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STOCK DEMAND: OUTLIER DETECTION AND ANALYSIS IN A VITAL AREA OF A CAR MANUFACTURER SUPPLY CHAIN

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Abstract: The supply chain is vital to an automobile manufacturer, controlling parts and products' arrival and departure flow. An area that dictates the pace of a supply chain is demand. A correct transport flow impacts a better demand-supply, guaranteeing a minimum and safe stock for the company. However, several factors lead to problems, such as delivery delays, faulty transport routes, and demand instability. With that in mind, this work aims to use techniques such as data science and statistical analysis to solve problems in the stock area. By implementing a dashboard containing data relevant to the company stock, it was possible to apply the Z-Score method to detect outliers. The results reveal problems in vehicle production recovery. With the identification and analysis of these outliers, better production and route planning is possible.

Keywords: Data analysis, demand, outlier detection, supply chain, stock

DEMANDA DE ESTOQUE: DETECÇÃO E ANÁLISE DE ANOMALIAS NA SUPPLY CHAIN DE UMA FABRICANTE DE VEÍCULOS

Resumo: Dentro da indústria automobilística, a supply chain tem um papel extremamente importante: controlar o fluxo de chegada e saída de peças e produtos. Uma área que dita o ritmo de uma supply chain é a de estoque e demanda. Um correto fluxo de transporte impacta no melhor atendimento da demanda, com garantia de estoque mínimo e seguro para a empresa. No entanto, existem vários fatores que levam a problemas como atrasos nas entregas, rotas de transporte defeituosas e instabilidade da demanda. Pensando nisso, este trabalho visa utilizar técnicas de ciência de dados e análise estatística para solucionar problemas na área de estoque. A partir da implementação de um dashboard que contém dados relevantes para o estoque da empresa, foi possível aplicar o método Z-Score para detecção de outliers. Os resultados revelam problemas na recuperação da produção de veículos. Com a identificação e análise desses outliers, é possível um melhor planejamento da produção e das rotas.

Palavras-chave: Data analysis, demand, outlier detection, supply chain, stock.

1. Introduction

The Supply Chain is a relevant part of several companies, mainly car manufacturers, with large sectors for receiving parts and products. An essential operation for a well-functioning supply chain is inventory/demand control (Nedergaard, 2001). The stock/inventory plays a critical role in the proper functioning of a supply chain. (Ottemöller, Friedrich, 2019). The stock part keeps a supply chain running with high performance. Supply chains usually have to offer a high customer service level while operating efficiently with low inventory levels. As this area plays a vital role in the functioning of a supply chain, stock, and inventory are under constant pressure, and different types of errors and failures are likely to happen, from natural disasters to human errors. (Boulaksil Youssef, 2016; Tang C.S., 2006). Along with the evolution of the Supply Chain, the digitalization of processes also comes to the fore. The rise of digital and connected technologies that combine all parts of the manufacturing and retail process has further underpinned these working methods over the past decade or so (Bagliardi et al., 2022). When analyzing different data types, these errors mentioned above, which can usually go unnoticed, can be studied, and classified as outliers. Bearing this in mind, this research focuses on identifying outliers in one of the most vital supply chain processes: stock and demand. The stock process is part of the inventory area, with demand information for distinct functions. Identifying outliers allows the mentioned process to save enormous amounts of time, money, and work and transform the supply chain processes into preventive methods, not reactive ones. Detecting outliers allows reassessment of routes taken, suppliers contracted, and planning conducted to improve such indicators. To implement the research on outlier detection, a database of the mentioned process relevant to the supply chain of a large vehicle manufacturer was used. For this, the objective was the implementation of Data Science techniques and statistical analysis to facilitate decision-making with the help of Data Visualization and tables made using the Spotfire software.

The present paper is divided into six sections. In section 1, the introduction is presented, which contextualizes the topics addressed, the motivation, and the objectives of the work. Section 2 has the entire theoretical framework, with explanations and contexts on the issues used during the project, such as Supply Chain, Inbound and Outbound Logistics, Data Science, Stocks and Demand, and Outlier Detection. Chapter 3 presents the research model, following the Spiral method. In addition, a detailed description of the problem is shown. Chapter 4 presents the development of the project. Section 5 deals with the results, while Section 6 presents the paper's conclusion.

2. Theoretical Reference

This section will comment on the main themes that will serve as a basis for understanding the problem, research, and proposed solution. The topics covered are Supply Chain, Inbound and Outbound, Data Science, Outlier Detection, Stock, Bill of Material, and Manufacture Resource Planning. The problem deals with inventories and demand, using calculations and forecasting algorithms to predict future use and availability of features. This project used data science and data visualization techniques to study the detected outliers, with the Spotfire software being the primary tool chosen for the project's development.

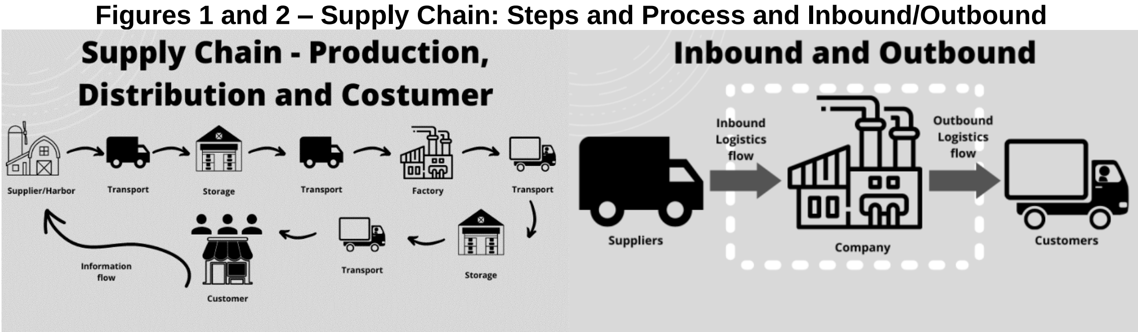
2.1 Supply Chain

The supply chain history can be traced back to the early days of civilization when people traded goods and services. However, the concept of a modern supply chain, where goods and services are produced, transported, and delivered to customers through a complex network of suppliers, manufacturers, distributors, and retailers, began to take shape during the industrial revolution in the 18th and 19th centuries. (Mollanger, 2017).

Booz Allen Hamilton Consulting consultant Keith Oliver introduced the term "supply chain management" in the early 1980s (Grzybowska, 2010). At the time, companies focused primarily on managing their internal operations rather than managing the flow of goods and services from suppliers to customers. Oliver recognized that companies needed a more holistic view of their operations. He began to use the term "supply chain management" to describe managing the entire flow of goods and services (Heckmann et al., 2003). Although the term appeared in the early 1980s, it was not until the following decade that it became popular, along with the idea of supply chain management. The term, which was previously related only to purchasing and cost reduction activities, now has a much more precise definition: "… a group of inter-connected participating companies that add value to a stream of transformed inputs from their source of origin to the end products or services that are demanded by the designated end-consumers" (Lu, 2011). In the 1990s, the concept of supply chain management began to gain popularity as companies realized the importance of managing their supply chains effectively to remain competitive in the global marketplace. Companies began to focus on reducing costs, improving efficiency, and increasing responsiveness to customer demands (Pomfret, 2014).

Important parts such as the integration of logistics activities involving the sharing of demand and sales data and the synchronization of the requirements of the customer with the flow of materials from suppliers also are vital parts that eventually affect the balance between high customer service, low inventory management, and low unit cost (La Londe & Master, 1994; Stevens, 1998). Finally, in a more concise and summarized definition, the supply chain and its management can be defined as an integrative philosophy to manage the total flow of a distribution channel from supplier to the ultimate user (Cooper et al., 1997).

Figures 1 and 2 – Supply Chain: Steps and Process and Inbound/Outbound



2.2 Data Science and Data Visualization

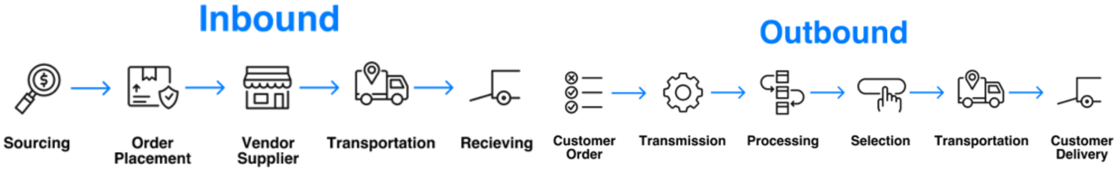
Data science is a field that encompasses various techniques and tools to extract insights and knowledge from data (Badia, 2020). It involves using statistical, mathematical, and computational methods to extract valuable insights from data. This can involve various processes such as data cleaning, exploration, visualization, and modeling (Grus, 2019). Data science plays a crucial role in supply chain management by helping organizations make better decisions and predictions based on data. The supply chain is a complex system that involves the movement of goods and services from suppliers to customers. It involves various processes, such as sourcing, production, logistics, and distribution. Data science can be used to optimize these processes by providing insights and predictions based on data (Schoenherr, Speier-Pero, 2015).

One of the essential Fields inside Data Science is Data Visualization, often regarded as "Data Viz." Data visualization is creating visual representations of data to help understand patterns and trends. It allows people to see and understand complex data more intuitively, making it easier to identify practices and insights. Data visualization can take many forms, such as charts, graphs, maps, and infographics (Grant, 2018). Data visualization is essential in supply chain management because it allows organizations to see and understand their data more intuitively. By creating visual representations of data, organizations can identify patterns and insights that might be difficult to see in raw data. This can help organizations make better decisions and predictions in demand forecasting, inventory management, logistics, and supply chain risk management (Goh et al., 2013). Interactive visualizations, such as dashboards that allow users to explore and analyze data in real-time, can also be created. For example, a real-time dashboard could show data on demand, inventory, logistics, and supply chain risks. This allows organizations to identify patterns and insights quickly and make decisions based on current data (Bach et al., 2022)

2.3 Inbound and Outbound

Inbound and Outbound are processes that are included within a supply chain. Inbound methods include various activities focused on receiving and managing the flow of raw materials, components, and finished goods. These activities are critical for ensuring a company has the necessary resources to produce and distribute its products. (Takita, Leite, 2016). The Inbound logistic process can be described in Figure 3 in five main steps, while the Outbound process contains six main steps:

Figure 3 – Main steps of the Inbound and Outbound logistic processes



2.4 Stock and Demand

In a supply chain, stocks and demand are closely related and work together to ensure that the right amount of inventory is available to meet customer needs (Li et al., 2016). A basic inventory model can represent the relationship between stocks and demand. Some definitions are similar in all models, such as:

- Demand: The demand for a product is the amount of the product that customers want to purchase. Companies use demand forecasting techniques to predict the future demand for their products. By forecasting demand, a company can determine how much inventory they need to keep on hand to meet customer needs.
- Lead time: Lead time is when a company receives an order from a supplier or produces the product in-house (if applicable). Lead time is essential in inventory management because it affects the amount of inventory a company needs.
- Holding cost: Holding cost is storing and maintaining inventory. These costs include warehouse rent, utilities, insurance, and opportunity costs. Holding too much stock can be costly, as it ties up capital that could be used for other purposes.
- Ordering cost: Ordering cost is the cost of placing an order for inventory, including transportation costs, the cost of processing an order, and the cost of stockouts.
- Stockouts: A stockout is when a company runs out of a product and cannot fulfill customer orders. Stockouts can lead to lost sales, damaged customer relationships, and increased production costs.

Companies use different techniques to manage their stocks to balance having too much inventory and needing more. Some of these techniques include safety stock, forecasting, inventory optimization, and demand planning (Beutel, Minner, 2011).

2.4.1 Bill of Material

A Bill of Material (BOM) is a comprehensive list of all the materials and components required to manufacture a specific product. It typically includes information such as the item number, description, unit of measure, and quantity needed for each element. The BOM can be represented in a hierarchical format, where the top level represents the final product, and each lower level represents the components that make up that product (Orlicky, 1971). In a manufacturing setting, the BOM is used as a guide for assembling products. It is often used with other production planning tools, such as a routing sheet, which provides detailed instructions for the assembly process. BOMs also help in production planning by providing insight into the availability of components and materials and alerting the company of potential shortages or delays. This is important because needs and additional costs can cause production delays (Kashkoush, ElMaraghy, 2015).

2.4.2 Manufacture Resource Planning

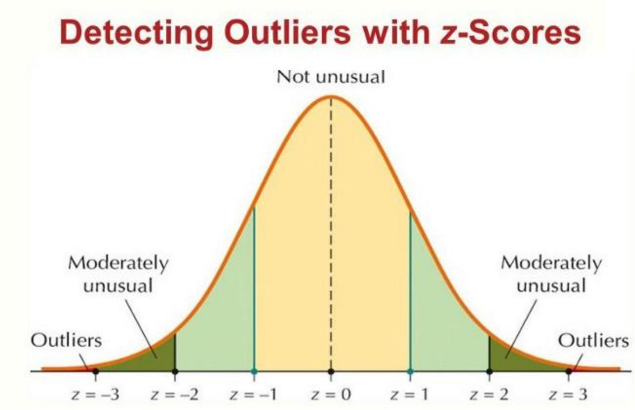
Manufacturing Resource Planning (MRP) is a software-based system that helps companies plan and manage the production process by considering the availability of resources such as raw materials, finished goods, and production capacity. It also helps to forecast demand and schedule production to meet that demand. MRP works by breaking down the production process into smaller components and tracking the flow of materials and resources through the production process.(Ptak, Smith, 2011). MRP is necessary in a supply chain because it helps companies to effectively plan and coordinate the use of resources, which can lead to cost savings, improved production lead times, and increased customer satisfaction by ensuring that products are delivered on time and to the proper specifications. Additionally, MRP can provide valuable insights into production performance, inventory levels, and resource usage, which can help companies identify improvement areas and make informed decisions about production planning and inventory management (Jiang, Han, 2009).

2.5 Outlier Detection

Outlier Detection identifies data points that deviate significantly from the usual or expected behavior. It is a technique used in data mining, statistics, and machine learning to identify unusual observations or patterns in a dataset that do not conform to the expected behavior. These observations or patterns are called outliers or anomalies (Gogoi et al., 2011). Various factors, such as measurement errors, data entry errors, or unexpected events, can cause outliers. They can also be caused by natural variability in the data. Identifying outliers is essential because they can skew the results of data analysis and can lead to incorrect conclusions if not appropriately handled (Aggarwal, 2016). There are some very famous and commonly used methods, and Z-score was chosen to be implemented in this project. This method calculates the distance between a data point and the mean of the dataset, measured in standard deviations. Data points that fall above a certain number of standard deviations from the norm are considered outliers. This method assumes the data is usually distributed (Salkind, 2007). Where X is the data point, μ is the mean of the data, and σ is the standard deviation of the data, as shown in equation (1).

$$Z = \frac{X - \mu}{\sigma} \tag{1}$$

Figure 4 – Z-Score method (Analytics Vidhya, 2022)



3. Tools and Methods

This section aims to present and explain the problem faced throughout the project, in addition to all the methods used to develop this paper and the tools used by the authors to achieve the objectives.

3.1 Background and Problem Description

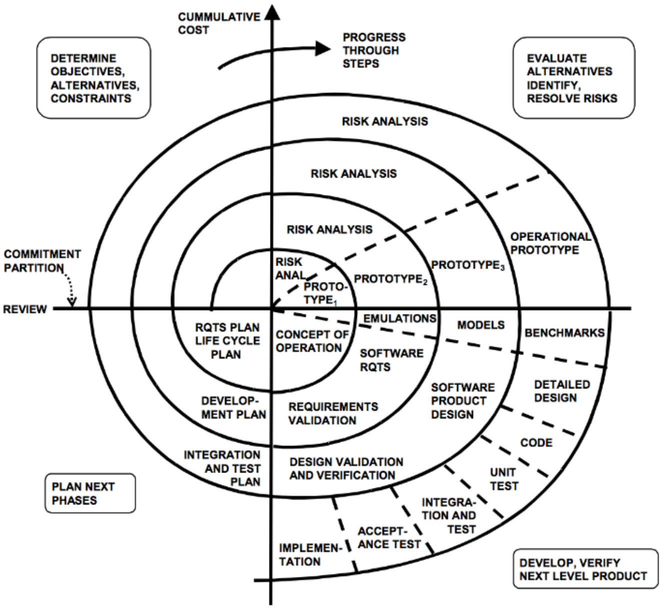
The research in this paper involves the Stocks and Demand part regarding the scheduled demand for details. First, the company uses concepts such as the Bill of Material and MPR to calculate how many features are needed to assemble different vehicle models. These values are then multiplied by the known demand for each vehicle, resulting in a final figure with the number of parts needed (both in general and for each car). The idea was to develop a dashboard containing graphs and visualizations to help the stock team understand the demands related to vehicle production.

3.2 Spiral Process Model

The Spiral Process Model is a methodology for software development and project management that Barry Boehm first introduced in the late 1980s. It is an iterative and incremental approach to handling software development projects' complexities and uncertainties. The model is called "spiral" because it involves repeating cycles of activity, each one building upon the results of the previous one (Boehm, 1988). Each process, or "spiral," consists of four main phases: planning, risk analysis, engineering, and evaluation:

- Planning/Setting Goals and Scope: The project objectives and requirements are defined, and a high-level plan for the project is developed. The planning phase also includes identifying potential risks and determining how they will be mitigated.
- Risk Analysis: Potential risks are identified and evaluated in this phase. Researchers assess the likelihood and impact of each risk and determine appropriate actions to mitigate or eliminate the risks.
- Engineering: The software is developed, and the project deliverables are of several companies, mainly created. This phase also includes testing and evaluating the software to ensure it meets its requirements and objectives.
- Evaluation and Actions: In this phase, the project is evaluated against its objectives and deliverables, and any necessary changes are made. The evaluation phase also includes reviewing the risks and determining whether they have been adequately addressed.

Figure 5 – Spiral Process steps (Boehm, 1988)



The Spiral Process Model is a flexible and adaptive approach that allows for changes and modifications throughout development. This can be particularly useful in software development projects, which are often complex and subject to change. The iterative nature of the model also allows for feedback and testing at each stage, which can lead to a higher-quality end product (Boehm, 1988).

4. Development

Initially, the project's objective was to analyze and understand the data available in the system and then build a dashboard with graphs that could help the team visualize the demand more easily for parts. For this, a duration of two cycles was imagined for analysis and development. With the dashboard built, it was noticed that some parts had too much demand compared to previous days. From this problem, two more cycles were launched, one for identifying these anomalies. In contrast, the fourth cycle was planned for applying statistical analysis to detect these anomalies via the Spotfire dashboard automatically. A last cycle (the fifth), albeit of a shorter duration, was launched to carry out final adjustments and modify filters within the dashboard. Each cycle generally had an average time of 1 month, with the entire project being 6 to 7 months.

Table 1 – Steps and main stages of the Spiral method applied to the stocks and demand problem

#	Goal(s)	Scope type	Development	Next phase
1	Data Analysis	Exploratory	File extraction and data analysis. Summary of all data.	Sketches of graphs that could help the team.
2	Dashboard Construction	Exploratory	Dashboard with graphs and real-time data.	Data analysis of the insights generated through the dashboard.
3	Anomaly Identification	Exploratory	Outlier identification and failure reports.	Evaluation of a way to detect these anomalies.
4	Statistical Analysis and Outlier Detection	Explanatory	Outlier detection. Evaluation of which method will be chosen.	Selection of some interesting filters to have on the dashboard.
5	Final Adjustments	Improving	Visual and Filter adjustments	Team response if the dashboard needs any significant improvement

4.1 First Cycle

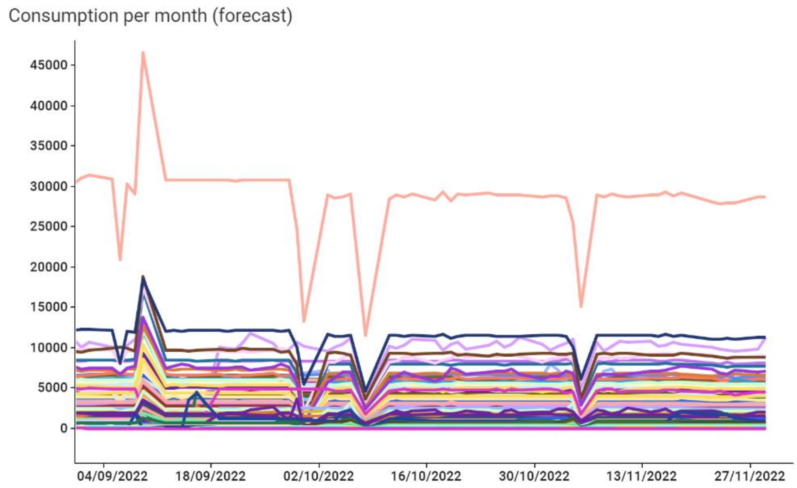
As previously mentioned, the project’s main objective was to build a dashboard with information relevant to the demand for parts. For this, the first step, and the first cycle in the Spiral methodology, was data analysis. The team extracted files directly from the BI4 system. A thorough analysis was conducted to identify which data would be interesting and fundamental in the dashboard. The maximum data available was for a period of two weeks. After that, a list containing the data reference name, the name of the data in the system, the system from which it came, and a brief explanation and example of the data was made, facilitating the next step: building the dashboard. The primary data extracted was about the part name, quantity of parts, date, usine, and currency.

4.2 Second Cycle

The second cycle started approximately one month after the start of the project and had one primary objective: creating a dashboard containing the data analyzed in the previous cycle. The last extraction was used for this, using only the team’s chosen data. With these data, a graph containing the future consumption line (based on the BOM and MRP data) and a Treemap of the total quantity of parts and value in Euros.

Although the first stage was done with data extracted from the system, the dashboard was built using information links, a Spotfire feature that allows obtaining real-time data directly from the cloud. As mentioned earlier, extracting a maximum of 2 weeks of data in the original system was possible. With information links, it is possible to see up to nine months of future data.

Figure 6 – Line chart showing the future consumption from September to late November 2022



By analyzing Figure 6, one can see some peaks in demand. This generated doubts in the group, contributing to creating a third cycle: analysis of peak values.

4.3 Third, Fourth, and Fifth Cycles

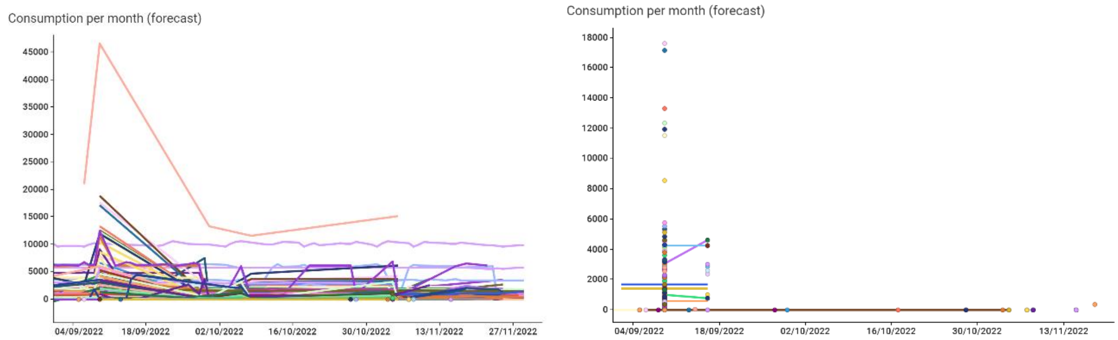
The third cycle was the shortest, consisting of a data analysis stage. From the graphs built in the previous step, the team realized it would be almost impossible to identify which pieces had peaked, firstly because the values were superimposed and secondly because there were many different references. With that in mind, the team opted to add one more step, thus creating the fourth cycle: Outlier Detection. This cycle focused on performing a statistical analysis to separate peak values from other average values. Several standard deviation levels were used, following the Z-Score method.

In this case, following equation (1), X is the value that represents the quantity of the part demanded on a specific day, μ is the average value of the quantity required of this same part, and σ is the standard deviation for the demand for the position. During this stage, eight different grades of outliers were developed, 5 for values above the average and 3 for values below the average. Below are the eight grades:

Table 2 – Different max. And min. grades of outliers

Name	Grade	Z-Score Value	Spotfire Implementation
Max Grade	1	≥1	Average + Deviation
	2	≥2	Average + (2 * Deviation)
	3	≥3	Average + (3 * Deviation)
	4	≥4	Average + (4 * Deviation)
	5	≥5	Average + (5 * Deviation)
Min Grade	1	≤-1	Average - Deviation
	2	≤-2	Average - (2 * Deviation)
	3	≤-3	Average - (3 * Deviation)

Figures 7 and 8 – Line chart of future consumption but only with the outliers selected. The second image shows only the grade 5 outlier selected

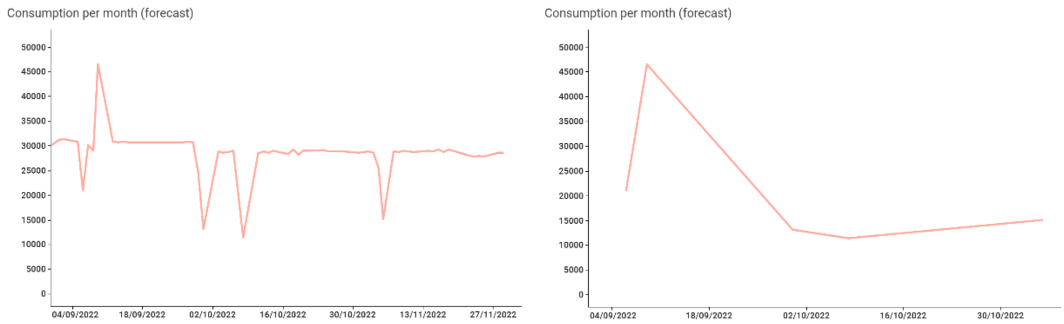


The fifth and final cycle consisted of 2 parallel steps: analysis of outliers and final adjustments to the dashboard.

5. Results

The result of the first cycle was, despite being complex, satisfactory, as the team determined everything necessary to proceed with the project, including the data that would later be used to create the dashboard. With the completion of cycles 2, 3, and 4, the statistical analysis for detecting anomalies proved functional. In Figure 9, on the left, we can observe the line of future consumption of a specific part. Then, all outliers and average values are selected, allowing the behavior observation of demand over a period of 2 months, with peaks in demand visible.

Figures 9 and 10 – Line chart of future consumption of a part. Then just the outliers



In Figure 10, anomalies with a high degree can be observed on the right, indicating parts that presented demand (on specific days) with a standard deviation at least five times greater than usual. It is possible to see that most parts have abnormal demand on the same days. After analysis by the team, it was discovered that the spikes in demand resulted from an attempt to recover production. On some specific days, the three, four, or even five days were scheduled in just one day. This explains why demand spikes are common in most parts. This recovery in production impacts the number of trucks received and contracted freight.

Regarding the improvements brought by the dashboard, the most impactful are in resource savings, both in time and money. The correction of demand means a better distribution in vehicle production, avoiding peak demand. This generates greater assertiveness in estimating trucks or vehicles for transport, resulting in better use of available operators within the company. The more accurate the demand forecast, the more precise the ordering of parts, resulting in a better-dimensioned operation.

In addition, the correction of demand results in significant financial savings. Internal demand information shows that weekly, between 40 and 50 trucks are sent to the company plant; between 8 and 10 trucks are sent daily. One day of production error can result in up to 10 trucks being shipped, most of them on emergency freight. Emergency shipping costs 5 to

10 times more than standard shipping. With the implementation of the Stocks and Demand dashboard, demand peaks can be identified and previously analyzed, allowing the company to distribute vehicle production better. The figure below shows the planned show for April, May, June, and July 2023. No abnormal peak is seen in the image, which proves the dashboard's success.

Figure 11– Line chart of future consumption after the team reviewed the demand using the dashboard and the actual process used in the company after the dashboard implementation

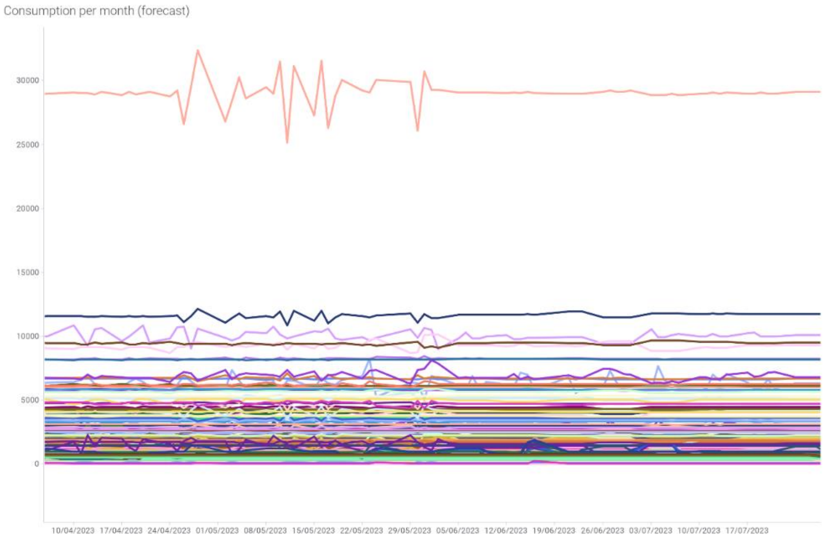
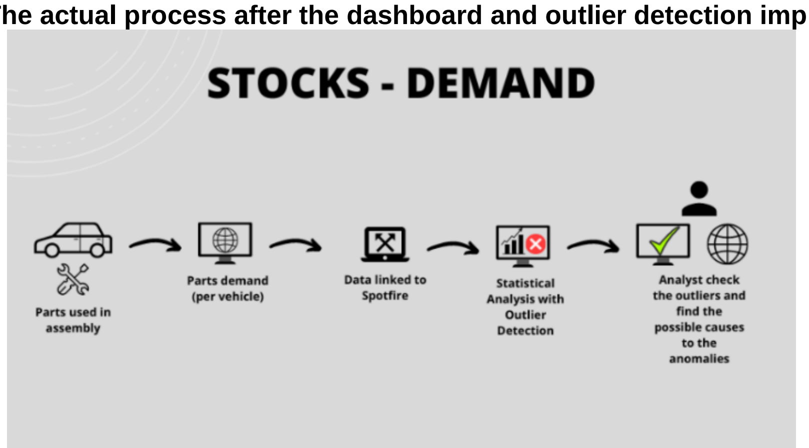


Figure 12– The actual process after the dashboard and outlier detection implementation



6. Conclusion

The problem presented in this paper is of great interest to companies or large companies that work with the supply chain. Although the idea was implemented in a car manufacturer, the same solution can be extended to other areas in supply chains. This research aimed to develop a dashboard with information on parts and demands for a large car manufacturer. The dashboard was successfully developed, and its construction allowed the authors and the team to observe some problems that were impossible to identify in the past. Using data science, statistical analysis, and data visualization, the authors separated the outliers from the average demand values, allowing a thorough examination with company specialists. With the dashboard in use, the demand team could carry out better parts planning, resulting in significant financial, time, and labor savings and allowing easy and quick visualization of demand in up to 9 coming months.

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