

Article

Data-Driven Quality Improvement for Sustainability in Automotive Packaging

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Featured Application: The methodology described in this paper was implemented in an automotive manufacturing facility that operates under a just-in-time manufacturing scheme. The methodology greatly improved the efficiency of day-to-day operations at the facility.

Abstract: This study addresses sustainability challenges in automotive packaging by introducing a novel data-driven approach to audit and improve packaging quality. Traditional manual auditing processes are both time-consuming and prone to errors. To counter these inefficiencies, we developed an automated system utilizing Microsoft Power Apps and SQL databases to streamline data collection and processing. The automated tools facilitate real-time data capture and visualization through Microsoft Power BI, enabling precise tracking and management of returnable and expendable packaging materials. Our results show that our approach offers a significant enhancement in the accuracy and speed of data analysis, leading to more informed decision-making. Our methodology supports sustainability by reducing waste and reliance on expendable packaging and improving the economic and operational efficiency of automotive packaging systems.

Keywords: automotive manufacturing; automotive packaging; data visualization; quality; sustainability



Citation: McKnight, T.; Ward, T.; Jenab, K. Data-Driven Quality Improvement for Sustainability in Automotive Packaging. *Appl. Sci.* **2024**, *14*, 5723. <https://doi.org/10.3390/app14135723>

Academic Editor: Qizhi Xu

Received: 12 June 2024

Revised: 25 June 2024

Accepted: 27 June 2024

Published: 30 June 2024



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1. Introduction

Automotive packaging plays a primary role in nearly all aspects of vehicle production. Vehicles are produced at volumes that require reusable packaging in the supply chain to reduce long-term costs; otherwise, the final cost of the vehicle will be vastly inflated. Proper material selection can make any vehicle more sustainable. By choosing lighter-weight but similar-strength materials, sustainability can be improved, and the overall cost of the vehicle could be reduced [1]. Not only does automotive packaging have a massive effect on the world, but the method in which sustainability is handled in this field has the potential to directly impact how other types of businesses view sustainability [2]. Maintaining sustainability in automotive packaging is extremely difficult. A proper balance of having enough packaging to support production while not having so much packaging that there is a maintained excess of packaging must be achieved. Any production plant will occasionally run into issues with the supply chain, weather, etc., which can impact production plans. This leads to an excess of packaging accumulating at the plant, forcing suppliers to ship in less preferred packaging—generally cardboard boxes. The process of implementing data-driven approaches to audit packaging allows engineers and analysts to quickly identify and resolve any issues that may result in poor conditions.

Packaging sustainability should be considered early on in determining the best way to safely transport components [3]. There are several reasons expendable packaging could be avoided, such as cost, potential damage to parts in shipping, and varying dimensions when compared to returnable packaging. The term “reusable packaging” is often interchangeable with “returnable packaging”. These variations can allow the parts that ship inside of this

packaging to be damaged at a rate far higher than otherwise would have been expected. While some parts being damaged may have little effect on vehicle production, others can have a far larger impact. There are several reasons why an automotive company would desire to adopt sustainable materials and practices. Two of the most prevalent reasons for the drive of companies to be more sustainable include consumer demand and legal requirements [4].

Proper training of employees in the manufacturing environment has been shown to reduce the frequency of mistakes and accidents while simultaneously improving the efficiency and safety of the plant [5]. A majority of accidents involving packaging are directly related to either a gap in a process that allowed the incident to occur or the processes not being followed in the first place. A prevalent occurrence of this involves forklifts. When forklift operators ignore the training that they have received, they have the potential to lift unsafe loads, drive too quickly, and have collisions within the plant. These collisions may involve other forklift operators, pedestrians, or even objects in the plant that can fall, causing a much larger incident. While these are generally the most dangerous types of accidents that can occur in relation to packaging, many more cases can have serious cost implications.

All packaging is clearly labeled to denote exactly which part is in a container, along with which supplier the container belongs to. These containers will have a designated location to be delivered to, and once the parts are consumed, there is a designated location to stage the containers to be returned to the supplier. At this point, three processes must work together to ensure that the containers make it back to the correct supplier. The containers must be properly labeled; if they are not, they could end up at a different supplier location. The team members who stage the containers must place the container in the designated spot; otherwise, the containers can be mistakenly combined with many different suppliers. Additionally, the staged containers must stay with similarly marked containers as they are returned to the supplier. These three processes are among the most common causes for one supplier's containers getting mixed with another supplier's containers.

Part selection is an integral portion of sustainability in automotive packaging. While it may not be obvious how parts are designed or even the materials that are selected, they can change the type of packaging required to transport said parts safely and efficiently. Traditionally, it might be assumed that selecting more durable yet lighter materials to be included in the assembly of a vehicle is strictly to improve the fuel economy of that vehicle. While this is certainly a large consideration when it comes to material selection, it is also important to understand how material selection can impact packaging.

As could be expected, heavier or oddly shaped components can require specialty packaging, which greatly increases the cost of maintaining a packaging loop. Material selection can be the determining factor of whether a component can be transported in a relatively simple tote or if a specialized rack will have to be designed to transport this part—which adds material costs, design costs, and fabrication costs that might not have been required otherwise. If any given part is damaged but is not caught by quality checks before it makes it onto the vehicle, this can lead to far more unnecessary expenditures. Some worst-case scenarios involving this would be if a vehicle found a defect in a part after the entire vehicle was assembled that damaged other parts and would make the vehicle considered a total loss. Even here, the vehicle itself is not the major cost—the loss of production time is. When an issue like this occurs in a larger time frame across many vehicles being produced, it is possible that a recall could occur for this vehicle. This is generally the most expensive mistake that can happen across vehicle production, as the company has to pay for the new part along with the costly labor required to remove the old part and install the new part.

The purpose of this paper is to review the current methods for auditing packaging conditions and improving the process. Automotive companies are plagued with the environmental and social responsibility to produce the most sustainable vehicles possible using sustainable practices. All stages of the life cycle of a vehicle can have a significant

impact on the environment, from the sourcing of materials to the assembly of the vehicle and even the vehicle itself [6]. The basic process for evaluating packaging involves manual data collection, entry, manipulation, and visualization. Through the creation of different tools and automation, this evaluation can be reduced to the singular manual step of data collection. With the help of a more streamlined process, it is possible to evaluate historical data to drive conversations with stakeholders and reduce expendable packaging usage. Sustainability in the form of packaging is based on reducing the amount of expendable packaging used and prioritizing recyclable or biodegradable materials for most forms of packaging. Coincidentally, this waste reduction will additionally reduce the amount of money spent in the automotive plant on packaging overall.

2. Literature Review

Rising fuel costs have encouraged society to become more aware of the environmental impact that their vehicles have before and after reaching consumers' hands. Design for sustainability typically focuses on the vehicle itself and reducing fuel consumption, along with the materials used. However, these same concepts can be applied to the packaging used to transport all of the parts required to fabricate and assemble vehicles [7]. Despite being one of the largest industries in the world, sustainability in the automotive industry has not been standardized. Generally speaking, existing research that has been completed on automotive sustainability tends to be inconsistent in both data collection methods and how sustainability is evaluated. All aspects of the business must be aligned and work together to ensure that the most sustainable outcome is achieved [8].

Automotive companies that focus on continuous improvement tend to see a significant reduction in defects and quality issues. This supports the notion that evolving to an improved process will lead to an increase in data quality and, therefore, assist in a reduction in expendable packaging usage [9]. It is important to develop innovative methods for existing processes. These new methods are often more cost-effective and can improve efficiency [10]. The ideal combination of returnable and expendable packaging is very difficult to ascertain. Returnable packaging has a higher initial cost than expendable packaging but will, over time, be cheaper to maintain than expendable packaging. The longer a specific packaging will be used, the higher the impact on sustainability it will have, creating a greater emphasis on the need for returnable packaging [11].

It is incredibly difficult to quantify all criteria when it comes to considering the environmental impact that the automotive manufacturing field plays a role in. There are social criteria that seem obvious—for instance, safety, energy and water consumption, and materials used. Defining the aspects that are worth tracking is essential to having effective data collection and communication about sustainability as a whole [12]. Determining the impact of sustainability is incredibly complex. While there are challenges in this area, it is still possible to initiate lasting improvements in the automotive environment. There is not one “correct” way to drive this change, but proper usage of the tools available to a company is the best way to ensure that there is a measurable impact on improving environmental impact [13].

There are three major categories when evaluating sustainability. These categories are economic issues, ecological issues, and social issues. Like all things in manufacturing, these three aspects are intertwined. Generally, more premium automotive manufacturers can focus more on sustainability than brands that prioritize volume for profit [14]. When working to improve production processes through automation, a key aspect is to consider which variables are the most important. If the entire scope of an issue is not collected, it is very difficult to determine the root cause of a condition [15].

While the type of packaging is not something that would typically be considered in the context of safety in automotive packaging, the forklifts that are used to move the packaging throughout an automotive facility can be very dangerous machines. Improper loads can amplify this potential. Using softer packaging materials can lead to unsteady loads that tip over more easily than more stable packaging. Those who are unfamiliar

with this machinery often do not understand how dangerous forklifts and their loads can be [16].

Material handling often refers specifically to the movement and storage of any material that would be used in a manufacturing or warehouse environment. The way that parts are packaged within containers will affect many aspects of material handling, as different container heights could obstruct views, weight must be carefully distributed within a load, and generally, selecting the correct forklift for the job. While these aspects are crucial to allowing the safe operation of forklifts, there are additional factors that make moving parts throughout a manufacturing environment by forklift potentially dangerous.

Wet conditions due to leaks, spills, or weather can cause the ground to be slippery, which greatly increases the chance of the forklift sliding unexpectedly. Navigating across holes or bumps in driving surfaces can have a similar effect as slippery roads. Each of the mentioned forklift driving conditions has the potential to cause the forklift operator to unintentionally drop or spill their load, causing unsafe driving conditions for other forklift operators or even having the possibility of hitting pedestrians within a manufacturing facility [17]. One way that many industries have reduced the potential for waste and accidents is by using automated guided vehicles. This can and will prevent many issues related to human factors in the general conveyance of goods [18].

The automotive industry has a social and ecological responsibility to the world. In the past, most improvements for sustainability have been mandated by policy. Many businesses are trending away from this policy-driven methodology for improvement. These businesses are taking the initiative to improve their impact on sustainability themselves [19]. The automotive manufacturing industry has a massive effect on the world's economy and sustainability. Due to this, it has been mandated that the industry improve the sustainability of its processes. It is possible to reduce the role that automotive manufacturing plays in climate change [20].

Once a nonrenewable resource is used, there is no natural method for creating that resource. Environmental sustainability is essential for preventing unnecessary overuse of these finite resources. Many governments across the world have encouraged or mandated the reduction of resource depletion in not only the automotive manufacturing field but across all types of manufacturing. It is not always simple or cost-effective to implement sustainable practices across a large organization to preserve precious resources and reduce pollution. This effort requires extensive cooperation across many levels of manufacturing management and their team members to plan improvements and upkeep the systems that are put into place [12].

While accurate data collection is a primary component of data analysis, it is not the only aspect that matters. It is exceptionally important to consider the information flow. Quickly and effectively communicating a problem to the required parties will vastly improve the overall decision-making time [21]. Using an SQL server to securely store data collected in the manufacturing environment allows for streamlined data pull into Microsoft Power BI. A dashboard can then be created to assist with making big decisions in manufacturing while having the correct data to support claims [22]. Focusing on the lowest-performing aspects of a system for improvement will allow for a baseline improvement. This can remove barriers from the process that might skew the appearance of the condition of the system to seem far worse than it is [23]. It is important to ensure that all the data that are being collected are fully applicable to the topic and without mistakes. Following this advice ensures the data will not lead analysts to draw incorrect conclusions [24].

3. Problem Description

When considering sustainability in automotive packaging, it is important to understand that there are many forms that sustainability can take. Automotive packaging sustainability largely focuses on waste: reducing, reusing, and recycling waste. Automotive packaging includes the containers for any part that gets brought into the plant to be put on

a vehicle or used otherwise. Additionally, one must consider how containers are secured for transit—through the use of pallets and lids.

The flow of packaging for an automotive plant is typically from the part supplier to the automotive plant and then back to the supplier. This loop will repeat on a set interval, such as a few times monthly, a few times weekly, once daily, or even a few times a day. An automotive plant will need to have enough returnable packaging to support the entire loop.

For example, if the distance from the supplier to a manufacturing plant and back takes ten days, they will need to have, at a minimum, ten days' worth of returnable packaging. Route and order frequency will affect how long it takes for this loop to exist. If the length of time for the loop to complete changes drastically, the loop will have to be re-evaluated to ensure that enough returnable packaging is purchased. Since most suppliers will service many different automotive companies and plants, it is not unreasonable to expect containers to get sent mistakenly to the wrong plant occasionally. Some portion of returnable packaging will end up being lost or broken over time, requiring replacement.

There are several reasons that a plant might begin to have a shortage of packaging. Most of these reasons stem from the fact that a majority of plants use just-in-time manufacturing—an engineering concept that reduces inventory and space requirements while increasing productivity. Any given plant will have a production goal that it aims to complete. If the plant goes down for any given reason, there is typically not enough time to inform the suppliers that they do not need to send parts for that portion of vehicles. Due to this, a manufacturer can accumulate more components than they would normally be able to use in a normal shift cycle.

Since most plants use just-in-time manufacturing, they do not have additional containers to support this behind-the-scenes condition. The suppliers will be forced to use backup expendable packaging rather than their typical reusable packaging. Additionally, this leads to creating overtime opportunities for staff to get back on schedule—depending on how far behind the plant is running. This could be a few hours of work spread across multiple shifts, or it could be an entire additional shift or shifts of work.

Three major categories of waste can be reduced for automotive packaging. The first type of waste is damaged product. Normally, when a part is damaged, it will be caught before making it onto a vehicle, limiting the effect it can have on sustainability and finances. If this damage is not caught before going onto a vehicle, it could lead to a large safety concern and potentially even a recall of the vehicle. The second type of waste that can be considered is excess grease or oil on some parts of vehicles, most specifically anything involving a bearing or oiled fasteners. The last type of waste that is frequent in automotive packaging is the packaging itself. There is a gradual breakdown of packaging, which will cause the packaging to no longer be suitable for transporting parts safely.

Reducing the number of returnable containers that need to be replaced is a very large aspect of reducing waste in automotive packaging. Having an effective design that lasts a long time will, in turn, reduce the number of spills of grease and oil, damaged parts that need to be replaced, and packaging that needs to be purchased. As long as the returnable packaging remains intact, over time, the total frequency of backup packaging required to support production will be reduced.

The use of returnable packaging is perhaps the most important factor in creating sustainable automotive packaging processes. Depending on the size of the plant and the volume of vehicles it is expected to make, any given plant could be handling thousands upon thousands of containers per day. Many countries have several dozen automotive plants, which further increases the necessity for returnable packaging. The sheer volume of expendable packaging would otherwise be catastrophic. All packaging should be designed with recycling in mind.

Most returnable packaging is based on plastic totes, pallets, lids, steel bins, and racks. Expendable packaging is frequently obtained through cardboard containers and cardboard lids on wooden pallets. Steel, cardboard, and plastic are among the most recyclable of all materials. While wooden pallets cannot be recycled, they are still eco-friendly because

they are biodegradable. When properly disposed of, wooden pallets can greatly benefit the environment. Returnable packaging is preferred as there is less of an environmental impact when compared to using expendable packaging frequently. This is why expendable packaging is usually reserved for backup packaging.

The object of this paper is to gain a general understanding of how sustainability is impacted in automotive packaging and use data to drive quality improvements. Automotive packaging has a great foundation for sustainability, but it is important to maintain this sustainability. This paper will explore existing manual methods for auditing the current condition of returnable packaging and expendable packaging volumes in a plant. Many of these methods can be automated to reduce the amount of time required to complete audits and manipulate the data, allowing for more time to utilize the data for improvements. Accurate data are the most important ingredient to lead a conversation with suppliers of an automotive plant to reduce the amount of expendable packaging utilized and ensure that there is plenty of reusable packaging to support production. By following these sustainability concepts, the quality of the final product is increased due to the decreased likelihood of defects and damage in individual components of the vehicle.

4. Methodology

Traditionally, when auditing the condition of packaging loops, the process would be completed on pen and paper. Audits will be conducted plant-wide on a schedule to allow for comparison between audit data to track improvements or know if the condition worsens. The simplest way to complete an audit for cardboard expendable packaging is by walking through the plant with a list of part locations. As the packaging employee reaches each location on their list, they will be able to write down how much expendable packaging is at every location. At this time, it is efficient to evaluate the condition of the flow rack.

A flow rack being mislabeled or not labeled at all can be a contributing factor in a supplier not getting the correct packaging back to their facilities, which leads to a shortage of usable, returnable packaging. The data that are collected manually will then need to be placed in some sort of database, usually an Excel table, for simplicity. Often, the data will need to be reformatted to allow data visualization to be possible. The data can be shown in Power BI or other similar tools to create a report that can be shared throughout the company without having to have direct access to the underlying data. This underlying data will likely be stored on a shared network drive or through a service such as Microsoft Teams or Microsoft Excel. This process in flowchart form is shown in Figure 1.

The process for manually tracking wooden pallets and expendable lids coming into a plant has similarities to the manual cardboard audit process. Since parts are staged in containers at the same location every day for each part number, it is possible to do an audit by walking through the plant auditing for expendable packaging. This is not the case for wooden pallets and expendable lids—the best place to audit the number of these entering the plant by supplier and dock is to physically have people stationed in the dock complete this audit as the packaging is brought through dock doors. As such, audit data will be collected by pen and paper. Every shift that this audit is completed will have its own sheet due to handling multiple people and preserving the legibility of the data. The auditing company will scan the documents to PDF—it is likely that the data will only be sent over to the packaging team at set intervals; for this example, a once-monthly interval will be used. For a two-line and two-shift plant, that would be four PDFs per day or eighty PDFs per month. These data will then have to be manually input into Microsoft Excel and then manipulated for use in a program like Microsoft Power BI for data visualization. With this structure, in a best-case scenario, there will only be an update on the charts used for tracking purposes once a month. This process is shown in Figure 2.

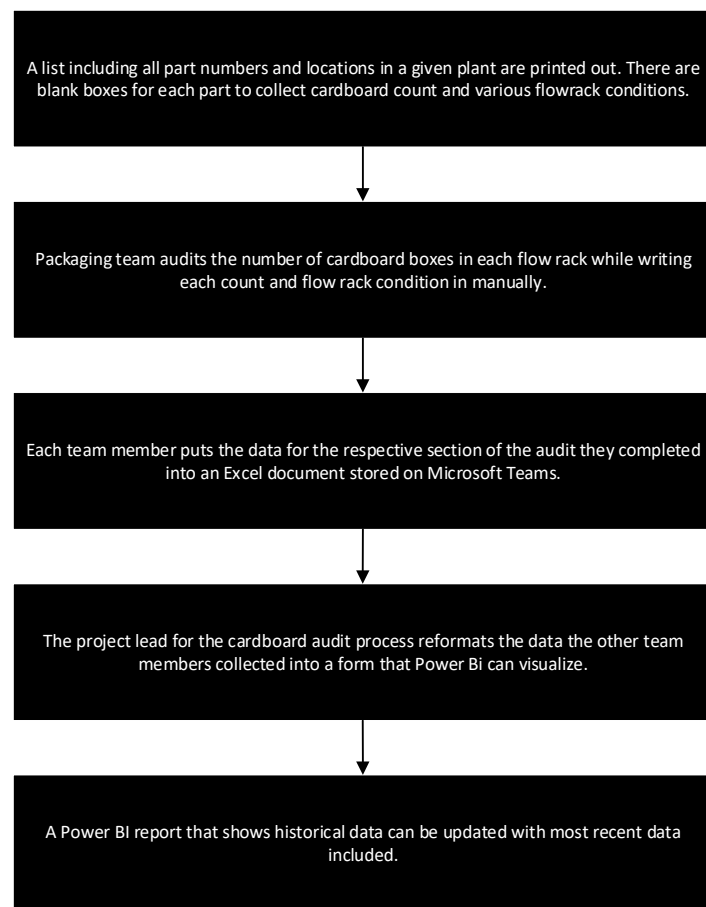


Figure 1. Manual cardboard audit process and data flow.

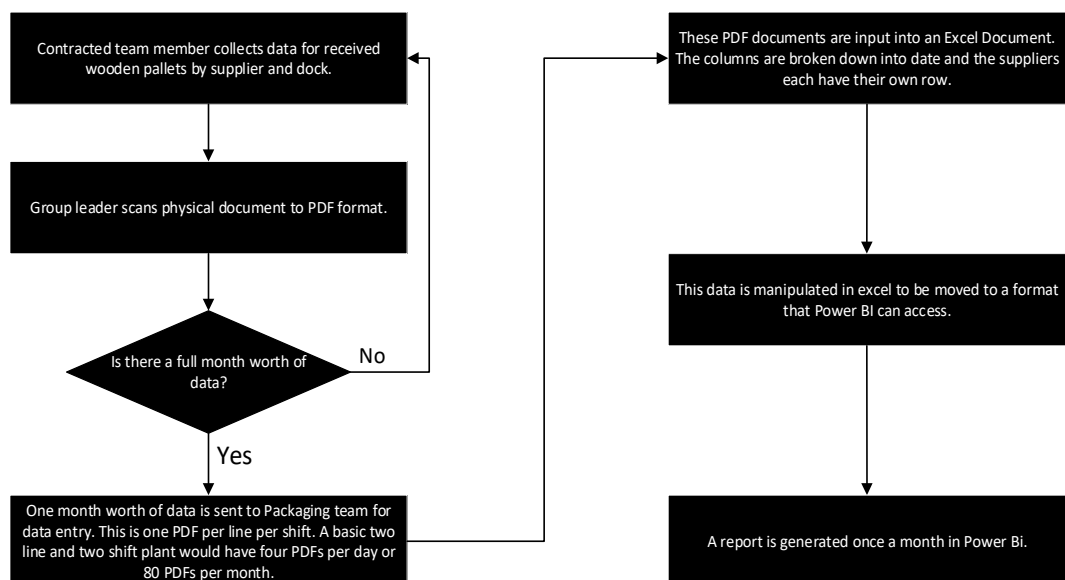


Figure 2. Manual wooden pallet audit process and data flow.

The most efficient way to handle these audits would be to introduce automation and combine the data output for simple and up-to-date data visualization. The manual process can be slightly modified to transform into a sophisticated automated process. This automation adds no work to end users once it is set up and removes several previously required stages. If a Microsoft Power App is created for this audit, there would be two

separate sections for the container portion and the pallet portion of the app. Power Apps allows for the introduction of basic data validation—it is possible to limit the audit user to only logging suppliers that exist or correct locations for each part. This app will allow the audit user to track each cardboard count and condition of the flow rack without having to print out dozens of sheets of paper per audit. These data will then be automatically uploaded to an SQL server, which allows for greater data security and a fully hands-off approach from the audit user. Microsoft Power BI (2.129.905.0) is an industry-standard piece of software used for data analysis and sharing. Conveniently, using Microsoft Power BI, it is simple to access data stored on a SQL server. Cloud-based SQL servers and locally hosted SQL servers are both accepted methods for storing data. For this application, a locally hosted SQL server is the preferable option, as the likelihood of a dataset breach is reduced and information technology teams can directly implement the company's data security protocols.

With the wooden pallet audit process, instead of scanning the physical documents to PDF, the data can be input directly into the Power App to upload data to a Microsoft List for easy data storage. A Power Automate flow can be created to automatically duplicate this into an additional Microsoft List that only the packaging team can access as a layer of data security. As both of the audit processes are largely automated, this will allow for a near-instant update of any visuals created through software like Power BI. This will empower the packaging team to combat issues with packaging volume with extreme accuracy and have the data to drive the conversation with the supplier. Both of these processes can be found in Figure 3.

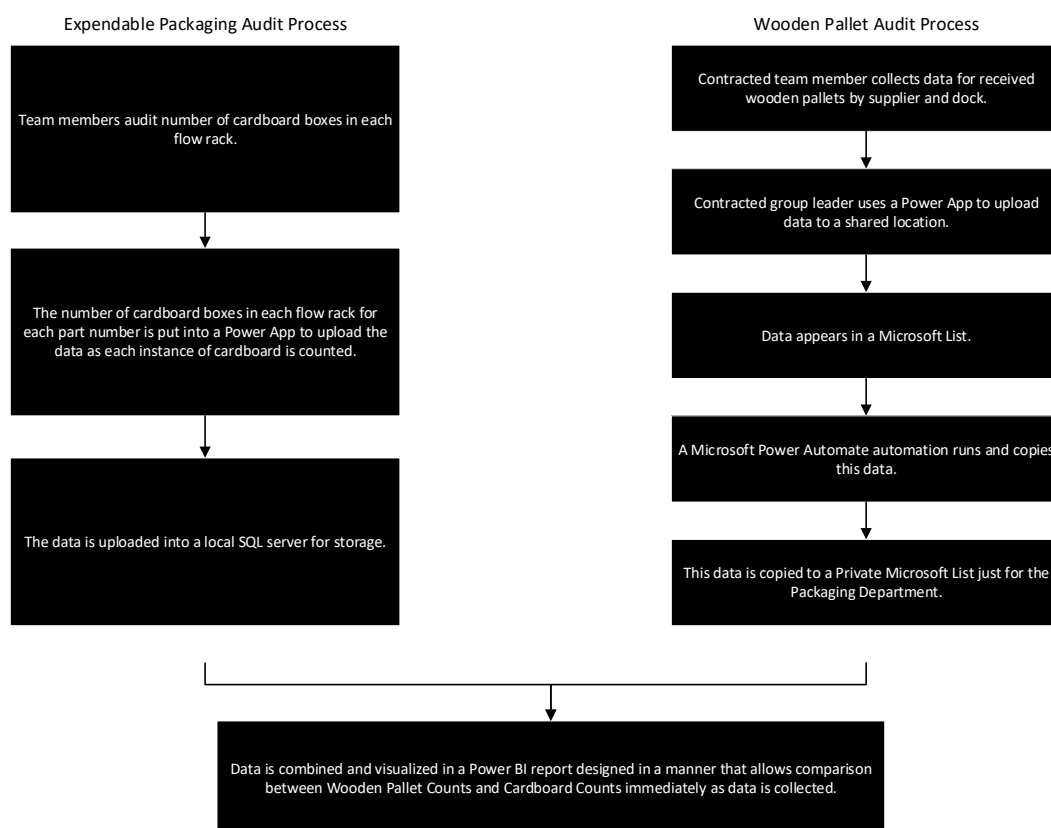


Figure 3. Proposed process and data flow.

5. Illustrative Example

Using the previously described methodologies, a single month's worth of data for each wooden pallet audit has been simulated, taking into consideration that occasionally, an automotive manufacturing facility might experience the need for weekend work. Addi-

tionally, a singular expendable cardboard packaging audit has been generated. For ease of visualizing these concepts, only five suppliers are being considered. Keep in mind that this is a small sample size in the context of an entire plant that may have hundreds of suppliers.

When observing Table 1 and Figures 4–6, it is easy to conclude that the simulated manufacturing plant tends to experience similar amounts of expendable cardboard lids as wooden pallets. Figures 4 and 5 can effectively illustrate the condition of wooden pallets and expendable lids received over some time—a month in this instance. Figure 4 would be most useful when evaluating wooden pallets and expendable lid conditions separately, whereas Figure 5 would be more useful when comparing both conditions simultaneously. Figure 6 is a great depiction of both conditions over some time per day. In this format, it would be extremely easy to see how the health of the packaging loop evolves. It is normal to see small amounts of expendable packaging used by suppliers, but a large increase in a short amount of time would indicate a new issue that needs investigation immediately. The ability to react earlier is a huge benefit of having day-by-day data rather than only data from the previous month.

Table 1. Total wooden pallet and cardboard lid count.

Supplier	Wooden Pallet Count	Cardboard Lid Count
1	132	118
2	114	109
3	103	101
4	69	46
5	81	70

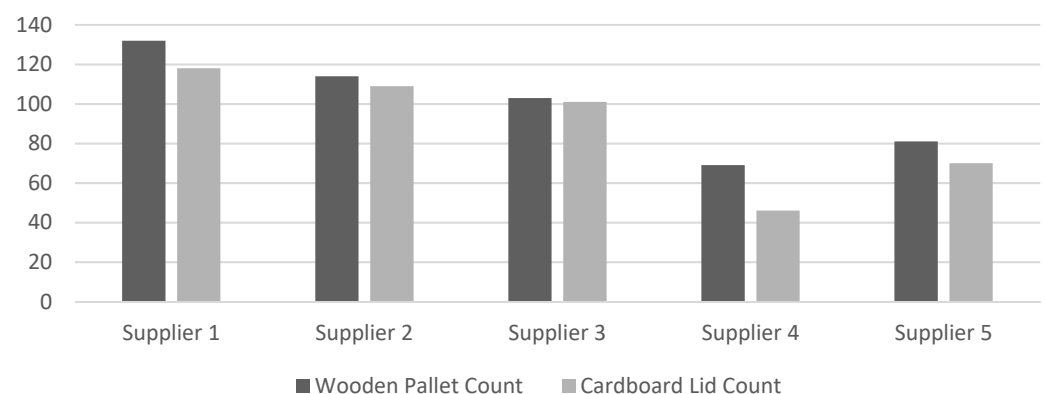


Figure 4. Expendable packaging by supplier and month—clustered columns.

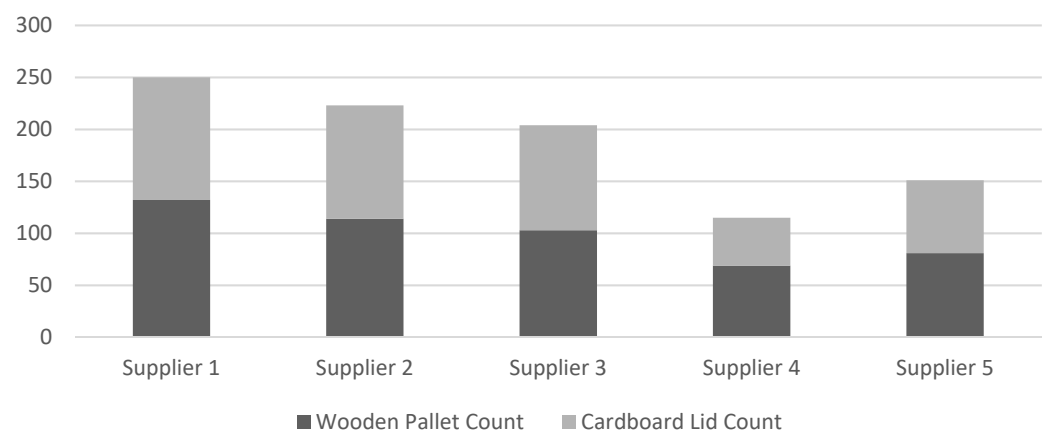


Figure 5. Expendable packaging by supplier and month—stacked columns.

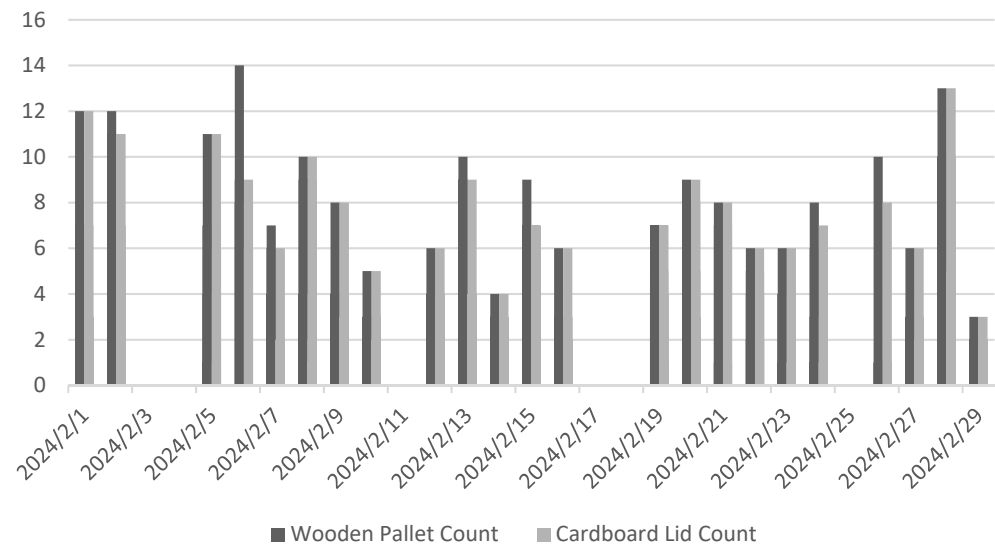


Figure 6. Wooden pallet audit by date.

Reviewing the data for the singular cardboard/expendable audit shows insightful data that are helpful to share with suppliers when investigating issues. Table 2 shows the raw data totals, while Table 3 shows percentages based on the number of instances in which cardboard was observed for a supplier. The formula utilized to obtain the cardboard count per instance is simply “cardboard count divided by the number of instances”. A similar formula can be used to understand how long an issue has lasted. By taking the total number of days a supplier has shipped cardboard or wooden pallets and dividing that by the total number of days, it is possible to understand what percentage of days a supplier has shipped poor-condition packaging over some time. These formulas are given as Equations (1)–(5). The missing return column indicates how many instances there are where there is no location for line team members to place containers to return them to the supplier. Missing labels indicate that there is at least one label missing on a flow rack for that supplier. Sometimes, an incorrect label will be considered a missing label. When considering the condition of “mixed containers”, the number of locations in which there are multiple different suppliers in the same return is marked. This condition often causes containers to be routed to the wrong location. Both of these tables are useful in their own way, and these tables indicate that in this scenario, flow racks being poorly labeled does not seem to be an issue. If it were determined that the flow rack condition was a primary cause of high expendable usage, Figure 7 would be a great visualization method for prioritizing suppliers with the highest percentage of this issue.

$$\text{Overall Frequency of Poor Loop} = \frac{\text{Total \# of Days with Poor Condition}}{\text{Total \# of Days with Data Collection}} \times 100 \quad (1)$$

$$\text{CBCPI} = \frac{\text{CBC}}{\text{\# of Instances}} \times 100 \quad (2)$$

$$\% \text{ MR} = \frac{\text{MR}}{\text{\# of Instances}} \times 100 \quad (3)$$

$$\% \text{ ML} = \frac{\text{ML}}{\text{\# of Instances}} \times 100 \quad (4)$$

$$\% \text{ MC} = \frac{\text{Mixed Containers}}{\text{\# of Instances}} \times 100 \quad (5)$$

Table 2. Cardboard audit data by value.

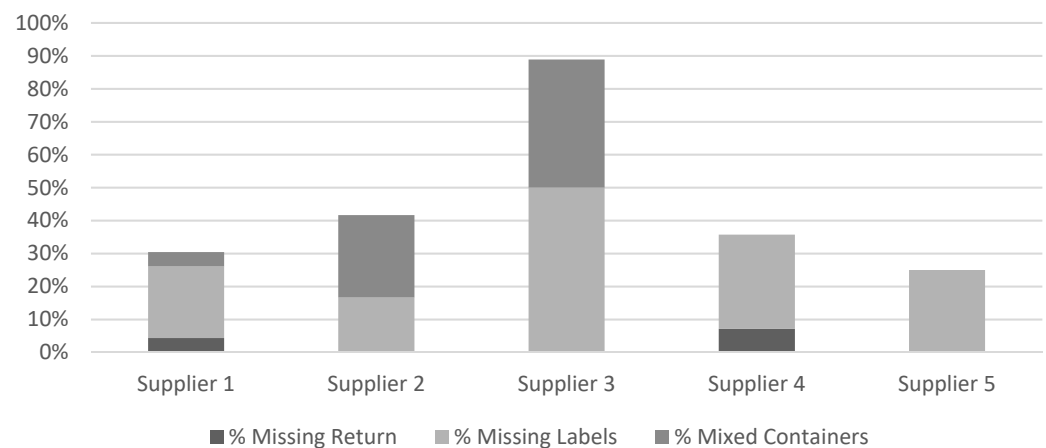
Supplier	CBC ¹	MR ¹	ML ¹	MC ¹	# of Instances
1	96	1	5	1	23
2	107	0	2	3	12
3	73	0	9	7	18
4	51	1	4	0	14
5	39	0	1	0	4

¹ CB—cardboard count, MR—missing return, ML—missing labels, MC—mixed containers.

Table 3. Cardboard audit data by percentage.

Supplier	CBCPI ¹	% MR	% ML	% MC	# of Instances
1	4.17	4.35%	21.74%	4.35%	23
2	8.92	0.00%	16.67%	25.00%	12
3	4.06	0.00%	50.00%	38.89%	18
4	3.64	7.14%	28.57%	0.00%	14
5	9.75	0.00%	25.00%	0.00%	4

¹ CBCPI—cardboard count per instance.

**Figure 7.** Irregular flow rack condition by the supplier.

Figures 8 and 9 are great methods for internal tracking documents; however, Figure 10 will be the primary structure used for determining which suppliers need to be contacted and which suppliers need to be prioritized. It is most helpful to select several suppliers to focus on at a time for reduction activities; three or five suppliers at once are a good starting point, depending on the size of the plant's packaging team. The charts described are excellent for reviewing a singular audit, but the true power of having an automated solution would be the ability to compare current data against historical data. That is the only way to be certain that continuous improvement is being made in the efforts to reduce expendable packaging for sustainability. Interestingly, the expendable packaging counts found in Figures 4–6 will be nearly proportional to the added cost versus using existing reusable packaging over time. These counts will be inversely proportional to the reduction in the potential number of safety incidents and sustainability (a higher cardboard count indicates a higher number of potential safety incidents and a less sustainable solution).

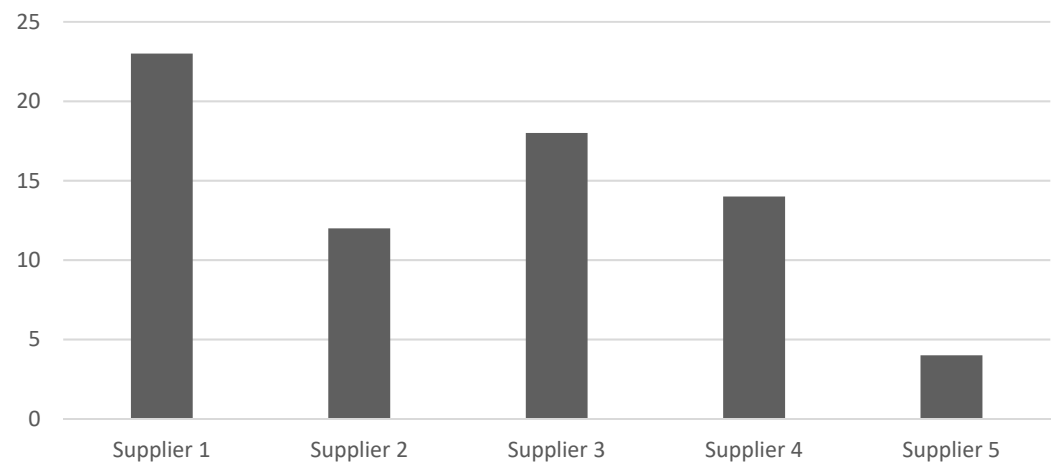


Figure 8. Number of instances of cardboard by supplier.

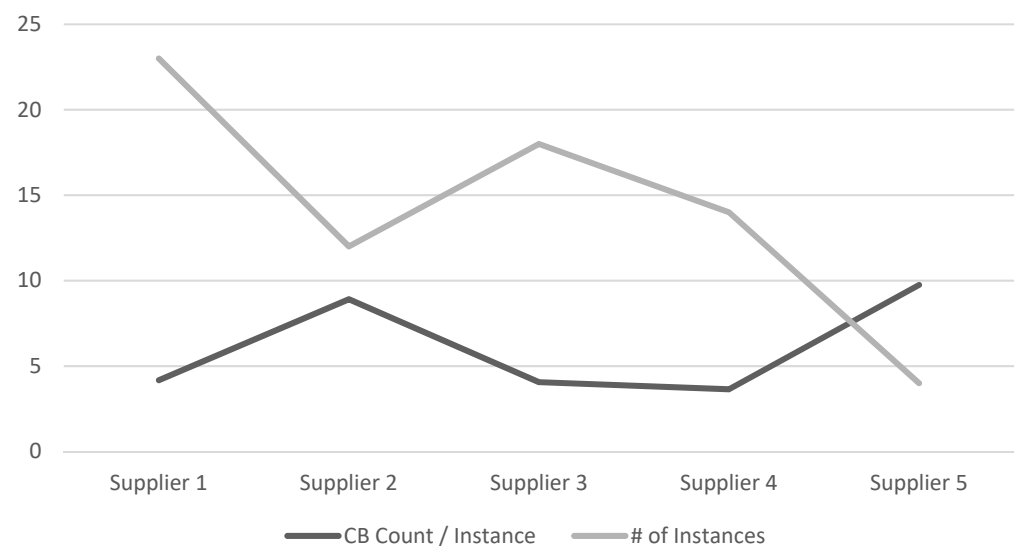


Figure 9. Cardboard count per instance vs. number of instances.

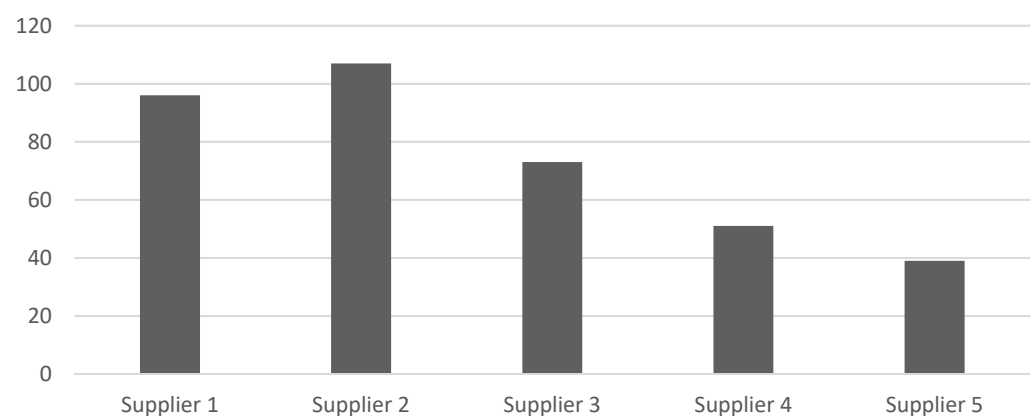


Figure 10. Cardboard count by supplier.

6. Conclusions

Automotive packaging is an incredibly complex concept with many evolving variables. It is not always simple to determine the root cause of an increase in expendable packaging usage. Many conditions might increase the need for backup expendable packaging, which is far less sustainable than the preferred reusable packaging. Some of these scenarios

include a slowdown/stop in production, poor flow rack conditions, and the supplier failing to identify lost or damaged returnable packaging. Correctly identified and prepared loads from the supplier will, in turn, reduce the amount of preventable damage to the containers in a packaging loop and prevent said packaging from being misplaced or sent to the wrong supplier [17]. Constant communication and transparency between the automotive plant and suppliers are paramount to keeping the packaging loop in an ideal state. Unfortunately, it is impossible to ensure that all data are perfect, which is the primary shortcoming of data collection processes. However, this shortcoming exists in both manual and automated processes. The primary innovation of implementing automated data analysis is that it allows analysts to swiftly identify and correct the causes of incorrect data.

A supplier cannot be accused of having a poor returnable packaging loop without specific data supporting that claim. While it is certainly possible to complete audits manually to obtain these supporting data, this paper has shown that it is far more time- and cost-efficient to use modern technologies to drive this quality improvement. Proper data visualization will make it possible to pinpoint issues that might not otherwise be obvious. These conversations reduce the need to use expendable packaging to support production. In turn, the amount of waste packaging and damaged components produced or received by the plant is reduced. This is the most impactful aspect of sustainability that automotive packaging holds. As expendable packaging is minimized, safety is improved, and cost is reduced. Future work in this field would be to complete an in-depth analysis of specific potential causes of excessive expendable packaging and methods to countermeasure them. Many industries, including automotive manufacturing, will likely transition away from archaic, outdated processes and begin to gradually automate many of these processes to reduce wasted manhours and improve data quality.

Author Contributions: Conceptualization, T.M. and T.W.; data curation, T.M.; formal analysis, T.M.; investigation, T.M.; project administration, T.W. and K.J.; software, T.M.; supervision, T.W. and K.J.; validation, T.M.; visualization, T.M.; writing—original draft preparation, T.M.; writing—review and editing, T.W. and K.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The datasets presented in this article are not readily available because the data are proprietary and belong to a third party. Requests to access the datasets should be directed to Tyler McKnight.

Conflicts of Interest: The authors declare no conflicts of interest.

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