,30
Scenario 6	**186,30**	100	100	186,30
Scenario 7	**106,80**	106,8	100	100,00
Scenario 8	**100,00**	100	100	100,00

Tab 4: Synthetic table showing the obtained results for each different MRP scenario

It can be noticed how in this context the offer remains unchanged since the production drop linked to the Intel missteps is not considered, bringing consequently the gap between demand and offer less evident in comparison to the one recorded in the scenarios examined with reference to the lean production. The decrease in the difference between demand and available supply naturally affects also the price corrected, which is therefore different from the one determined in the previous hypothesis.

The N.P.V. was also calculated for the decision tree linked to the MRP approach, according to the methodology used in the previous subsection (Figure 17).

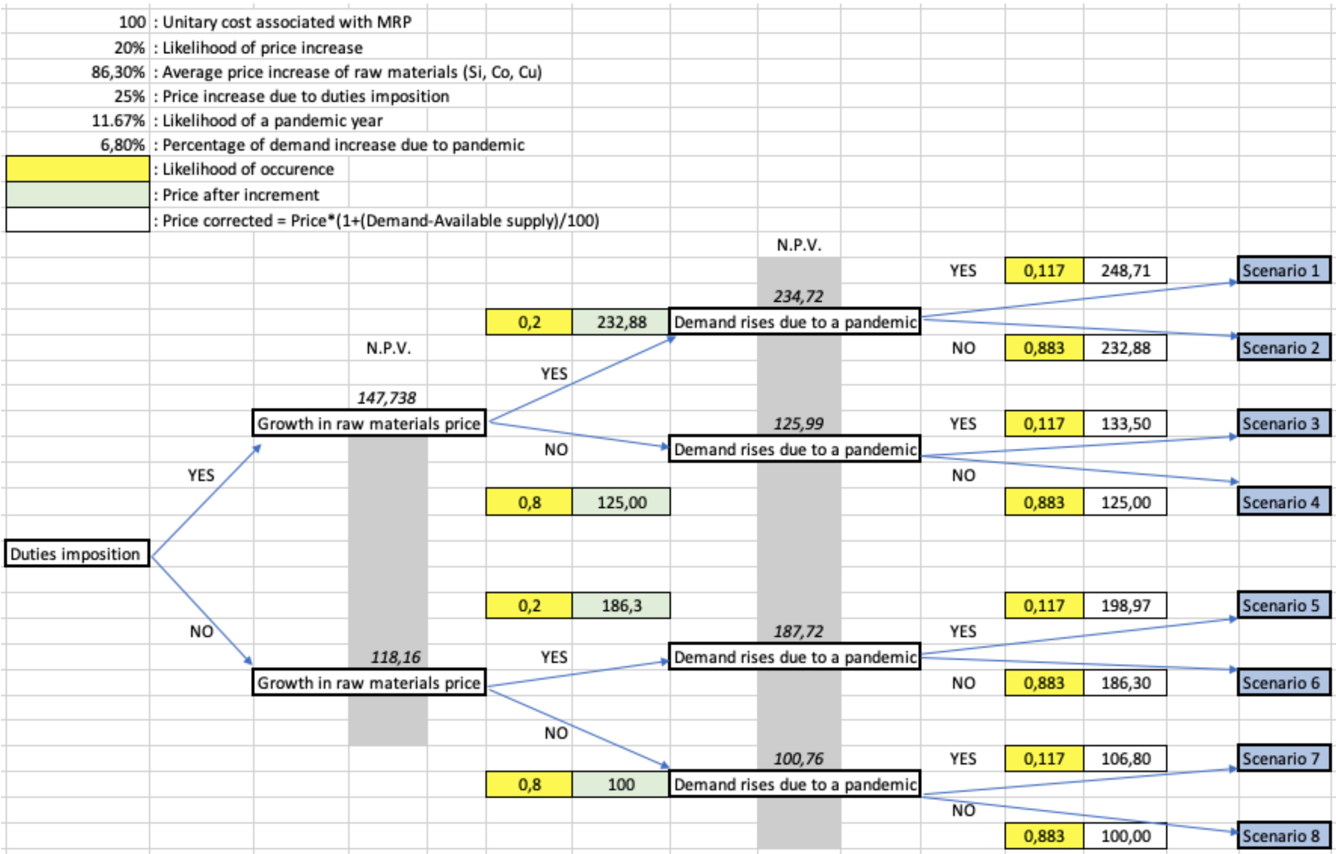


Figure 17: Calculation of N.P.V. in MRP scenario, starting from the price corrected

4.3.3. Final considerations

From the comparison of the different scenarios obtained by following first a lean logic and then the MRP one, some interesting observations have emerged, despite the fact that it is still a basic model and that the data used in many cases are hypothetical and may not be perfectly consistent with the real ones.

The first consideration is linked to the scenario that actually occurred, identified in both cases in the path that follows the branches located higher up (called "scenario 1" in both instances), which implies that each of the risks analyzed occurred following the worst of the available hypotheses. It can be noticed how, despite the fact that the section dedicated to MRP does not take into account a decrease in available supply, factor that theoretically would have favored this inventory management system, the price corrected relative to scenario 1 of the MRP is, however, higher than the one linked to scenario 1 of the lean production.

This means that despite there has been an additional disruptive event to aggravate the situation represented in the model of a company following a lean production logic, this last one turns out still more advantageous in terms of cost regarding the case in which it had followed the MRP method.

However, to this observation it is necessary to add the further consideration that in the model described by this decision tree it has not been held in account even the fact that an increase of the raw material prices as the one that has been occurred, the inventory management system more in trouble would have been surely the one that follows an approach of just-in-time type.

This is because the lean logic is more affected by the rise in the price of raw materials, since although it begins with a lower cost level than the MRP, it then turns out to be penalized due to the fact that it does not have large warehouses of stocks that allow it to keep producing. Consequently, a lean company finds itself forced to buy raw materials also at that price level, not being able to procrastinate the purchase without risking to stop its production.

This does not happen when the company follows the MRP method, which permits it to continue the production in the short term despite the occurrence of such a shock.

In the long period obviously also this type of logic is affected by the increase of the prices of the raw materials, as it has been chosen to represent in the model introduced in this chapter.

As it was expected, it is not therefore possible to decree in absolute way which of the two antithetical methods of management of the warehouse is the more advantageous at all, but what has emerged turns out useful in the evaluation of the trade-offs between an approach and the other.

In fact, it can be asserted that in the light of these considerations the method of lean production is less robust with respect to the occurrence of a sudden negative event, since it does not hold additional material stocks other than those strictly necessary and therefore it is bound to suffer in the short term the external perturbations, by adapting itself to the relative disadvantageous conditions or by stopping the production.

Instead an approach of the MRP type allows to have less concerns regarding the disruptive events, since in general it is possible however to continue the production at least in the short period.

In the long run, however, it proves to be a more disadvantageous choice of business model from the economic point of view compared to the lean production, as can also be observed by comparing the corresponding values of the N.P.V. in the two different approaches. The numbers associated with lean production in fact turn out to be in each case smaller in comparison to those assumed in the scenario connected to the MRP.

This therefore leads to emphasize the importance of taking into account also the risk attitude of a generic manufacturing company when choosing its inventory management system. In the case in which the risk propensity is in fact high, it brings a lean orientation, more economically convenient but also more subject to disruptive events, while in the case of a low risk propensity, it naturally leads to the choice of the MRP method, which is not associated with cost savings like those linked to the just-in-time but which has higher robustness with respect to external turbulence, at least in the short term.

CONCLUSION

The objective of this research was to examine the reaction of different inventory management systems when they face disruptive events, which occur under various forms and are increasingly frequent over the last few years, changing suddenly the environment in which companies are used to operate.

The first step was therefore to define what is meant when referring to these adverse events, underlining their heterogeneous nature and which may be the possible consequences they may have when hitting the supply chain of a company, with the aim of providing a useful context to the reader.

In the course of this paper, a path was developed with the aim of investigating the behaviour of few inventory management methods from different perspectives, by starting from a theoretical point of view, then moving on to the analysis of two emblematic real cases and ending by proposing an analytical model built on the basis of data concerning one of the two contemporary analyzed events.

During the first step of the research, where the different approaches to warehouse planning were presented using the available literature on the subject highlighting their respective strengths and weaknesses in an uncertain environment, the hybrid method of DDMRP was also analyzed in addition to the antithetical MRP and lean approach. This innovative method, based on a hybrid logic with respect to the others, was however abandoned in the successive analyses since being a new and promising approach it is still less widespread than the other two, and consequently it is more difficult to obtain data, information and real case histories linked to the specific topic addressed in this research.

In the second part of the analysis, two concrete cases have therefore been exposed, in which industries operating according to a logic of lean production have found themselves in difficulty when external events have hit their business. As it had already emerged from the previous theoretical reflections, this method of inventory management is in fact heavily subject to lead times lengthening and to the threat of being without the necessary supply of key components for its production process each time the environment is less stable than expected.

The last stage of research led to the construction of a decision tree considering the events that actually happened in one of the case studies and those that might instead have happened according to a "what if" analysis, comparing the different situations from a lean production perspective and then from a MRP perspective. The results emerged from this analysis underlined how, even in the worst of the possible scenarios, the just-in-time method is still associated with lower costs than those calculated in relation to MRP under the same conditions. This leads to suppose that this approach, despite being penalized in the short term as it is more subject to the lengthening of lead times and the risk of supply when compared to the MRP, in the long term it results in a cost advantage even in an uncertain context.

Naturally it has been also underlined that the model taken in consideration is an extremely simplified one and much data and information used in the calculation have been estimated in the most reasonable possible way, but clearly they are not perfectly adherent to the reality. For this reason, although this Master's Degree thesis has proposed a framework as detailed as possible on the subject and has brought to light some useful hints for managers who are facing the choice of the inventory management system more appropriate to their company, additional analysis and modeling are considered to be required in order to obtain further results on a subject that is believed to be more and more object of interest in the near future, considering the increasingly uncertainty of present times.

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