The potential impact of RFID Technology on the Bullwhip Effect within the Automotive Industry

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ABSTRACT,
The automotive industry is very complex in nature and supply chains are getting more complex due to increasing globalisation, growing market and the fact that customer preferences are constantly changing. This increasing complexity can result in a lack of visibility of assets, inefficient handling of stock or logistic mismanagement. In the end, these complexities contribute to the existense of the well known phenomenon 'The Bullwhip Effect' in the automotive industry. Many researchers claim that RFID technolgy is able to mitigate this effect, for it is expected to increase the supply chain visibility and information sharing. This paper tries to investigate to which extent RFID technology has a potential impact on the Bullwhip Effect within the automotive industry. In order to research this, the hypothesis that RFID technology increases information sharing and chain visibility and thus mitigates the Bullwhip Effect, is tested. This is done with the aid of secondary data and semi-structured interviews with several parties active within the automotive supply chain. The paper starts by first explaining what the Bullwhip Effect and RFID technology exactly are. After data was gathered, an analysis on the automotive industry and its supply chains is made in order to give an overview on how such a complex industry looks like. After that it explaines what exactly causes the Bullwhip Effect and how RFID technology is currently applied within the automotive industry. Finally, the paper analyses and discusses these findings. From the discussion it can be concluded that the hypotheses has to be revised and that RFID technology is co-dependent on information sharing and when used together it can enhance the chain visibility and transparency. This in turn leads to a decrease of the Bullwhip Effect. Also, the outcome of the research therefore is that RFID technology has high potential to mitigate the Bullwhip Effect within the automotive industry because it enhances the chain visibility and transparency.

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1. INTRODUCTION

This part of the paper first tries to introduce the topic of the research by explaining what general problems exist within the automotive industry. Furthermore, a focus is put on more specific problems within this industry, after which an emphasis is put on what is exactly researched, and how this is researched.

1.1 General Problems within the Automotive Industry

Because of several factors like increasing globalization, product variety and the ever changing customer needs, organizations in the automotive industry face many challenges regarding their Supply Chain Management (SCM). The supply chains within this industry are very complicated in nature and are getting more complex than ever due to an even more increasing globalisation, growing markets and the fact that customer preferences are constantly changing. According to Kothari (2018) this increasing complexity results for instance in a lack of visibility of assets, inefficient handling of stock, transportation or logistic mismanagement, improper handling of data and ineffective supply chain risk management. Also the cost related to inefficiency and unreliability increases as a result of the above called increasing complexities. As an example, according to a study done by Deloitte, supply chain interruptions cost manufacturers 1 billion dollars a year.

1.2 Specific Problems within the Automotive Industry

According to an expert interview, the most important and biggest aspect that enlarges the complexity is the increasing product variety. Nowadays, consumers can mass customize their cars to the last detail which had led to manufacturers implementing the so-called Just-in-Sequence (JIS) strategy. This means that the right parts of the car have to be at the assembly line at the right time and in the right order (Siemens, n.d.). All these complexities within automotive supply chains can in the end lead to a decrease of supply chain visibility. According to Srivastava (2014) as stated in Vance, Lowry and Ogden (2010), this lack of supply chain visibility is one of the main factors leading to the so called 'Bullwhip Effect'. Lee, Padmanabhan and Whang (2004) as cited in Naude and Badenhorst-Weiss (2011) state that the bullwhip effect is seen as one of the main factors that negatively impacts the supply chain and it can even drive 13 to 25 per cent of the operating costs. The bullwhip effect is the phenomenon in which a small variance in customer demand leads to an even greater variance of orders further up the supply chain. This effect can be caused by many factors like parties only operating in self-interest, a lack of supply chain visibility and a lack of information sharing between organisations within the supply chain. Wang and Disney (2016) found out that this bullwhip effect is still evident in the automotive industry. Because of this, supply chains in the automotive industry have to be highly transparent and co-operative in order to mitigate this bullwhip effect.

In order to counteract the problems stated above, the Internet of Things (IoT) could play a significant role. IoT can for instance be applied to warehouse management, which in place can result in improved inventory management, real-time SCM and increased logistics transparency (Machado & Shah, 2016). A widely used IoT tool in the automotive industry are Radio Frequency Identification (RFID) tags. With the aid of this technology, parts equipped with these tags can now be tracked throughout the whole chain which increases asset visibility and thus supply chain transparency.

1.3 Aim of the Research

Many researchers claim that RFID technology is able to reduce the bullwhip effect in different industries (Jones & Chung, 2008; Herrman, Rogers, Gebhart & Hartmann, 2015; Khan, Qianli & Zhang, 2016; Vance et al., 2010). However, this is not yet widely analysed within the automotive industry. Because there can be several causes for the bullwhip effect, the first aim of this research is to find out what actually causes the bullwhip effect in the automotive industry. After that, it is researched how RFID exactly is applied within the automotive industry and the supply chain in particular. And finally, the main aim of this research is to make an analysis on the degree to which the RFID technology within the automotive industry has an impact on the bullwhip effect within this industry. This is done in order to test whether the hypothesis that RFID has a positive effect on the bullwhip effect, is also true for the automotive industry.

1.4 Central Research Question

The paper first briefly outlines what the bullwhip effect exactly is, what the causes and its countermeasures are. After that, there will be more of a focus on what RFID technology is, how it can be applied, what the benefits and challenges are and finally where the technology currently stands. Then, a more emphasis will be put on the automotive industry; the nature of its supply chains and the challenges and problems they face. Also, it will be researched what exactly causes the bullwhip effect within the automotive industry. After this, the research will dig deeper into asset tracking based on RFID and how it is applied within the automotive supply chain. And finally, an analysis will be made to find out to which degree RFID has an impact on the bullwhip effect in this particular industry. So in short, the aim of the research is to find out what causes the bullwhip effect in the automotive industry, how RFID tags are used in this industry and to which degree this has an impact on the bullwhip effect. In order to do so, this paper tries to answer the overall research question: *"What is the potential impact of RFID technology on the bullwhip effect within the automotive industry?"*

2. METHODOLOGY

This chapter of the paper tries to give an overview of the entire design of the research. In order to do so, it sums up the techniques used to collect and analyse data about the specific topic in this research. Furthermore, it gives an overview on how the central research question will be answered with the help of sub-questions. Next to that, the underlying hypotheses of the research will be discussed.

2.1 Sub-questions and Hypotheses

In order to answer the central research question, it is broken down into two separate questions: *"What causes the bullwhip effect within the automotive industry?"* and *"How are RFID tags currently used within the automotive supply chain?"*

There are many researchers who claim that the bullwhip effect is caused by a lack of information sharing and supply chain visibility (Lee et al., 1997a; Min, 2000; Jeong & Hong, 2017).
Next to that, there are many researchers who claim that RFID technology is able to improve this information sharing and chain visibility (Zelbst, Green, Sower & Baker, 2010; Melski, Muller,

Zeier & Schumann, 2008; Sabbaghi & Vaidyanathan, 2008; Véronneau & Roy, 2009).
Therefore, it can be assumed that RFID has a positive impact on the bullwhip effect and the following hypotheses can be drawn:

H0: RFID has no positive impact on the bullwhip effect

H1: RFID has a positive impact on the bullwhip effect

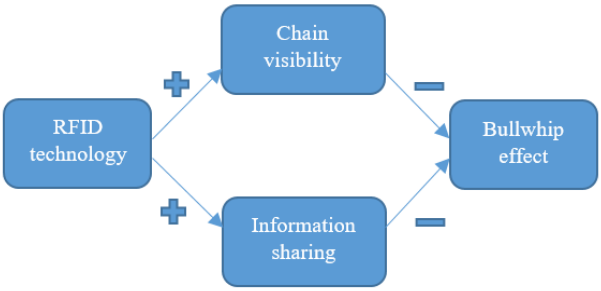

Figure 1. Visual representation of hypotheses

In figure 1, a visual representation of the hypotheses is given. As can be seen it is assumed that RFID technology is able to increase supply chain visibility and information sharing. These in turn are able to decrease the bullwhip effect.

2.2 Research Design

The aim of this research is to answer the central research question, i.e. "What is the potential impact of RFID technology on the bullwhip effect within the automotive industry?". In order to answer this research question, an extended literature study will be conducted. Next to that, a short field study within the automotive world will be done in the form of qualitative interviews and tours. These interviews will be done with a manager of automotive company Daimler AG, employees of Audi and Volkswagen and experts in the field of car manufacturing at Autostadt Volkswagen. Besides these, also other experts in the field of the automotive industry, supply chain management and RFID tags will be contacted. These experts range from a warehouse engineer at Scania, to marketing managers of dealerships in Twente and people working at organisations that supply automotive companies with the RFID technology. Also the vice president of the organisation that supplies Volkswagen and Daimler with RFID technology, will be interviewed. Next to that, a tour will be done at the biggest importer of Volkswagen in the Netherlands after which an interview is done with the inventory planner of this specific organisation.

2.2.1 Data Collection

The outcome of the interviews are used to get a better understanding of the complexities within the automotive supply chain, how the manufacturing works and which problems arise during the processes. Next to that, via interviews the aim is to find out what actually causes the bullwhip effect within the automotive industry. Also they are used to get to know more about the specific technology of RFID and how they are actually used at the moment in the automotive industry and supply chain in particular. At first, secondary research will be done in order to outline what the technology of RFID tags holds, its applications, its benefits, challenges and current developments. Also, this type of research is done in order to get a better understanding of the concept 'bullwhip effect' itself. After this also an analysis is made on the supply chains and complexities of the automotive industry itself, and Volkswagen in particular. When enough information is obtained, semi-structured interviews will be conducted.

3. BULLWHIP EFFECT

The bullwhip effect is a very well-known concept in the business world and is observed in many industries. There is not one specific definition of the bullwhip effect, however there are many researchers who explain the phenomenon in their work. Therefore, this part of the paper first tries to explain what the bullwhip effect exactly is. After that, the causes of the bullwhip effect and what can be done in order to counteract it, are discussed.

3.1 Definition of the Bullwhip Effect

One of the first researchers who wrote about the bullwhip effect extensively were Lee et al. (1997a, 1997b, 2004). According to Lee et al. (1997b), the bullwhip effect refers to "the phenomenon where orders to the supplier tend to have larger variance than sales to the buyer (i.e., demand distortion), and the distortion propagates upstream in an amplified from (i.e., variance amplification)" (p. 546). The bullwhip effect can lead to "distorted information from one end of a supply chain to the other" (Lee et al., 1997a, p. 93). This in turn can lead to enormous inefficiencies like missed production schedules and lost revenues. Fransoo and Wouters (2000) describe the bullwhip effect as "the result of information distortion in a supply chain, where companies upstream do not have information on actual consumer demand" (p. 79). Here, upstream refers to the part of the supply chain where the suppliers and manufacturers operate. According to Wang and Disney (2016) the bullwhip effect refers to "the phenomenon where order variability increases as the orders move upstream in the supply chain". However, these explanations are still a bit vague. Therefore, an example of a case where the bullwhip effect is evident, is now given. Procter & Gamble (P&G) were the first to call this phenomenon the bullwhip effect when they encountered it with their best selling products; Pampers (Lee et al., 1997a, 1997b; Wang & Disney, 2016; Dai, Li & Peng, 2017). Logistics executives of P&G noticed the effect when the sales at their retail stores were starting to fluctuate, however, the variability's weren't that high. Unless this small fluctuating demand, it led to the fact that the orders of their distributors increased and the increase of P&G's orders to their suppliers were even greater. Here, you can see a typical example of the bullwhip effect where a small change in demand leads to a great change in order variability upstream the supply chain.

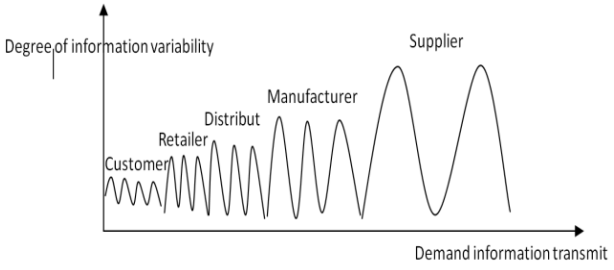

Figure 2. Schematic diagram of bullwhip effect (Dai, Li & Peng, 2017)

In figure 2, a visual representation of the bullwhip effect can be seen. From the figure it is clear that the degree of information variability increases as the demand information transmits through the supply chain from customer to finally the supplier.

3.2 Causes and Countermeasures of the Bullwhip Effect

The opinions about the causes and of the bullwhip effect are a bit varying, therefore the works of different researchers are being analysed in the coming part. Lee et al. (1997a, 1997b) propose four major causes of the bullwhip effect. These causes can be described as follows:

- Demand forecast updating
- Order batching
- Price fluctuation
- Rationing and shortage gaming

These four causes in combination with the infrastructure of the supply chain and the order managers' rational decision making create the bullwhip effect (Lee et al., 1997a).

According to Naude and Badenhorst-Weiss (2011), *demand forecast updating* refers to how a change in demand forecast by a company becomes amplified in the order to a supplier. In other words; when an organisation downstream the supply chain makes an order, managers upstream the chain see this as a signal about future demand and based on this the managers adapt their demand forecasts and thus the orders placed (Lee et al., 1997a). According to Chopra & Meindl (2007) as cited in Naude and Badenhorst-Weiss (2011) the bullwhip effect occurs when orders are placed based on demand forecast instead on actual customer demand. *Order batching* refers to companies periodically ordering products in large amounts where they order more than actually needed to satisfy future demand (Naude & Badenhorst-Weiss, 2011). This order batching leads to the fact that somewhat stable demands are translated into irregular demand on a supplier which in turn contributes to the bullwhip effect. The next one, *price fluctuations*, are a contribution to the bullwhip effect because due to these fluctuations, orders can change immediately. For instance, companies tend to order large amounts before a price increase will happen which in turn can lead to a distortion in demand upstream the supply chain. The last one, *rationing and shortage gaming*, is referred to as 'self-interest behaviour' (Naude & Badenhorst-Weiss, 2011). When for instance, there is a shortage, customers will order more than they actually need to ensure getting what they need. An example given in Lee et al. (1997a), when total supply is only 50 per cent of the demand, all customers get half of what they actually order. Therefore, these customers will order more so that they are ensured of getting enough. Later on, when the customers have enough, they will cancel the rest of the orders which leaves suppliers stuck with all the products. According to Min (2000), potential causes for the bullwhip effect are *information failure, chain complexity, product proliferation, sales promotion, economies of scale and speculative investment behaviour.* Looking at all these causes mentioned in this chapter, it can be concluded that it could be counteracted if there is at least more information sharing between downstream and upstream organisations which in turn can lead to chain visibility. This can also be confirmed by some countermeasures proposed by Lee et al. (1997a). For instance, "One remedy to the repetitive processing of consumption data in a supply chain is to make demand data at a downstream site available to the upstream site" (p. 98). Also, "When an upstream company receives consumption data on a fixed, periodic schedule from its downstream customers, it will not be surprised by an unusually large batched order when there is a demand surge" (p. 100).

Here can be seen that information sharing and cooperation is key in counteracting the bullwhip effect. This can also be confirmed by Min (2000), in which he proposes 'information failure' and 'chain complexity' as causes for the bullwhip effect. Next to that, Jeong and Hong (2017) did research into the impact of information sharing on the bullwhip effect. As a result of this study, it could be concluded that information sharing has a positive impact on the bullwhip effect. The results showed that a higher information sharing rate, more significantly reduced the bullwhip effect than a lower information sharing rate. Therefore, this only proves more that information sharing can be seen as a countermeasure of the bullwhip effect. Other countermeasures as proposed by Min (2000), are 'inter-organizational information sharing systems' that enable the exchange of information with open communication channels. According to Min (2000), an example of such a system could be electronic commerce with point-of-sale system and enterprise resource planning (ERP). Another countermeasure proposed by Min (2000) could be 'order fulfilment agility' in which organisations use a pull strategy like Just-In-Time (JIT) and quick-response manufacturing. The third countermeasure is 'the postponement of final product configuration' which means that firms postpone the customization of finished products. In the end, this could lead to minimized inventories and a decrease in the need for reconfiguration of finished good forecasts if customer demand changes (Austin, Lee & Kopczak, 1997, as cited in Min, 200). According to Min (2000), vendor-managed inventory (VMI) is a popular way to postpone and reduce inventory and costs. With these programs firms ask suppliers upstream to remain the owner of semi-finished goods until there is actual demand. And the final countermeasure proposed is 'value pricing' in which firms don't do promotional sales, but for instance like P&G use a 'everyday low pricing' approach (Min, 2000). In this way customer demand remains steady and won't fluctuate much because of promotional sales.

3.3 Current Research on the Bullwhip Effect

Looking at the time the phenomenon was first introduced, it can be concluded that it is a very old concept. Although the fact that it is very old, the bullwhip effect and its presence is still being researched nowadays. The previous chapters merely focused on what the bullwhip effect is, how it is caused and how it can be counteracted. This part of the paper focuses more on current research done into the bullwhip effect and its presence in several industries.

Bray, Yao, Duan & Huo (2019), did research into the effect of ration gaming on the bullwhip effect in which they studied the sixth largest supermarket chain of China. In the study they found out that upstream scarcity led to inventory runs which in turn increased their bullwhip measures by 6 to 19 per cent. From this they concluded that their hypothesis of ration gaming causing the bullwhip effect is affirmative. This study therefore provided empirical evidence for the fact that ration gaming causes the bullwhip effect, as Lee et. al (1997) already proposed many years ago. As stated before, the bullwhip effect is already studied in many industries like retail, wholesale and manufacturing. Over the past few years industries of resource extractions as oil and

gas have become very important. However, according Zhu, Balakrisnhan & Da Silveira (2019), the bullwhip effect hasn't been much studied in these industries. Therefore, they investigated the bullwhip effect in the oil and gas industry and which factors impact it. For this research they used case study evidence from six North American companies. The findings of this study were that the theories on the bullwhip effect still have some limitations with regard to explaining this effect in the oil and gas industry. Also the countermeasure of information sharing isn't applicable to this industry. Therefore Zhu, Balakrishnan & Da Silveira (2019) provided an overview of propositions which could provide guidance for countermeasures of the bullwhip effect within the oil and gas industry. Khan, Ahmed and Husain (2019) had been studying the bullwhip effect from a human behaviour perspective. The findings of this study were that peoples personality has an influence on the bullwhip effect and even people with high openness and consciousness are less likely to start of a bullwhip effect. As can be seen from these examples, the bullwhip effect is still being looked into, unless the fact that it is a very old concept. The only difference is that it is being investigated in more different industries than it was the case before (like oil and gas industry). Also, there are still researchers nowadays who try to find evidence for the theory of Lee et al. (1997a, 1997b, 2004) like Bray et al. (2019) did. Therefore there has not much changed with regard to the theory about what the bullwhip exactly is and what causes it.

4. RFID TECHNOLOGY

RFID is a rapidly growing technology and widely used in many industries. As stated earlier, information sharing is key in the supply chain. RFID is considered to play a vital role for these information sharing processes within the supply chain by enabling visibility (Jones & Chung, 2008; Herrman, Rogers, Gebhart & Hartmann, 2015). Jones and Chung (2008) describe visibility as: "the ability of anyone, including customers, to have access to inventory, orders, raw materials and delivery points at any time" (p. 119). Due to latest and real-time information RFID offers, companies can minimize upcoming risks and maximize the profitability of supply chain end-to-end (Khan et al., 2016). One of these risks also include the bullwhip effect. Because of this influence on supply chain visibility and information sharing processes this part digs deeper into the technology of RFID. First it is explained what RFID technology exactly is and how it is applied at the moment. Also a deeper analysis on its advantages and implications is made.

4.1 Definition of RFID Technology

According to Chechi, Kundu and Kaur (2012), RFID is "a generic term for technologies that use radio waves to automatically identify people or objects from a distance of several inches to hundreds of feet" (p. 109). Hunt, A. Puglia and M. Puglia (2007) describe RFID as "a wireless communication technology that is used to uniquely identify tagged objects or people" (p. 1), where, through radio-frequency electromagnetic fields, an RFID tag corresponds with an RFID reader (Whitmore, Agarwal & Da Xu, 2014). This technology makes it possible for people to identify, track and monitor every object equipped with RFID tags automatically (Jia, Feng, Fan, & Lei, 2012). Also, RFID systems are able to distinguish lots of different tags within the same general area without human assistance (Kaur, M. Sandhu, Mohan & S. Sandhu, 2011). The type of data that is communicated between the tags and readers vary. However, the main type of data used for IoT are the Electronic Product Code (EPC), which are used to give objects individual identities (Whitmore et al., 2014).

RFID systems are built upon a combination of RFID technology and computing technology. These systems consist of five components:

- Tag/transponder
- Antenna
- Reader
- Communication infrastructure
- Application software

The antennas are used in order to collect all the information the tags contain. After information is collected, the reader reads the information and the communication infrastructure enables the reader to send the information through the IT infrastructure. Via the application software, users can see the information through application or interface. Finally, there are two types of RFID tags: passive and active. Passive RFID tags don't need a power source or transmitter, are cheaper than active tags and don't require any maintenance. Active tags on the other hand are used over longer distances, mainly on large assets like cargo containers.

4.2 Applications of RFID Technology

As stated earlier on in this chapter, RFID technology is a widely used tool and therefore has many different applications. According to Ahuja and Potti (2010) RFID is used for many tasks ranging from managing supply chains to tracking livestock and controlling building access. Because of the fact that RFID is used in such a wide spectrum of application areas, this part only highlights some popular and most used applications of RFID in order to give a better understanding of the technology.

RFID technology has many applications in the health care industry where RFID tags are for instance used to store medical history of patients (Ahuja & Potti, 2010). When the RFID tag on the patients wristband is scanned, the development or changes of the health condition, medication and blood type of patients can be seen. In this example, a wireless reader communicates with the tag after which the information is displayed on the mobile device of the consultant (Domdouzis, Kumar & Anumba, 2007). Also, these tags are used for blood transfusion, where the blood bags contain different tags. Together with the tag that contains the information about the patient, the correct blood bag for the specific patient can be found. According to Ahsan, Shah and Kingston (2010) delivery services and airline companies lose a lot of profit due to lost/late delivery of packages or luggage. Therefore, these companies use RFID tags to track and identify the packages and keep customers informed about it. In June 2019, the International Air Transport Association (IATA) decided to support the global deployment of RFID for baggage tracking. Another popular application of RFID is their usage at toll gates with the help of the so called E-ZPass. These E-ZPasses are RFID tags applied to car licence plates which automatically identify the account holder. After the tag is scanned at the toll gate, the toll will charge directly via the credit card connected to the licence plate or sends a check to the account holder. This technology allows smoother traffic flow because cars now don't have to stop and wait to make the payment. RFID technology is also used in the retail industry where RFID tags are put onto physical objects in order to identify and track them along the supply chain (Domdouzis et al., 2007). RFID is used by organizations like

Wal-Mart for instance for supply chain crate and pallet tracking applications (Whitmore et al., 2014; Hunt et al., 2007).

4.3 Advantages and Limitations of RFID Technology

As described earlier this chapter, RFID technology plays a vital role in sharing processes within the supply chain. This is due to the fact that RFID can create visibility throughout the whole chain. As a result of this real-time information RFID enables, companies are able to minimize risks and even be more profitable than before. According to Khan et al. (2016), real-time information sharing between downstream and upstream organisations within the supply chain is the biggest advantage of RFID technology. Véronneau and Roy (2009) also claim enhanced visibility in the supply chain to be one of the main benefits of RFID. Also from this can be concluded that RFID is able to counteract the bullwhip effect, because it is caused by a lack of visibility and real-time information sharing. Jones and Chung (2008) foresee both benefits and challenges with regard to real-time information RFID offers. On the one hand it is a benefit because with the latest information, best decisions can be made. On the other hand, at that time, the amount of data led to data storage problems. However, nowadays data storage is getting bigger and bigger. Another big advantages Jones and Chung (2008) propose is that RFID reduces business costs. This is due to the fact that operations become more productive because labour, transportation and facility costs of moving inventory is getting reduced. Also a benefit they name is manipulating inventory by using RFID. Finally, they conclude that RFID is able to counteract the bullwhip effect because it supports the need for timely information: "RFID technologies provide an opportunity to reduce the uncertainty leading to the bullwhip effect through more real-time information" (Jones & Chung, 2008, p. 125). Vance et al. (2010) concluded after their research that "RFID technology has significant potential to increase supply chain agility and mitigate the bullwhip effect through additional and enhanced information that RFID uniquely provides" (p. 33). Next to the visibility issue, Véronneau and Roy (2009) state that RFID reduces direct labour of routine tasks like inventory control. Next to this, RFID also increases accuracy. According to Fescioglu-Unver, Choi, Sheen and Kumara (2014) as cited in Pasqualeto, Costa and Da Silva RFID technology offers many benefits compared to barcodes. They have, for instance, a longer lifespan and are reusable. Next to that, RFID tags are more resistant, even in harsh surroundings and are able to store more data. But the most important advantages over barcodes are that they can be scanned without line of sight and it is possible to scan many different tags at the same time.

5. RESULTS & ANALYSIS

The following section of the paper will analyse the results and findings of the research. In total, seven interviews were conducted. The interviewees varied from background reaching from managers and employees at Audi, Volkswagen and Daimler to an inventory planner at the biggest importer of Volkswagen in the Netherlands. These interviewees were able to give a deeper understanding of how the automotive industry and its supply chains look like. Next to that, the vice president of an RFID technology supplier and a warehouse engineer of Scania were interviewed. These interviews gave a deeper understanding on RFID technology and how it is used in the automotive industry at the moment. The interviewees range from background and are all active in different parts of the supply chain and therefore enables getting a better understanding of the supply chain itself and the problem the industry faces. In Appendix B, the interview questions are shown.

5.1 Automotive Industry

This part of the paper first outlines how most supply chains in the automotive company generally look like. Later on, a more focus is put on the supply chain of Volkswagen in the Netherlands. After that, the complexity of these supply chains in general and the automotive industry itself will be outlined in detail.

5.1.1 Automotive Supply Chain

Mapping a supply chain can be done in a downstream or upstream manner. In this example the upstream way is used. When starting upstream the supply chain of for instance a big German automotive company like Volkswagen, the stream begins with the last tier supplier. This can be the 4th tier but also the 7th tier, because the supplier tiers in the automotive industry can range from 1 to 7. However, what in general can be seen is that the supply chain starts for example with the raw material suppliers (4th tier). For example a big German steel manufacturer that makes the steel for the automotive industry. Then the material goes downstream to the part manufacturers (3rd tier), where steel is made into screws. After that the screws go to the component manufacturer (2nd tier) which for example produces the seats. Then the produced seat frames are passed on to the subassembly supplier (1st tier) which assembles the whole seat where the frame, electronics and the leather come together. And after this process, the whole seat is delivered to the automotive manufacturer which then assembles it into the car. After the cars are assembled, they are distributed to dealer networks all over the world where they are finally sold to the customer. In this example, a simplified supply chain is mapped, another example of different supply chains within the automotive industry can be seen in Figure 1 (Appendix A). As stated earlier, the suppliers can range from 1 to 7 tiers, so the supply chains can be much more complex than outlined above but in general for certain parts, the supply chains can look like this. So what can be seen from the supply chain is that car manufacturers like Volkswagen don't even manufacture the components themselves and only carry out the assembly of the car. All the different components and parts come from elsewhere. However, according to Kraljic (1983) as cited in Caniëls and Gelderman (2005), the supply strategy of a manufacturing firm depends on two factors as can be seen in Figure 2 of the Appendix (section A). So, the supply depends on the supply value and risk. According to the interview with an Audi employee, this is also the case for automotive manufacturers. For example leverage products, it makes sense to use the market to reduce products and get the components from suppliers. But on the other hand, for strategic products some car manufacturers produce in-house or have a very good relationship with one supplier. However, all automotive companies merely operate as an assembling company and a lot of work is done by the first tier supplier.

5.1.2 Volkswagen Group Nederland

In order for the reader to get a better understanding of an automotive supply chain as described above, an example of the supply chain of Volkswagen Nederland is now analysed and described. In this way, the reader can actually get a view on how such a complicated supply chain looks like and will make it easier for the reader to understand such a complicated

phenomenon. In order to map the Volkswagen Group supply chain in the Netherlands, an interview is conducted with a marketing manager from Pouw Automotive, a prominent dealership in Twente. After that it became clear that Pon Logistics is the only importer in the Netherlands and gets the cars directly from the Volkswagen factory and distributes them to dealerships nationwide. Therefore, also an interview with an inventory planner Service & Supply at Pon Logistics is conducted. After the interview also a guided tour around the plant and warehouse is done.

To start off with mapping, the supply chain of Volkswagen Nederland begins upstream at the first tier supplier. This example begins at five first tier suppliers only, because when mapping all the suppliers until the seventh tier would exceed the time and scope of the research due to the fact that Volkswagen has many thousands of suppliers. So, Volkswagen get their components from different first tier suppliers. For assembling the Volkswagen Tiguan for example, they get the navigation systems from Continental. The video and radar sensors for the drivers assistance systems come from Bosch, camshafts from ThyssenKrupp, tires from Bridgestone and the back windows from Pilkington. To clarify the complexity of mapping the whole supply chain until the last tier supplier; Continental and Bosch get their electronics for the navigation systems and video and radar sensors elsewhere, Bridgestone gets the rubber for their tires elsewhere and Pilkington gets the glass for the back windows elsewhere. Therefore, as said earlier, this part only focuses on mapping the supply chain until some of the first tier suppliers. So, when Volkswagen get the components from their first tier suppliers, they assemble the cars at their factories. When the cars are assembled, they are transported to Pon Logistics in Leusden, the only importer and distributor of the Volkswagen Group brands in the Netherlands. Then, Pon Logistics distributes the cars to dealerships nationwide. Some examples of prominent dealerships are Pouw Automotive, Huiskes-Kokkeler and Pon Dealer. Finally, at the end of the supply chain, the cars are supplied to the consumer.

The supply chain will now be explained a bit more from the other side, the downstream perspective which starts at the customer. When a customer comes at for instance Pouw Automotive to order a specific car, they can configure the whole car in a system called 'Auto Line'. When the car is configured, it will be converted into an order. Mostly, Pouw Automotive doesn't have highly configured cars on stock. What they do then, is they look at other dealerships throughout the Netherlands if they have the car. When they also don't have it, Pouw Automotive sends the order to Pon Logistics who will order it at Volkswagen. Volkswagen maybe already built the car, because they generate data from websites where customers can create their own car and in that way they can make a prognosis for upcoming cars to be sold, for instance mostly cars in the colour red. However, when the car isn't there, Volkswagen has to build it. They then go to their first tier suppliers and order what is needed. These first tier suppliers go to their suppliers and so on, this goes on till the last tier supplier. Then the needed components will in the end come back to Volkswagen and they will assemble the car. When the car is ready it gets transported to Pon Logistics again and finally to Pouw Automotive and the consumer.

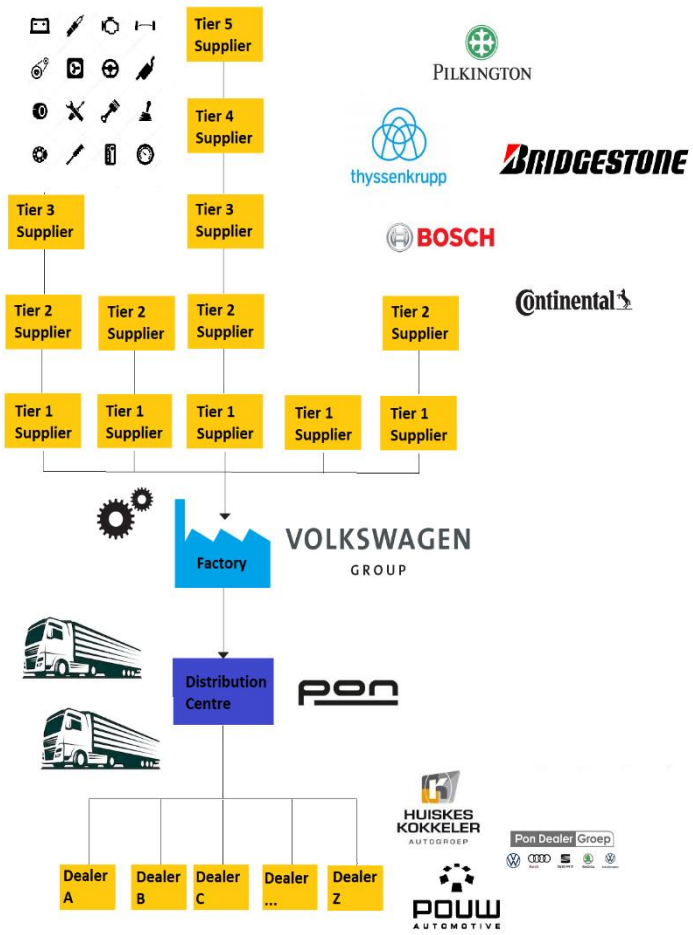

Figure 3. Supply chain Volkswagen Nederland

In figure 3 a clear overview of the Volkswagen Group supply chain in the Netherlands can be seen. This overview presents also some second till the fifth tier suppliers, to give a bit of an impression on how it could look like. Here also can be seen that the number of tiers can vary, depending on the product. As said earlier on in this part of the paper, this overview is used to give the reader a better view and understanding on how an automotive supply chain can look like. In this way, the reader is better able to see the complex nature of the industry and its supply chains.

5.1.3 Industry and Supply Chain Complexity

As stated earlier on in the introduction, automotive companies face many challenges nowadays. Naude and Badenhorst-Weiss (2011) state that competition amongst companies has changed; "Companies no longer compete against companies. Supply chains compete against other supply chains for supremacy" (p. 72). This section of the paper, outlines the complexities of the automotive industry and its supply chain.

In an expert interview with a manager at Daimler, it became clear that the automotive industry is so different compared to other industries because of the great variety of products they offer. As an example, some car manufacturers in Germany produce two and a half thousand (2,500) cars in one facility each day (personal communication). This so called 'mass customization' has led to customers fine tuning their cars from special seats to steering wheels and engines with different sorts of power. Because of the

fact that every car is assembled differently, due to high variety of tuning, the supply chain is very sensitive to errors. When for instance the wrong seat is put in the wrong car, the whole assembly line has to be stopped, which takes time, which costs money. Also, these cars are all assembled as so called Just-in-Time (JIT). This means that for instance the correct seat has to be at the assembly line on the right time and in the right order (Siemens, n.d.). For example when you take seats of a car manufacturer the moment they are ordered sometimes it only takes 6 hours before it is delivered, so really short in time (personal communication). Therefore, everything has to go very smooth and if one thing goes wrong, the whole chain gets affected and that's why the supply chain of automotive companies are so sensitive. According to another interview (personal communication), the fact that a lot of things are done in JIT is also one of the main reasons that the whole automotive supply chain is so complex. However, what makes it even more complicated is that there are so many different components like every button and every screw. It could lead to serious supply chain interruptions when only one button is missing from a supplier. This is also due to the tight production schemes car manufacturers have. When a certain part has to be put into a car at the assembly line at a certain moment, it would cost a lot of money when that isn't possible. So, in the end when something isn't there at the right time, in the right quantity or sequence, the whole car can't be build. Because of the fact that there are so many different components, car manufacturers also have many suppliers. What makes this massive amount of suppliers even more complicated, is that most of these suppliers are in Asia. The fact that these suppliers are very dispersed all over the world, makes also the supply chain and the routes very long. These longer routes the components have to travel is also prone to problems when there is a JIT production scheme because when for instance a ship arrives too late or doesn't even arrive, it could lead to massive supply chain interruptions. So, to conclude the supply chain gets more complicated, because the product is so complicated. Because of the complexity of the product, there are so many components which in turn leads to the fact that car manufacturers have very dispersed suppliers all over the world which makes the complexity of the supply chain bigger. So, therefore it can be seen as a bit of a vicious circle.

What also makes the whole industry complex, is the fact that there is a lot of competition on the customer market because every car manufacturer want to attract as many customers as possible (personal communication). Due to the competition over there, there is also a lot of competition on the supplier market. So what generally happens is that car brands like Volkswagen and BMW are really competing for the best suppliers. Due to innovation, suppliers, for example for light systems make car manufacturers want to have a competitive advantage. Some suppliers are very advanced in developing for instance these light systems. Therefore, car manufacturers as Audi and BMW have to fight for these kind of supplier and their innovations.

In a research, done by Thun and Hoenig (2011), supply chain risks in the German automotive industry are investigated. Automotive supply chains are vulnerable because managers fail to fail to implement proper instruments of supply chain risk management (Tang, 2006, as cited in Thun & Hoenig, 2011). Thun and Hoenig (2011) provide several reasons for this to happen. The first reason is that managers underestimate the risks, as the second reason is that managers aren't familiar with certain instruments that can aid to minimizing risks and therefore neglect them. Also the benefits of minimizing supply chain risks aren't widely known. As stated earlier and mentioned in the expert interview, automotive organisations have to offer a high variety of different products or variants so that the customer is satisfied. Harland, Brenchley and Walker (2003) as cited in Thun and Hoenig (2011) state that this high variety leads to higher vulnerabilities due to higher complexity. Also the fact that automotive companies have to globalize in order to remain competitive results in a more complex supply chain. Next to earlier mentioned factors, also outsourcing, reduction of suppliers, focus on efficiency, central distribution and centralized production can be seen as drivers of supply chain risk (Thun & Hoenig, 2011). In Figure 3 (Appendix A) can be seen which factors affect the supply chain most. As can be seen from this figure, globalization (next to earlier mentioned product variants) is one of the main drivers of supply chain risk. Due to the increasing globalization, automotive supply chains need "information transparency and synchronized processes across supply chain members to increase service levels, maximize profit and respond in real time in dynamic situations" (Drakaki & Tzionas, 2018, p. 360). Globalization in combination with demand or product variance, as a result of the earlier mentioned mass customization, can lead to a lack of information transparency and thus supply chain visibility which in the end can create the Bullwhip Effect (Srivastava, 2014, as cited in Vance et al., 2010). They also state that next to a lack of visibility, the lack of collaboration throughout the supply chain is a main factor leading to the bullwhip effect. This factor is also applicable to the automotive industry. This is due to the fact that automotive companies have many partners in the form of suppliers, distributors, retailers and customers. Lee et al. (2004) as cited in Naude and Badenhorst-Weiss (2011) state that the Bullwhip Effect is seen as one of the main factors that negatively impacts the supply chain and it can even drive 13 to 25 per cent of the operating costs. Also, Metters (1997), concluded that eliminating the bullwhip effect would increase profits by 15 to 30 per cent.

6. THE BULLWHIP EFFECT IN THE AUTOMOTIVE INDUSTRY

The previous part, mainly highlighted the main characteristics and complexities of the automotive industry and supply chains in general. Also, a connection is made to the bullwhip effect, because it is assumed that several complexities could lead to this phenomenon. Therefore, this part of the paper digs deeper into the presence of the bullwhip effect in the automotive industry and what factors, characteristics and/or complexities actually could cause or contribute to the bullwhip effect within this industry.

6.1 Presence of the Bullwhip Effect in the Automotive Industry

Wang and Disney (2016) did research into the bullwhip effect and its presence in different supply chains. They concluded that the bullwhip effect is present in the automotive industry. In figure 4 (Appendix A) the empirical evidence of the bullwhip effect within the automotive industry can be seen. Also in a study done by Wang, Dou and Chen (2014), the presence of the bullwhip effect in the automotive industry is proven. As can be seen in Figure 5 (Appendix A) , relatively small changes in the ordered units at the distributors, leads to even bigger variations in inventory at the raw material suppliers. Bray and Mendelson (2015) further investigated the bullwhip effect and production

smoothing in the automotive industry. Because production smoothing is expected to be a counter actor of the bullwhip effect. The research consisted of a sample comprising 162 car models from car brands worldwide, from Audi to Toyota and found out that 75% of the car models, only 5% smooth production. However, 99% of the sample encounters the bullwhip effect. Furthermore, they found out that, on average, the production is 220% as variable as sales, so there exists a significant bullwhip effect on average in the automotive industry. Yu, Li, Xiao, Luo and Ou (2011), investigated the impact of lead time on the bullwhip effect in the process of automotive sales. Yu et al. (2011) state that the automotive supply chain is complex and "information sharing between members is local; the response speed and operation of logistics systems are inefficient; costs of auto products are high" (p. 1518). Also due to the previous mentioned mass customization the "lead time in the auto sales process continuously extended and supply chain inventory control management is becoming increasingly difficult" (p. 1518) and concluded that "the bullwhip effect has serious influence on auto sales chain property and performance" (p. 1518). Chiang, Lin and Suresh (2016) empirically examined the effect of forecasting on the magnitude of the bullwhip effect in the U.S. auto industry. For all the types of cars, from mid-size SUVs to sports cars, they examined the presence of the bullwhip effect with different methods of forecasting. From their findings can be concluded, that the bullwhip effect varies based on different forecasting methods. Pastore, Alfieri and Zotteri (2019), investigated the bullwhip effect within the automotive industry and in Europe specifically. The company they use for their study, sells spare parts to automotive companies all over the world. "The results showed that moving from the bottom (final consumers) to the top (external suppliers) of the supply chain, the demand variability increases, both at an aggregated level and at a single product level" (p. 27).

6.2 Causes of the Bullwhip Effect in the Automotive Industry

As it is made clear in the previous parts of this paper, the automotive industry has many different characteristics compared to other industries. Therefore it has many different complexities that come with it. Also, previously in this paper it can be read that the bullwhip effect can have many different causes. However, it is still not made clear what actually causes the bullwhip effect in this specific industry. Therefore, this part of the paper tries to connect the complexities of the industry and the bullwhip effect in this industry, in order to clarify how it is exactly caused. Therefore, the main causes of the bullwhip effect within the automotive industry are now summarized. This is mainly done based on interviews with experts in the field of the automotive industry. These experts mostly were or are still active within this industry and thus know a lot about it.

According to the interview with a former employee at Volkswagen it became clear that the bullwhip effect is caused because it takes time to ramp up production and produce something, which is caused by a delay of information. When information comes from the top of the chain, it might take a week till it runs through the whole supply chain. When this information is at the end of the chain, information goes back all the way to the other end when for instance one supplier can't make it. What makes it even worse is that the supply chains are so long; sometimes up to 7 tiers. Plus the fact that there are so many different components. This information delay effect is caused by the fact that information has to go through the chain and up the chain again; for every tier it takes exponentially more time because they also have to contact their tier again. So it can be concluded that information delay is one of the causes of the bullwhip effect in the automotive industry. This information delay is caused by the fact that there are a lot of different components and therefore also many different suppliers which makes the supply chain very long.

In the interview with a former Volkswagen employee, it also became clear that there is a lot of secrecy within the supply chain. Big car manufacturers like Volkswagen try to map their whole supply chains, but that is made very difficult due to several factors. Car manufacturers do know who their first tier suppliers are of course. However, these first tier suppliers don't want to give information on who their suppliers are. This can be due to the fact that it is simply company secret, or that they are afraid that the car manufacturer at a certain point orders directly at their suppliers and thus lose their client. Also these suppliers, are often afraid of giving too much information, because it may be used against them in the future. When Volkswagen for instance knows the margin of their supplier, they can actually say this is too high for them and go to another supplier or push prices which in the end causes in-transparency throughout the supply chain. Unless this secrecy, bigger automotive companies are very good at squeezing out the information at their first tier suppliers and use it. However, this is very co-dependent because car manufacturers can't simply bypass the bigger suppliers like Bosch; Volkswagen depends on Bosch. When there is a strong co-dependence, automotive companies can less force their suppliers to be transparent. On the other hand, when suppliers are extremely dependent, these companies can much easier force them to open the books. However, it is still very hard for car manufacturers to get all the information simply because the complexity of the industry that there are so many suppliers all over the world. Volkswagen can still get little information because some of their first tier suppliers depend on them, however there are so many other suppliers, and not even first tier suppliers (also second, third, etc.), where they simply can't. So this secrecy, which causes major supply chain invisibilities, is definitely also one of the main factors contributing to the bullwhip effect. Also, very often, buyers or supply chain managers simply don't have the time to completely map the whole chain.

Next to chain visibility, information sharing is of big importance for supply chain performance and bypassing the bullwhip effect. Therefore, a look into the information sharing aspect within automotive supply chains is now analysed. In an interview with a former employee of Audi, it became clear that information sharing between the manufacturers and suppliers is depending on the type of products they supply. Referring back to the Kraljic matrix, leverage products for instance exist in very price-based markets. Car manufacturers try to push the prices and the supply risk is low, therefore there is not a lot of communication or information sharing between them and the suppliers. On the other hand, strategic products have a very high supply risk and influence on company results, there is quite a bit of communication and information sharing. Next to that, for routine items, car manufacturers have vendor managed inventory (VMI) which means that the supplier is responsible for filling up the inventory and in that case a lot of data communication is needed. However, some car manufacturers choose not to do that because

when a supplier manages the inventory of a car company, they could get into a lock-up situation.
According to another interview, information sharing is also dependent on the type of sourcing project. For forward sourcing, when a product is first time sourced for a new prototype, there is more often contact with suppliers. On the other hand for normal or global sourcing, the manufacturer only shares the specification of the product with the supplier. So then there is much less communication. According to an interview with a manager at Daimler, it became clear that their factory has a lot of information sharing with their first tier suppliers. These first tier suppliers precisely know how much components are needed, when they are needed and in which sequence they are needed.

7. RFID IN THE AUTOMOTIVE INDUSTRY

During this research, it became clear that there are many applications of RFID technology within the automotive industry and many car manufacturers use different cases of usage. Next to that, car manufacturers are very busy testing new RFID projects, so it is a hot item in the automotive industry because it is believed to optimize many processes within the industry. Therefore, this part of the paper summarizes different usages of the technology at car manufacturers and its benefits.

7.1 Applications of RFID in the Automotive Industry

In an interview with the Vice President of Confidex it became clear that many car manufacturers make use of the RFID technology and that it is used through the whole car manufacturing and supply chain process. However, different car manufactures have different use cases. Confidex designs and manufactures short-range wireless identification solutions and products for linking assets in business-critical processes. Confidex supplies for instance car manufacturer Volvo and Daimler with their RFID technology. In this part of the paper, only a few applications are mentioned, because analysing all applications at different manufacturers in-depth would simply exceed the time and scope of the research. According to Confidex, Volvo mainly uses the technology for production. To be more specific, Volvo is using RFID to uniquely identify (UID) a car to be produced. In other words, the UID of a RFID tag is linked to the production details of the ordered car. They consist the colour, engine type, tyre type and so on. At each of the production stations the manufacturing robots read the UID and get the right information for the specific car to be produced. The RFID tags are attached to the chassis of the car being manufactured at the beginning of the process. Furthermore, it is identified at several points in the process. After the production process, a unique car is produced. Volvo does not use RFID tags for its aftersales, however, other car manufacturers do so.
At Autostadt, Volkswagen has an RFID system in order to track over 15,000 vehicles. This system ensures that each vehicle goes through several different task and quality controls in a timely manner. According to Ralf Michael, project manager of Identec, Volkswagen has already earned the investment costs back in one year because of increased productivity. Next to this, Volkswagen also uses RFID for producing prototypes. Suppliers attach RFID tags on the components which contain information about for instance part type and even before the components are on their way, Volkswagen receives the information and are able to prepare. When the parts arrive, they pass an RFID gate that scans them all. This makes assembly of prototypes more efficient and reduces errors. An article on Volkswagen AG states that already 280 suppliers are connected to the system and also Audi and Porsche joined. Furthermore at the Volkswagen factory, the car gets an RFID tag at the body shop, this establishes which car body belongs to which order. Also, in the warehouse the parts contain a specific RFID tag, so that at the assembly, the correct part can be tracked very quickly.
In a news article on RFID Journal, Collins (2016) states that Daimler uses RFID to improve the flow of parts from its onsite storage to the workstations on the production lines which enables accurate and automated inventory and part orders to suppliers. In that way, Daimler also directly knows how many parts there are and where they are. According to Daimler manager, Mercedes also uses RFID between them and their first tier suppliers. It enables Mercedes to exactly see where the ordered parts are and when they arrive which increases the supply chain transparency.
In 2014, Scania invested in RFID in two of their parts logistic centres. In an interview with the warehouse engineer of Scania, who was directly involved in installing the technology, it became clear that there are many benefits that come with using RFID. All dock doors at Scania are equipped with RFID antennas. So when a container or pallet leaves the warehouse, the system checks if everything is correct. RFID also enables a 'proof of delivery'. Next to this, with the help of this technology, Scania can exactly see where every container or pallet is.
At Audi, RFID is used when products come out of inventory. All the packages and all the parts that are needed, are taken out of the inventory. With the help of RFID, it is exactly known where the needed parts are. They're put on a truck, the truck drives out of the inventory and when it drives through the gate of the inventory everything that is on the truck will be scanned. The ERP system knows which parts left the inventory. RFID is also used between first tier suppliers and Audi.

7.2 Benefits of RFID in the Automotive Industry

At the beginning of the paper it is stated that RFID enables information sharing and chain visibility. In order to test whether these assumptions are justified, the main benefits of RFID in the automotive industry are now analysed. After that, it will be analysed to which extent it has an influence on the bullwhip effect in the form of a discussion and finally a conclusion.
With the help of RFID, car manufacturers always know where their products are. It also enables accurate and automated inventory and part orders to suppliers. At the assembly, the correct part can be tracked very quickly. And also according Confidex' Vice President, RFID makes "supply chains, transactions and authentication of goods more efficient and secure". Because of the fact that RFID is live communication and with the help of this technology car manufacturers do not always need employees to scan barcodes. Therefore it prevents kinds of mistakes. Also, more information can be stored. From this, it can be concluded that it makes processes within the internal supply chain way faster and less sensitive to errors. When something goes wrong at Scania's warehouse for instance, everybody in the supply chain gets affected (they get their products too late etc.). Because with the help of RFID they are way faster and the other operations in the supply chain can go smoother and there will be less supply chain interruptions. Therefore, it can have a certain influence on the whole supply chain. According to the interview with a warehouse engineer at Scania, RFID is used just for a

small part in our supply chain, but it has a positive effect throughout the whole supply chain. Furthermore, RFID makes the supply chain visible. Not only the internal supply chain, but also the external supply chain. Car manufacturers have their whole internal supply chain exactly visible, because every component, every car can be tracked throughout it. Next to that, many car manufacturers use RFID between them and their first tier suppliers, which thus also makes the external supply chain visible. With RFID used in the whole supply chain information is available in real time. All inventories of raw materials can be traced at suppliers warehouses, semi-final products can be followed during its transport and finished products can be followed up till arrival at car manufacturer location. RFID is seen as the only enabler of getting the information from each asset in the supply chain.

8. DISCUSSION AND CONCLUSION

This study began with the central research question, i.e. "to which extent has asset tracking based on RFID have an impact on the bullwhip effect in the automotive industry?". In order to try and give an answer to this central research question, the study is divided into two parts. Namely, the first part, on how the bullwhip effect is exactly caused within this industry. The conclusion that can be made out of this part is that because automotive companies sell such a complex product, they simply need lot of different components, therefore they have lots of different and dispersed suppliers which makes the supply chain very long. In the end, this causes an information delay. Next to that, car manufacturers have many suppliers which leads to the fact that there is much secrecy and therefore there is not much of information sharing. This can in the end lead to decreased supply chain visibility and transparency which causes the external bullwhip effect. After the causes of the bullwhip effect were analysed a connection was made to the second part, which mainly consisted of how RFID is used in the automotive industry and what effect it has on internal and external supply chain logistics and production processes. This is done in order to connect the RFID part to the bullwhip part and test whether the hypotheses mentioned in the introduction is true.

After all, based on the interviews, it can be concluded that first RFID has a very positive impact on the supply chain processes, internally as well as externally. The logistic and production supply chain processes are way less sensitive to errors due to this technology, which makes the processes quicker and has a positive influence on the whole supply chain. Next to that, RFID makes the chain visible, partially externally and mostly internally. This increased chain visibility has led to a higher supply chain transparency. Therefore, the assumption that RFID enables higher supply chain visibility is true. However, the information sharing assumption has to be revised. Because of the fact that there has to be information sharing for RFID to be of added value. If suppliers don't share their information with the manufacturer, they simply don't benefit from RFID. Therefore it can be concluded that information sharing and RFID are co-dependent.

Because of the fact that RFID enables less time delay, quicker processes and internal supply chain visibility and transparency, it can be concluded that RFID has a positive influence on the internal bullwhip effect. I.e., RFID has a positive impact on counteracting the internal bullwhip effect within the automotive industry. Also, many automotive companies use the RFID technology externally, i.e., with their first tier supplier. This enables external supply chain visibility up and till the first tier suppliers. However, RFID is not used with every first tier supplier. Plus the fact that there is still quite some invisibilities and secrecy in these long supply chains. Therefore it can be concluded that RFID has moderate impact on the external bullwhip effect. In other words, there is still work to do in order to increase external supply chain visibility and transparency and therefore RFID has not a very strong impact on counteracting the external bullwhip effect. However, many processes with first tier suppliers are smooth because of RFID and therefore it can be concluded that RFID has a moderate positive influence on counteracting the external bullwhip effect.

After all, the hypotheses that RFID enables information sharing and chain visibility which in turn decreases the bullwhip effect had to be revised during or after this study. The new model that is created can be seen in figure 4 below.

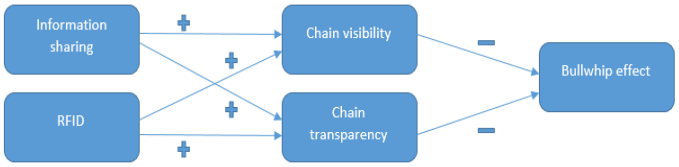

Figure 4. Revised model of the hypotheses

In the figure above, the revised hypotheses can be seen. As can be seen from figure 4, RFID technology does not enable information sharing specifically like it was assumed initially. This is due to the fact that there has to be information sharing in the first place for RFID technology to be of added value. Therefore as said before, they are co-dependent and when used together it can be a very powerful tool to increase the chain visibility and transparency. These two aspects, chain visibility and transparency, are a powerful tool that in the end can help to decrease the bullwhip effect in the automotive industry.

However, as said above, there is still work to do namely for the external bullwhip effect. For RFID technology to fully counteract the external bullwhip effect it is of importance that all parties within the supply chain work together and want to make the investment, i.e. have full information sharing and make use of RFID technology. Currently RFID is still relatively expensive, but in the future it will be only getting cheaper. Cheaper also in the sense that the benefits outweigh the costs. This is due to the fact that in the near future, everything has to go faster and RFID technology has the potential to fully automatize the supply chain processes which in the end saves time and cost. Furthermore, in the near future many processes will be robotized, human jobs will be cut and therefore RFID technology will be only used more and more. Next to that, production processes are JIT which holds that reliable and accurate information about inventory has to be there in real-time. RFID technology is an enabler of information to be available in real-time. So the prospect for RFID technology is looking quite promising. It is already used in many industries and many companies are already testing the new technology throughout their processes. Also, RFID technology has proven in many projects that it has the potential to optimize several processes and therefore cut time and costs. The only challenge for the technology is to convince every party in the chain to implement it. But with a look into the future, it's usage is expected to rise because like said before; in a fast changing

world, processes have to be optimized and be as fast as possible; a promise that RFID technology can and will fulfil.

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10. APPENDIX A

***Figure 1*. Overview of automotive supply chain (McGraw-Hill, 2006)**

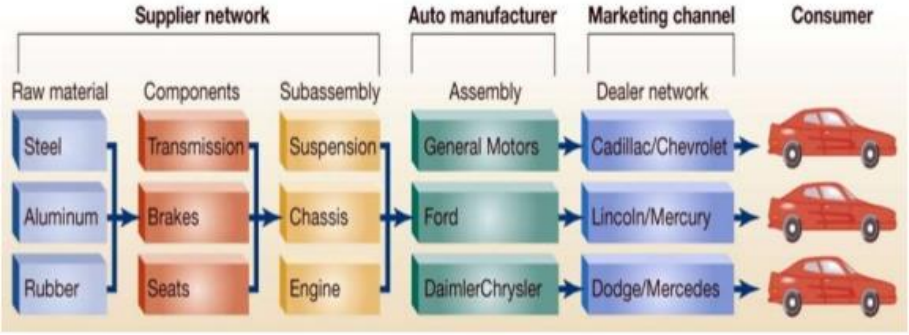


***Figure 2*. Kraljic matrix. Retrieved from "The Kraljic Matrix | How to Optimize Purchasing Costs and Risks". Accessed on 20 November, 2019, from https://expertprogrammanagement.com/2011/08/the-kraljic-matrix/**

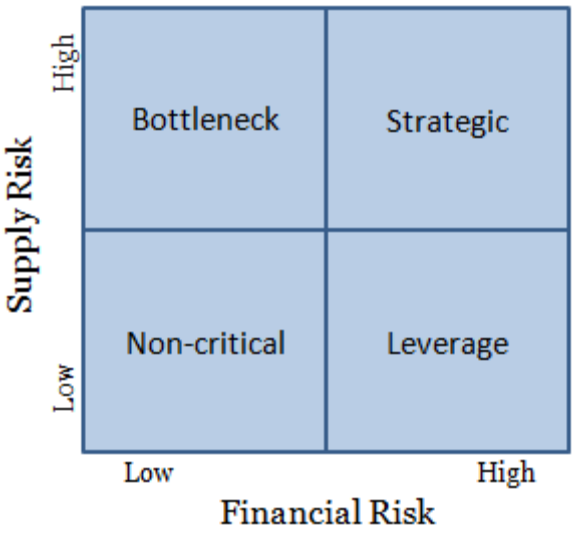


***Figure 3*. Drivers of supply chain risks. Retrieved from "An empirical analysis of supply chain risk management in the German automotive industry" by J.-H. Thun and D. Hoenig, 2011, *International Journal of Production Economics, 131*, p. 246.**

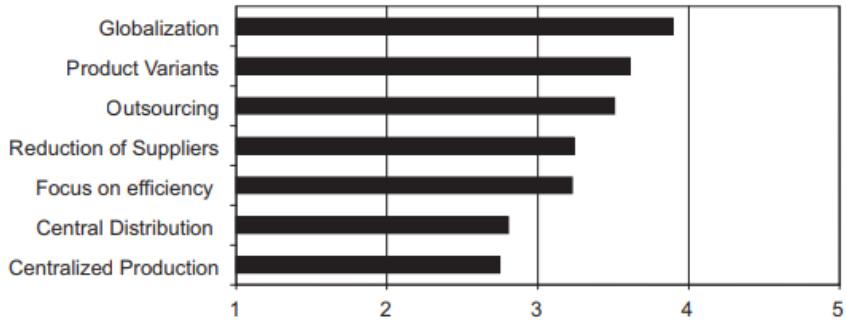


Figure 4. **Empirical evidence of the bullwhip effect. Retrieved from "The bullwhip effect: Progress, trends and directions" by X. Wang and S.M. Disney, 2016,** ***European Journal of Operational Research, 250(3),*** **p. 692**

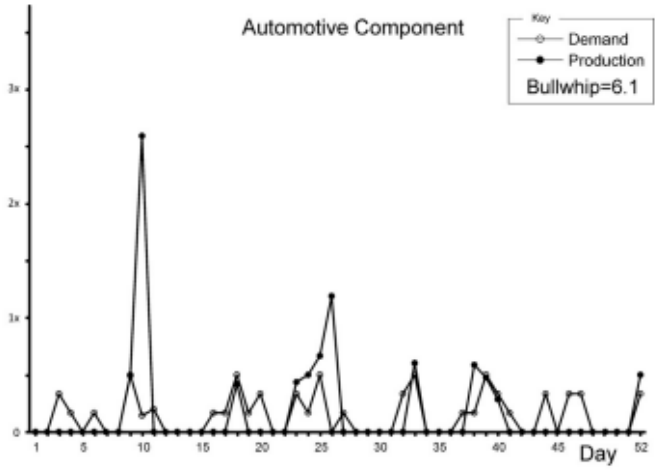


Figure 5. **SC inventory level changes of all nodes with traditional strategy. Adapted from "Automobile Industry Supply Chain Inventory Modelling and Optimization Based on MPC" by D. X. Wang, J.J. Dou and Y.H. Chen, 2014,** ***Advanced Materials Research, 945-949,*** **p. 3244.**

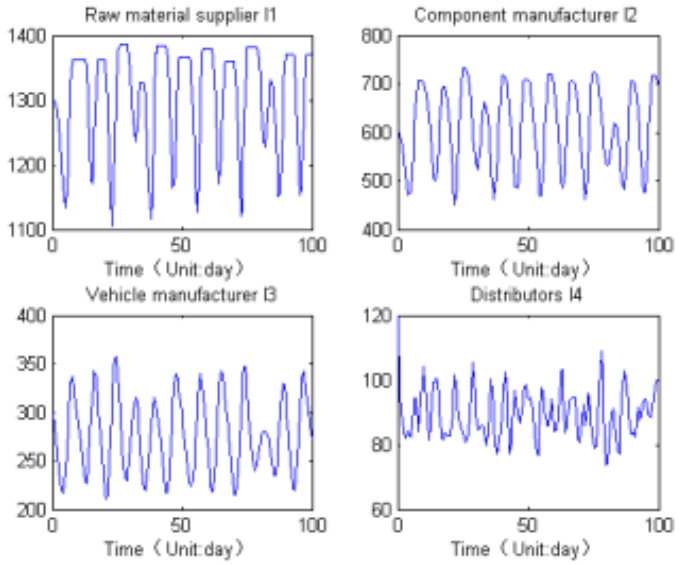
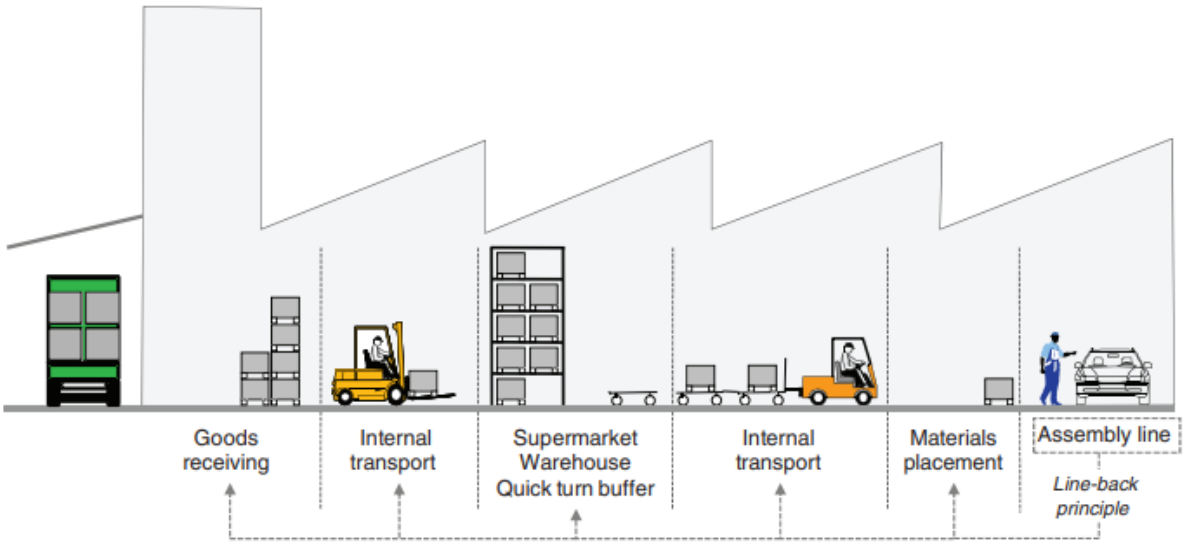


Figure 6. **The internal logistics supply chain. Adapted from: The internal bullwhip effect in car manufacturing by F. Klug, 2013, *International Journal of Production Research, 51(1),* p. 304**



11. APPENDIX B: Interview Questions

Q1: What makes the automotive industry, and especially the supply chain so complex?

Q2: What does a supply chain of a car manufacturer like Volkswagen or Daimler look like, from beginning to end?

Q3: How many suppliers do these companies have on average? How many 1st, 2nd, 3rd? (tiers)

Q4: How is the cooperation between different parties within the supply chain? (example between 1st tier suppliers and manufacturers) Is there a lot of information sharing? What is shared at the moment and what is preferred? Is the supply chain transparent?

Q5: How are customer orders processed? When for instance a customer comes to the dealership and he wants a new car, how does this order go through the supply chain, from customer to suppliers?

Q6: Are u familiar with the bullwhip effect? What causes the bullwhip effect in the automotive industry?

Q7: What is done at the moment to counteract this problem as much as possible?

Q8: Are you familiar with RFID? How is RFID used at the moment in the automotive industry and especially in the supply chain? Mainly in production or also logistically wise through the supply chain?

Q9: From your point of view, what effect does RFID have on the bullwhip effect in the automotive supply chain? Do you agree it improves information sharing and the chain visibility.

Q10: Do you think, that with the help of this technology the bullwhip effect could be decreased? If yes, to which extent? If no, why not?

Extra questions:

- What are the downsides of RFID?
- What are the costs of RFID?
- What are the current trends in the field of RFID?