Modeling Total Delivered Cost in the Automotive Industry

by
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Submitted to the MIT Department of Civil and Environmental Engineering and MIT Sloan School of Management, in partial fulfillment of the requirements for the degrees of

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Abstract

Automotive part sourcing is a large scale complex problem that involves the procurement of thousands of individual parts from hundreds of different suppliers. This project focuses on the development of a new Total Delivered Cost (TDC) methodology for automotive part sourcing at Nissan. Initially, a calculation methodology was developed using operational data from the Nissan Smyrna plant. This methodology, which aims at capturing the direct and indirect costs of sourcing, comprises 10 different cost drivers including part, tooling, packaging, transportation, last mile, storage, inventory, obsolescence, quality, and tariff. Subsequently, the methodology was integrated in a TDC tool for ease of use and applied in a preliminary TDC analysis. The results show that: (1) part cost is the main driver of TDC with 90% of parts studied having non-part cost less than 15% of TDC; (2) non-part cost has an important compounding effect due to correlation between transportation, last mile, storage, inventory, obsolescence, and pipeline quality costs; (3) the relation between available information, TDC accuracy, and TDC value is highly asymmetric across time. Overall, the results highlight the importance of TDC methodologies in improving automotive part sourcing. Lastly, a review of typical implementation challenges associated with TDC methodologies was performed with the objective was identifying strategies that increase business impact. Two strategies were investigated including adopting a gradual implementation plan to mitigate the negative impact of initial low TDC accuracy and deploying TDC methodologies as filter in the sourcing process to reduce workload and allow for better resource allocation. The incorporation of cost of complexity and cost of supply chain risk in TDC is discussed as future work.

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List of Acronyms

AGV	Autonomous Guided Vehicle
BOM	Bill of Materials
CCM	Cost Control Module
COCA	Carry Over Carry Across
CV	Coefficient of Variation
DDP	Delivered Duty Paid
ERP	Enterprise Resource Planning
EXW	Ex Works
GAAP	General Accepted Accounting Principles
ILC	Integrated Logistics Center
LTL	Less than Truck Load
OEM	Original Equipment Manufacturer
MR	Milk Run
PDI	Pre-Delivery Inspection
RFQ	Request for Quotation
SOP	Start of Production
SSC	Supplier Score Card
TDC	Total Delivered Cost
TFR	Truck Fill Ratio
TL	Truck Load
WF	Weight Factor

Introduction

1.1. Problem Statement

Automotive is a multibillion-dollar industry that involves the design, manufacture, sale, and repair of new and used vehicles. To remain competitive, automotive companies continuously develop new vehicles that attract consumer interest and increase sales. Because the development of a new vehicle requires a significant investment, companies need to be able to accurately predict costs to guarantee long term profitability.

One of the main cost elements of a new vehicle is part sourcing. A modern vehicle has thousands of individual parts that are sourced from hundreds of different suppliers. Each supplier has different locations, capabilities, and levels of quality. This large combination of options creates a difficult sourcing problem that is further complicated by the long development schedule of a new vehicle. Depending on the model and segment, a new vehicle can take several years from early concept to start of production. During this period, part sourcing occurs typically 3 to 4 years prior to start of production. At this point, most engineering and market research work is still unfinished which means there is still significant uncertainty.

The combination of large scale and high complexity has led automotive companies to developed simplified sourcing methodologies that avoid the need to continuously increase the size of the sourcing organization. In the case of Nissan, this has resulted in a sourcing methodology that is often too focused on part cost alone and ignores others costs such as logistics, storage, and quality.

The purpose of this project is to develop a new calculation methodology for part sourcing. This methodology will be based on the principle of Total Delivered Cost (TDC) which aims at capturing all direct and indirect costs associated with sourcing. To facilitate implementation, the methodology will be integrated in an enterprise tool with a simplified user interface. This tool will improve part sourcing by expediting the decision making process and reducing cost.

1.2. Total Delivered Cost

In the context of this project, sourcing refers to all the activities involved in purchasing a part for a vehicle. In any sourcing transaction there is a buyer and a seller, with the latter often referred to as supplier. The objective of the buyer is to purchase the part for the lowest cost. But what is the right definition of cost that the buyer should use? Should the buyer consider only the cost of the part or should it consider other costs too? The answer to these questions is the reason behind Total delivered Cost (TDC).

TDC is a methodology that aims to capture all the direct and indirect costs associated with sourcing. With a TDC methodology, the buyer purchases the part from the supplier with the lowest TDC, regardless of the part cost. Because all costs are considered, if implemented correctly, TDC methodologies lead to overall cost savings. The following example illustrates the use of a TDC methodology in a simple sourcing decision.

> *A company wants to source a part and it has identified two possible suppliers, X and Y. Supplier X is located near the plant, has a part cost of $50, and a high quality performance. Supplier Y is located far from the plant, has a part cost of $45, and a low quality performance. The results of a preliminary TDC study indicates that transportation, storage, and quality costs are 2$,1$, and $0.5 for supplier X and $6, $2, and $1.5 for supplier Y, respectively. Adding all costs, the TDC for supplier is X is $53.5 (50+2+1+0.5) and for supplier Y is $54.5 (45+6+2+1.5). Therefore, in this example, if the company uses a TDC methodology for sourcing it should purchase the part from supplier Y, despite its higher part cost as this is beneficial to the company as a whole.*

The example above describes a TDC methodology with four cost components: part, logistics, storage, and quality. In reality, TDC methodologies can have a large number and variety of cost components depending on the industry and application. Ferrin and Plank (2002), confirmed this observation in a comprehensive industry study involving 146 professionals. They identified 135 different TDC cost drivers split into 13 categories, including, operating, quality, logistics, technology advantage, supplier reliability and capability, maintenance, inventory, transaction, and life cycle costs [1].

One of the main challenges of any TDC methodology is the scope and granularity of the cost components. In other words what is the right breadth and depth of the analysis. With regards to scope, TDC methodologies should be exhaustive and include all the cost that are the result of sourcing and excludes all those that are not. Unfortunately, in a high complexity environment such as automotive manufacturing this distinction is not always clear.

Granularity refers to the depth of the analysis. Without criteria, TDC methodologies can extend indefinitely as smaller and smaller costs are continuously added. To prevent this, a relevance criterion must be defined. This criterion can be a cost threshold below which all TDC cost components are ignored or a maximum number of cost components that is previously agreed.

Wu (2005) examined scope and granularity in the semiconductor industry and developed a cost architecture framework with a hierarchically structure composed of three cost levels [2]. In this pyramidical framework, low level costs (granularity) are continuously aggregated into high level costs (scope). This results in a supply chain model where total cost is calculated as the sum of five high level costs comprising material, labor, logistics, inventory and overhead [2]. A similar approach with a limited number of cost elements will be used in this project.

1.3. Project Approach

This project aims at developing a Total Delivered Cost (TDC) methodology for part sourcing in the automotive industry. This methodology will be developed based on the manufacturing and supply chain operations at the Nissan Smyrna plant. The scope of the TDC methodology will cover all cost components associated with sourcing, including pre-manufacturing costs such as transportation and storage and post-manufacturing costs such as quality and obsolescence. Figure 1-1 presents a simplified schematic of the supply chain of an overseas part in the Nissan Smyrna plant.

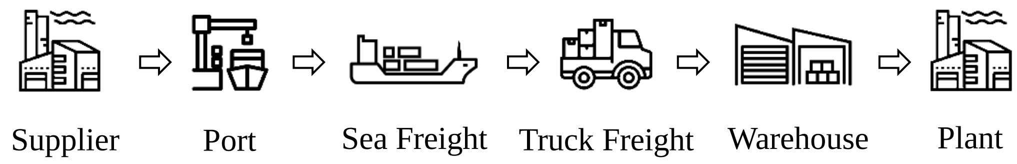

Figure 1-1: Automotive Industry Supply Chain

The primary purpose and application of the TDC methodology developed in this project will be the new vehicle development process. This type of application includes the sourcing of more than 2,000 new parts for a new vehicle, 3 to 4 years before production start. A detail description of the new vehicle development process is provided in Section 2.1 for reference. However, the principles of this methodology can be extended to any other part relevant sourcing application. To facilitate implementation and increase business impact, the TDC methodology was integrated in an enterprise tool developed using Python® and data from the Nissan ERP system.

Background

This chapter presents an overview of important concepts for this project. The chapter is organized by sections and covers a wide range of topics from new vehicle development to sourcing strategies. While all topics are related, each section is independent and self-contained. This chapter combines Nissan specific concepts and relevant literature review for better comprehension.

2.1. New Vehicle Development Process

As mentioned, the TDC methodology developed in this project is focused on new vehicles. Large automotive companies, referred to as OEMs (Original Equipment Manufacturer), typically manufacture multiple vehicles and models in different segments. While vehicle, model and segment are often interchangeable concepts the following definitions are considered in this document:

- Segment: A segment is defined as group of vehicles that share similar attributes such as size and prize. Luxury sedan is an example of a segment.

- Vehicle: A vehicle is defined as a specific design by an OEM within a segment. Nissan Altima is an example of a vehicle.

- Model: Model is a specific iteration of a vehicle by an OEM. Nissan Altima L33 (2013-2018) is an example of a model.

The product lifecycle of a model is typically 5 to 7 years from initial launch to end of sales. At the end of this period, an OEM can decide to launch a new model of the same vehicle or abandon it. Throughout its lifecycle, a model is constantly updated for commercial and regulatory reasons. An existing model can receive a minor update, typically every year, or a major update that happens 3 to 4 years after launch. Figure 2-1 presents the typical lifecycle of a vehicle model together with sales forecast.

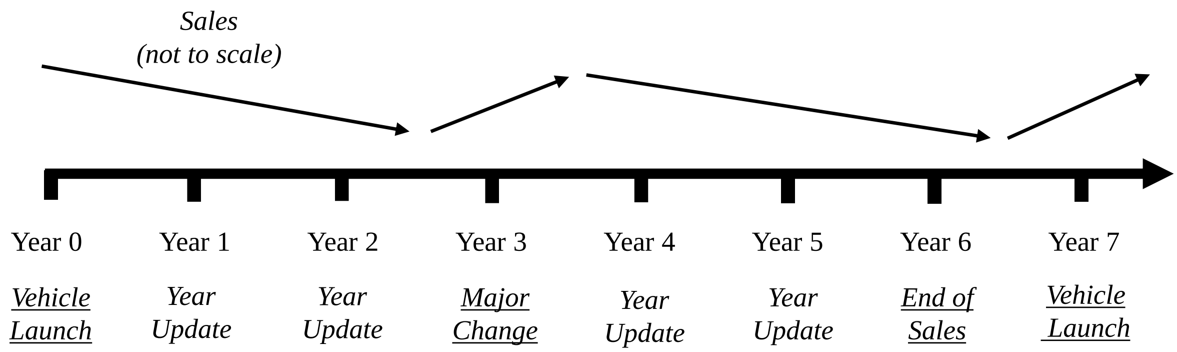

Figure 2-1: Vehicle Program Lifecycle

The development process of a new vehicle model starts with product planning defining the main technical and design attributes. Next, engineering and marketing work together to build the model from early concept to final product. This work includes detailed engineering as well as consumer response research. Once this work is completed, the vehicle is considered a final digital product and is, in principle, ready for manufacturing.

At this point, the program management team, which is responsible for the vehicle development program, gathers cost, price, and demand data and presents it to senior leadership for approval. If, based on the information provided, senior leadership approves, the vehicle or model is confirmed for launch and production. This internal milestone is known as the “Contract”. “Contract” represents the main approval step in a new vehicle or model. Once “Contract” is signed there is a significant investment commitment both internally and externally. From “Contract” to start of production (SOP) it takes approximately 3 to 4 years. Figure 2-2 presents a schematic of the new vehicle development process.

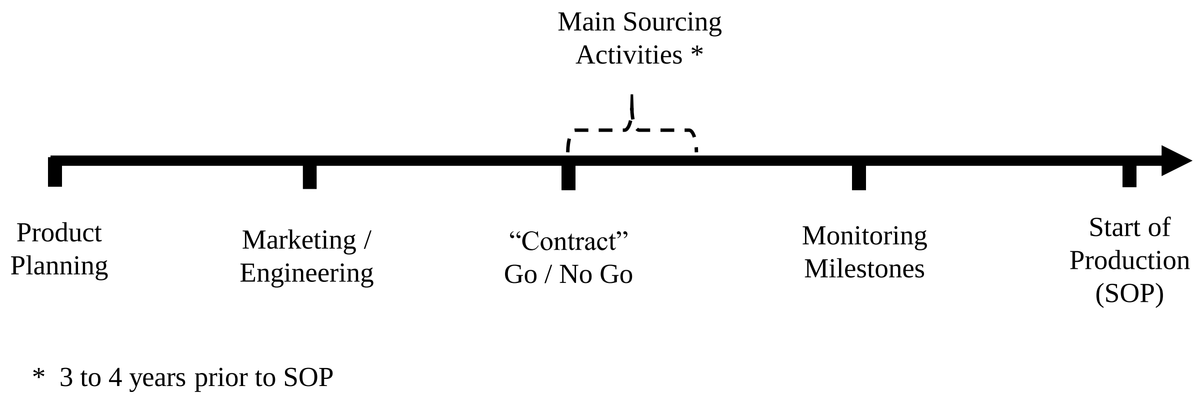

Figure 2-2: New Model Development Process

"Contract" marks the beginning of the main sourcing activities. Suppliers for key components are contacted first to secure contracts, and in a relative short period of time, typically measured in months, a significant portion of all sourcing decisions is made. This is the relevant period of application of the TDC sourcing methodology to maximize impact.

From this point onward the vehicle development continues with further involvement from manufacturing and supply chain. Between "Contract" and start of production the program progress is measured through monitoring milestones. These aim at guaranteeing that the vehicle is ready for manufacturing and that the development program remains within the bounds of "Contract", in terms of schedule and cost. Once production starts, the vehicle responsibility is transferred from the program management team to the manufacturing team which becomes responsible for regular production.

2.2. Cost Control Module

Cost Control Module (CCM) is an important concept in the new vehicle development process. To improve market penetration and increase sales, modern vehicles are offered in a multitude of configurations that typically include paint color, trim level, and optional equipment packages. This large offering combined with market specific regulations, creates significant complexity and product proliferation.

Figure 2-3 presents a pareto chart of model configurations for the highest production vehicle at the Nissan Smyrna plant. This particular vehicle is manufactured in 61 different combinations, excluding paint color. The pareto chart shows a highly skewed distribution with the 10 most common configurations representing over 80% of the total volume. This product proliferation induces significant operational complexity. This is an important topic in the automotive industry; however, it is not within the TDC scope of this project, and therefore not covered in detail in this document.

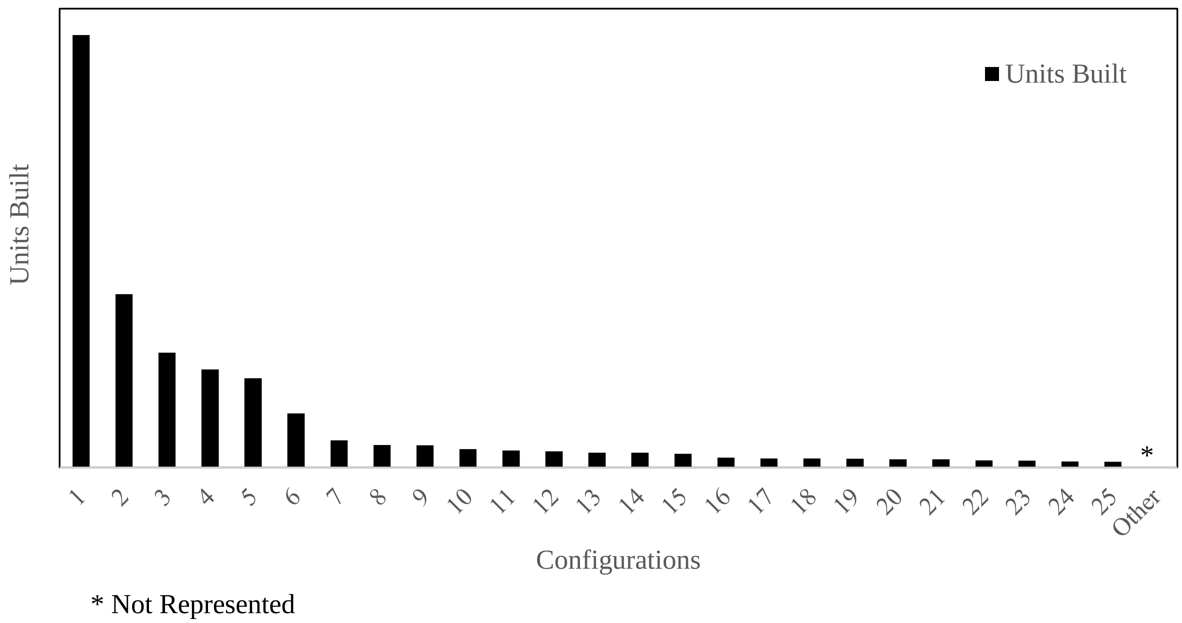

Figure 2-3: Pareto Chart of Production Distribution

Considering the example of Figure 2-3, if the development of a new vehicle or model were to require the assessment of 61 different configurations, the amount of work would be enormous and impossible to manage. To avoid this, Nissan and other OEMs use the concept of Cost Control Module (CCM). A CCM is a specific vehicle configuration that aims at representing a “typical” configuration. In this case, the CCM would be 1 configuration out of 61 possible.

The use of 1 CCM only, would make it impossible to capture all the diversity in vehicle configurations. Therefore, for new vehicles, Nissan typically defines 4 to 5 different CCMs. For each CCM a Bill of Materials (BOM) is produced and this BOM is the basis of TDC. The CCM methodology reduces the amount of work involved in the development of a new vehicle of model. However, this methodology also has limitations which are discussed in Section 5.4.

2.3. Sourcing Process

This section provides an overview of the sourcing process at Nissan together in a relevant industry analysis. There are multiple ways to organize sourcing in a company. The two most common are to concentrate sourcing in a single team or to distribute sourcing as an activity in cross-functional teams. Companies that concentrate sourcing in a single team, typically have dedicated buyers that are responsible for sourcing. Depending on the product complexity, buyers can be specific or generic, i.e., responsible for one or multiple commodities. In this type of organization, buyers are often focused on the commercial aspects of sourcing and lack detailed operational knowledge.

Alternatively, companies that have sourcing as an activity in cross-functional teams, do not have dedicated buyers. Cross-functional teams are typically organized by commodity, and sourcing is performed by a person who is also responsible for design, operations, and production. This person is likely more operational knowledgeable. However, in this type of organization, sourcing can be less efficient if there are significant economies of scale associated with concentrated sourcing, such as multiple commodity negotiation.

Sourcing at Nissan is concentrated in a single sourcing team that is composed of buyers. Depending on the commodity, buyers can be specific or generic. Buyers typically work across vehicles and models, i.e., a buyer responsible for windshields, sources windshields for 3 or 4 different vehicles and models.

As detailed in Section 2.1, the main sourcing activities for a new vehicle start right after “Contract”. These activities include the procurement of more than 2,000 different parts, including optional parts, but excluding engine parts. For a part to be sourced a specific sourcing plan has to be approved. This plan includes purchasing, logistics, and packaging details, that define the contract terms and responsibilities of the buyer (Nissan) and seller the (supplier). The process and volume of parts results in a significant amount of work for each new vehicle or model.

To alleviate this work and reduce the number of news parts to source for a new vehicle, Nissan has developed a system of carry-over / carry-across (COCA) parts. COCA parts are parts that are already approved for use in an existing vehicle and are re-used. Carry over, are parts that are transferred from a previously discontinued vehicle, e.g., when the Nissan Altima L33 (2013-2018) model was discontinued and replaced by the Nissan Altima L34 (2018-Present) several parts from the L33 were carried over to the L34. Carry across parts are shared by two different vehicles in production at the same time, e.g., the Nissan Altima L34 (2018-Present) and the Nissan Maxima A36 (2016-Present) share multiple carry across parts. COCA parts are very important as they reduce the amount of investment and work Nissan and the suppliers need to commit to qualification, tooling, and packaging.

Nissan has additional sourcing guidelines in place. From the more than 2,000 parts that need to be sourced for a new vehicle, a restricted group that represents up to 80% of the total volume (measured in ft3/m3) needs to be sourced close to the plant due to volume and/or quality constraints. These parts, which include large items such as fuel tank or rubber tires, are organized in four different groups as described below:

- Type 1: Insourced or sourced from a supplier that is located inside the plant.
- Type 2: Sourced from a supplier that is within 20 miles from the plant.
- Type 3: Sourced from a supplier that is within 200 miles from the plant.
- Type 4: Sourced from a supplier that is within 800 miles from the plant.

This set of rules aims at preventing that a large or fragile part ends up being sourced too far from the plant which could increase cost and reduce quality. If a part in this group requires an exception to be sourced farther than the guideline allows, a specific review process is conducted prior to approval. For all remaining parts not in this group there is no specific rule and as per Nissan guideline all parts should be sourced based on lowest TDC.

The typical sourcing process starts with a buyer contacting a list of pre-approved suppliers with a request for quotation (RFQ). Interested suppliers reply and a negotiation process ensues. This process includes technical and commercial discussions, and it continues until the final terms with each supplier are set. Once this step is completed, the buyers identify the preferred supplier and summarize the information in a comparison form. This form, which includes sourcing, logistics and packaging information, is submitted by the buyer for management approval.

This process can be complex, especially the logistics and packaging portions. Because a buyer is typically responsible for multiple parts, there is an incentive to simplify. As a result, supplier selection is often performed with an excessive focus on part cost only. This is particularly true for smaller or less expensive parts, where logistics and other costs are perceived to be small.

2.4. Sourcing Strategies

The cost of sourced parts often exceeds 70% of the total cost of a modern vehicle. Large OEMs like Nissan can create significant competitive advantage by employing the proper sourcing strategy. Sourcing strategies can create value to companies by increasing flexibility and reliability, improving quality, and ultimately reducing cost.

For any given part, the first sourcing decision a company must make is between insourcing (make) or outsourcing (buy). Nissan, like many others OEMs has developed a strong and complex network of suppliers and, as a consequence, it outsources most of its parts. Therefore, the TDC methodology developed in this project is focused on outsourced parts.

Within automotive, the three most common outsourcing strategies are: single sourcing, multi-sourcing, and parallel sourcing [3]. Single sourcing occurs when two or more suppliers can provide the part but only one supplier is selected. This type of strategy promotes improvements in quality due to long term cooperation and can lead to unit cost reduction through economies of scale [3]. However, single sourcing reduces competition, increases supplier power, and increases supply chain risk [3][4]. Single source differs from sole source as in sole source only one supplier can provide the part.

Multi-sourcing occurs when more than one supplier is selected. This sourcing strategy increases competition, reduces supply chain risk, and increases exposure to external sources of innovation. Multi-sourcing can lead to unit cost increases by splitting supply and losing economies of scale, and quality differences.

Lastly, parallel sourcing combines single and multi-sourcing. In parallel sourcing an OEM with two or more plants or vehicles can: i) single source from a different supplier to each plant, or ii) multi-source a part type but single source for a particular vehicle. Parallel sourcing provides incentives to supplier's performance similar to multi-sourcing while maintaining some of the benefits of single sourcing such as quality improvement. Single, multi and parallel sourcing are commonly used in the automotive industry and the option that will ultimately deliver the overall lowest cost will depend on the specific part and circumstances[3].

When discussing automotive sourcing it is important to talk about tooling and, to a lesser extent, packaging (refer to Section 4.2 for further details). For multiple types of parts, there is a need to invest in tooling for manufacturing. Tooling refers to additional equipment that the supplier must obtain to manufacture the part. Tooling can be a mold for injection molding, a dye for stamping or any equivalent temporary equipment. It is common practice in the automotive industry for the tooling cost to be burden by the OEM. This reduces the risk and cost to the supplier and increases the OEM flexibility to change suppliers, i.e., if an OEM decides to switch suppliers, it can simply transfer the tooling, which it already owns, to the new supplier. Because tooling is an upfront fixed cost per supplier, it creates a significant incentive for OEMs to single source. This is particularly true in cases of high demand uncertainty or cases where tooling represents a large upfront cost. Investment in returnable packaging has a similar effect by promoting single sourcing strategies to reduce upfront cost.

2.5. Total, Absolute and Relative Cost

TDC methodology can be designed using different approaches to cost. Among all, the three most common are absolute, relative, and total cost. These are described below:

- Absolute Cost: An approach focused on the whole cost of sourcing for all options. With this approach there is an emphasis on accuracy of the largest cost components. Smaller costs components might be ignored even if important in relative terms.

- Relative Cost: An approach centered on the cost difference between two sourcing options. With this approach there is an emphasis on the accuracy of the differentiating cost components. Cost elements that are common to all sourcing options can be ignored even if substantial in absolute terms.

- Total Cost: An approach an analysis that covers a group of parts. In the case of a vehicle a total cost analysis can included 1,400-1,700 parts. Total cost approaches can be applied in relative or absolute terms.

The following simplified example involving only the transportation cost for two different suppliers illustrates the application of the principles of absolute, relative, and total cost. Figure 2-4 is provided for further reference.

Supplier A and Supplier B are located in two different cities of country X. Both suppliers use the same port of origin and port of destination and the part arrives at the plant using the same logistics network in country Y. The absolute cost of transportation for the two suppliers is comprised of origin, sea freight, and destination costs. In this example, the two largest cost elements are sea freight and destination, which happen to be common to both suppliers. Therefore, in absolute terms these are the two cost component that should be focused on. However, because these costs are the same to both suppliers, they are less relevant in terms of relative cost. The most relevant cost component in relative terms is the origin cost, which is different for both suppliers. So which cost approach should be used in a TDC methodology applied to sourcing in the automotive industry? And perhaps more importantly is there a trade-off between relative and absolute cost accuracy?

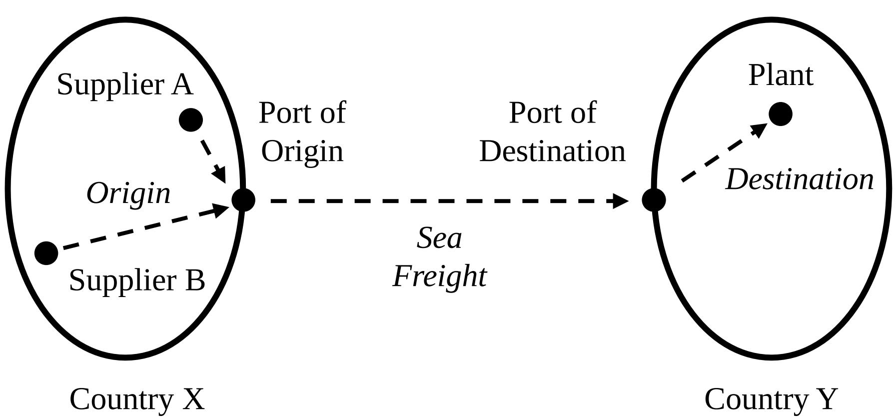

Figure 2-4: Sourcing Example

The three cost approaches described above are complementary and in a perfect TDC methodology would be equally weighted. However, in real lie the implementation of these approaches is often conflicting and there is a need to compromise.

The first point to discuss is how different groups perceive the usefulness of each approach. Program managers, which are responsible for an entire vehicle program, typically care about total and absolute costs only, as these are the real drivers of profitability. This group is less concerned with relative accuracy, in particular if only relevant to a specific sourcing decision.

Buyers, on the other end care about relative accuracy. Buyers are responsible for buying parts and for making specific decisions between multiple similar options. Buyers often select ideal sourcing based on small difference between suppliers. Therefore, this group cares mostly about accuracy in the differentiating terms. The balance between these different approaches to cost is fundamental in guaranteeing the TDC methodology is well accepted across a company and its valu recognized.

The difference between absolute and relative cost approaches also impacts the methodology complexity. Assuming the same scope of analysis, a model with high relative cost accuracy is more complex and requires more information. This phenomenon negatively affects high relative cost accuracy models in two ways. First, the model needs a larger dataset to be built as there are more variables to consider and parameters to estimate. Second, because the model is more complex, the user needs to input more information to get an estimation. This behavior can make the implementation of high relative cost accuracy models difficult in the business environment. Figure 2-5 presents a schematic of information required versus accuracy for different TDC approaches.

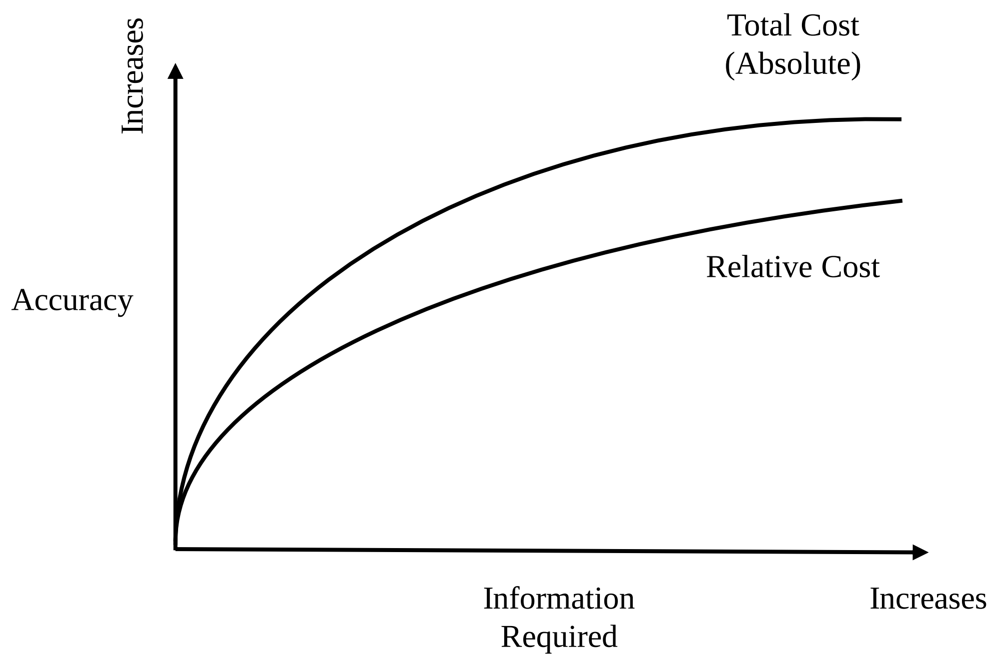

Figure 2-5: Trade-off between Total and Relative Cost

Morita (2007) investigated this topic in a cost model for sourcing decisions in high versus low cost countries using a GAAP financial accounting methodology. This research highlighted the importance of focusing on relative instead of absolute cost analysis when deciding between two or more sourcing decisions [5]. Similarly, the methodology developed in this project will focus on relative cost accuracy.

Nissan Operations Overview

This chapter presents an overview of the manufacturing and supply chain operations at the Nissan Smyrna Plant. The objective is to map the flow of parts to and within the plant that are relevant to TDC. For further information, Addy (2020) and Danner (2020) provide a detail review of the Nissan Smyrna Plant manufacturing including the stamping, body assembly, and trim and chassis lines [6][7].

3.1. Overview

Nissan Motor Ltd. is a global OEM headquartered in Yokohama, Japan. In North America, through its subsidiary Nissan North America, Nissan operates three manufacturing units in Smyrna, Tennessee; Canton, Mississippi; and Decherd, Tennessee. These units produce both vehicles and powertrains for the local market and export. The Nissan plants are supported by a complex network of domestic and overseas suppliers that constantly deliver parts.

The flow of parts to the plant and within the plant is typically managed by Nissan in cooperation with the suppliers and logistics network partners. Depending on the manufacturing plant and the type of part, each part can follow a different path. Figure 3-1 presents an example of the steps followed by two different parts, A and B, from the supplier to the plant.

Part A follows a path with "minimum" steps. Part A is delivery by the supplier directly to the plant inbound location and from there goes to the assembly line, in a process managed by the material handling team. A good example of such a part is a vehicle seat. On the *opposite end, Part B follows all the possible steps. After the part leaves the supplier it arrives to the plant and is placed in a warehouse as inventory. Once the part is required for manufacturing it goes to sequencing center and then to the plant inbound location. Inside the plant, the part is picked and added to a kit that goes to the assembly line. After the part is used, its packaging is returned to the supplier through the return center. In this case, all the steps after the warehouse are the responsibility of the material handling team. A good example of such a part is a side mirror.*

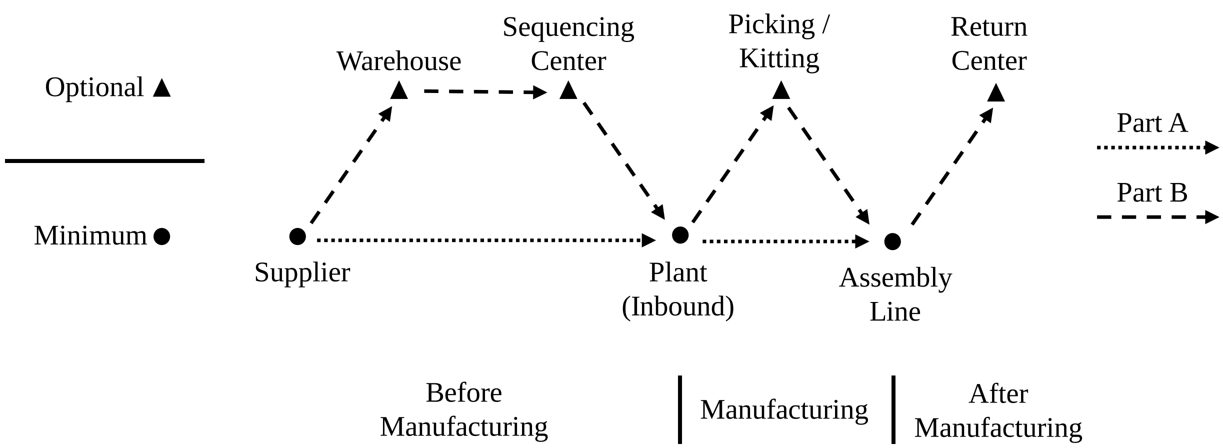

Figure 3-1: Part Flow Overview

The following sections in this chapter provide a better understanding of all the steps described in Figure 3-1.

3.2. Delivery Terms and Mode

Delivery terms are part of contractual agreements established between the buyer (Nissan) and seller (supplier) and they define the responsibility split for all costs related to transportation. The most common standard for delivery terms is the Incoterms and it applies to both domestic and overseas parts. The two main Incoterms options used by Nissan are Delivered Duty Paid (DDP) and Ex-Works (EXW). If a part is sourced DDP, the supplier is responsible to deliver the part to the Nissan plant and pay for any transportation, insurance, or duty cost. Conversely, if a part is sourced EXW, then Nissan is responsible to pick up the part from the supplier location of choice and pay the exact same costs.

Transportation mode depends greatly on the location of sourcing. If a part is sourced domestically, transportation consists mostly of trucking. On the contrary, if a part is sourced overseas, transportation involves a combination of trucking, sea freight and occasionally train. Due to the large volume carried, large automotive companies like Nissan, establish long term contracts with domestic logistics companies and international sea freight carriers to develop their own networks.

Domestic parts delivered in truck can arrive in Truck Load (TL), where only one supplier fills the entire truck, or Milk Run (MR), where a truck is filled with parts from multiple suppliers (see Figure 4-3). Truck freight cost for TL and MR is normally charged on a per route basis, and a typical trailer can carry up to 115 m^3. If a domestic part needs to be expedited, a truck team can be used at a higher cost.

Overseas parts are transported from country of origin to destination using sea freight carriers. Parts are typically consolidated in a Nissan overseas warehouse prior to shipping for optimization. Once the parts arrive to the US, they are transported to the plant by truck and occasionally by train. Expedite for overseas parts typically involves air freight.

3.3. Logistics Network

Due to the large number of parts that are sourced domestically and EXW, the Nissan Smyrna plant has developed its own logistics network composed of trucks and trailer that are owned and operated by a logistics partner. This network allows Nissan to reduce cost by leveraging economies of scale associated with transportation a large number of parts from multiple suppliers. As a consequence, for domestic parts it is often possible for Nissan to realize TDC savings by changing a part from DDP to EXW if it is able to obtain from the supplier a discount equal to its original transportation cost. The TDC methodology developed in this project is based on this Nissan network.

In this network, Nissan is responsible for continuously updating routing and schedule details. Adjustments in routing and/or schedule are typically the consequence of changes in production forecast or network improvements. These can include changing route periodicity, changing route suppliers and stops or switching from TL to MR and vice-versa.

In the transportation contracts for EXW parts, the transportation cost, which is paid by Nissan to the logistic partner, is divided in two terms known as freight and fuel surcharge. The first term, freight, is a "fixed" cost paid by route and is based on long term contract arrangements. Freight only changes if a route changes. The second term is fuel surcharge and is a variable term that depends on current fuel prices. This split transfers the risk of fuel from the logistics partner to Nissan.

3.4. Packaging

Packaging refers to all activities involved in enclosing and protecting a part for transportation and storage and it is a very important topic in automotive manufacturing and supply chain operations. Due to the large number of parts in a vehicle and the high volume of vehicle production, parts arrive continuously to the plant, and all the packaging must be handled. Although this simple, packaging in automotive is not a trivial problem.

To better understand packaging, it is important to define the concepts of packaging material and packaging type. Packaging material can be disposable or non-disposable (returnable). Disposable packaging typically allows for tighter packing which reduces transportation cost but requires additional handling at the plant to remove and recycle the dunnage, which mostly consist of cardboard and wooden crates.

Returnable packaging is constructed of durable materials and can be reused. This creates a closed loop where packaging is returned to the supplier once the part is used. To improve reverse logistics, returnable package is typically collapsible with a ratio between collapsed and non-collapsed volume of approximately 3 to 1. Returnable packaging reduces the handling at the plant which improves operations. Returnable packaging requires an upfront investment by the buyer or the seller which is a function of the package design and supplier lead time. The longer the lead time, the more packaging is required to cover the pipeline and delivery cycle. While returnable packaging is more common, disposable packaging is still used in some overseas parts.

The definition of packaging type applies mostly to returnable packaging. Returnable packaging can be divided in bulk or tote. Bulk is commonly used for larger parts and is typically the size of a pallet which requires forklift handling. Tote is used for smaller parts and can be handled manually.

3.5. Material Handling and Last Mile

In the Nissan Smyrna plant, the Material Handling department is responsible for all internal movement of parts. This includes “small” movement of parts from the picking/kitting area to the assembly line using autonomous guided vehicles (AGV) and forklifts, and “large” movement of parts between buildings using delivery and switch trucks. The latter is commonly referred to as last mile and there are four last mile options depending on the part: direct, pre-sequenced, sequenced and warehouse. Figure 3-2 presents a schematic of the four last mile types.

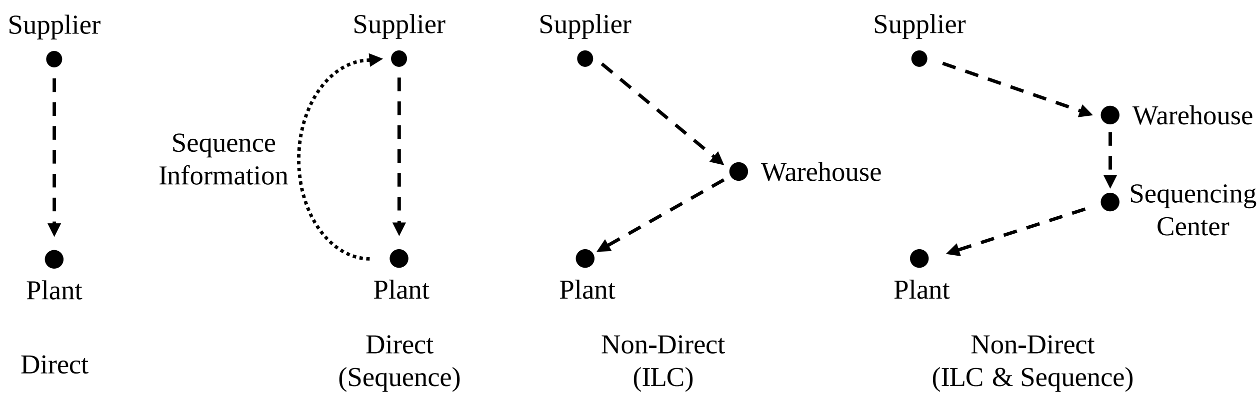

Figure 3-2: Last Mile Options

Direct parts are delivered by the supplier directly to the plant. For a part to be delivered directly to the plant it needs to be sourced domestically and typically from a location close to the plant. Direct parts require minimum inventory at the plant, typically 4 to 8 hours of production, and the inventory is held in the plant inbound location. Direct parts require high supply chain coordination but have the lowest operational and storage cost. A subset of parts delivered directly are pre-sequenced. These are special parts, such as the vehicle seats, that arrive from the supplier in the exact production sequence. These parts spend a minimum amount of time in the plant, with minimum inventory but require much higher supply chain coordination.

Parts that are sourced far from the plant, including overseas, or parts with low utilization, cannot be delivered directly and need storage. In the case of Nissan Smyrna Plant, storage is conducted at the Integrated Logistics Center (ILC), where safety inventory is kept. A subset of these parts require sequencing, and, in that case, these parts go through a sequence center after leaving the ILC and before going to the plant. Storage and inventory costs are lower for direct parts versus non-direct and supply chain coordination is higher for sequenced parts versus non-sequenced.

3.6. Quality

Because the TDC methodology developed in this project includes the cost of quality, this section briefly introduces the quality process system at the Nissan Smyrna plant. The Pre-Delivery Inspection (PDI) and Part Quality Engineering (PQE) groups are directly involved in the supplier quality at the Nissan Smyrna Plant. PDI is responsible for the final vehicle inspection in the assembly line and for identifying any defect that is attributable to suppliers. PQE works directly with suppliers to define quality objectives, monitor quality performance, and resolve quality incidents. PQE defines for each a supplier a Supplier Score Card (SSC) to track quality performance. The SSC is based on four independent factors:

- Number of defective parts per million of parts.
- Direct cost in repair caused by defective parts.
- Indirect disruption cost in manufacturing caused by defective parts.
- Rate of warranty claims caused by defective parts.

Cost of quality can be divided in direct and indirect cost. Indirect cost includes elements such as consumer presentation and brand image impact and is typically very difficult to measure.

The two main direct components of cost of quality are the cost of line repair and the cost of warranty. Cost of line repair includes all costs associated with repair a defect while vehicle is on the manufacturing line prior to vehicle delivery. This includes cost of parts, cost of repair technician and cost due to loss of productivity. Unfortunately, cost of line repair is difficult to track as man-hour utilization and loss of productivity information is easily not available.

Cost of warranty represents the cost incurred by Nissan when a consumer detects a defect and request a repair after delivery. Nissan maintains detailed warranty claim data related to quality defects. Therefore, the cost of quality methodology developed in this project is focused on cost of warranty claim.

Total Delivered Cost Methodology

This chapter presents the details of the TDC methodology developed for this project using historical data from the Nissan Smyrna plant. The chapter is organized by section with each section focused on one component of TDC. For clarity, the details of the methodology are presented together with the relevant data analysis.

Section 4.1 introduces the TDC methodology main aspects. Sections 4.2 to 4.8 present the data analysis and calculation details for each TDC component. Finally, Section 4.9 provides a brief discussion of the results.

4.1. General

As mentioned in Section 1.2, the first step in a TDC methodology is to define the scope and granularity of the analysis and the cost elements. The TDC methodology developed on this project has 10 cost elements that cover both supply chain and manufacturing. These are part, tooling, packaging, transportation, last mile, inventory, storage, obsolescence, quality, and tariffs as described below:

- Part: Cost of the part which is paid directly to the supplier.
- Tooling: Cost of the upfront investment in tooling which is paid upfront.
- Packaging: Cost of the packaging which is paid upfront.

- Transportation: Cost of domestic or overseas transportation which is paid to the logistics partner.
- Last Mile: Cost of moving the part within the plant which is internal.
- Inventory: Cost of holding inventory which is internal.
- Storage: Cost of the space used by inventory which is internal.
- Obsolescence: Cost of unused parts which is internal.
- Quality: Cost of warranty claims which is paid to external dealers and vendors.
- Tariff: Cost of importing parts which is paid to authorities.

Figure 4-1, presents the average breakdown of TDC per cost element excluding part, tooling and packaging as these greatly depend on part type. The typical value of tariffs is provided for comparison only. The results show that on average transportation and last mile are the largest costs element followed by inventory and storage.

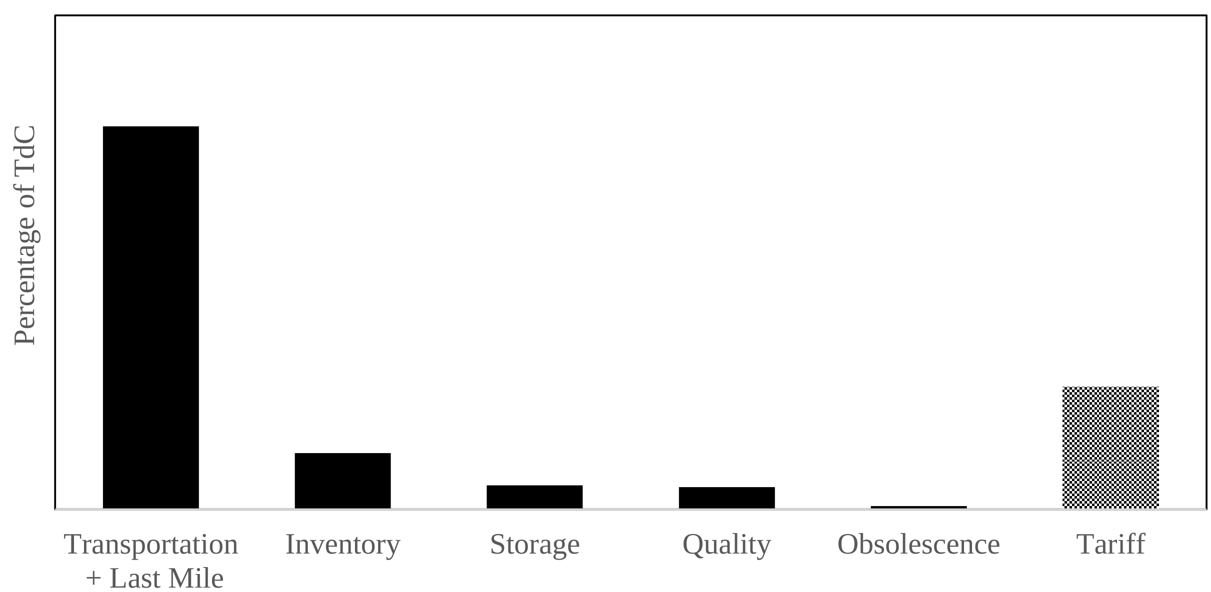

Figure 4-1: Cost of Transportation

Equation (4-1) provides the general formulation of the TDC methodology.

$$TdC\ (\$/part) = Part + Tooling + Packaging + Transportation + Last\ Mile + Inventory + Storage + Obsolescence + Quality + Tariff \quad (4\text{-}1)$$

4.2. Part, Tooling and Packaging

Part, tooling, and packaging costs are all part specific cost elements that vary greatly from part to part. Part cost can include small additional items such as disposable packaging and is paid directly to the supplier. Part cost can be subjected to foreign exchange fluctuations throughout the contract lifetime.

Tooling cost is the responsibility of Nissan and is not included in the part cost. The cost of tooling is a function on the individual tooling cost and the number of suppliers, i.e., in case of multi-sourcing the cost of tooling is multiplied by the number of suppliers. Equation (4-2) presents the calculation methodology for tooling cost.

$$Tooling\ (\$/part) = \frac{Tool\ Cost \times Number\ of\ Suppliers}{Production\ Volume \times Program\ Duration} \quad (4\text{-}2)$$

As discussed in Section 3.4, packaging can be disposable or non-disposable (returnable). Disposable packaging is typically included in the part cost and paid directly to the supplier on a per part basis. Non-disposable or returnable packaging is a fixed upfront cost that is fractioned across all forecasted parts. The cost of non-disposable packaging is a function of the packaging design and supplier lead time. Equation (4-3) presents the calculation methodology for packaging cost.

$$Packaging\ (\$/part) = Packaging\ Cost \times f_{Quantiy}(leadtime, production) \quad (4\text{-}3)$$

4.3. Transportation

Section 3.2 presents the delivery terms and transportation modes typically used by Nissan. For parts sourced Delivery Duty Paid (DDP) transportation cost is the responsibility of the supplier and the cost is included in the part cost. As mentioned in Section 3.3, for domestic parts sourced Ex-Works (EXW), transportation cost is composed of freight and a fuel surcharge. A detailed calculation methodology for both is presented in this section. For overseas parts sourced EXW, transportation cost is covered by door to door rates under long term sea freight contracts. This transportation option is not covered in this document. Figure 4-2 presents a schematic of the possible transportation cost options.

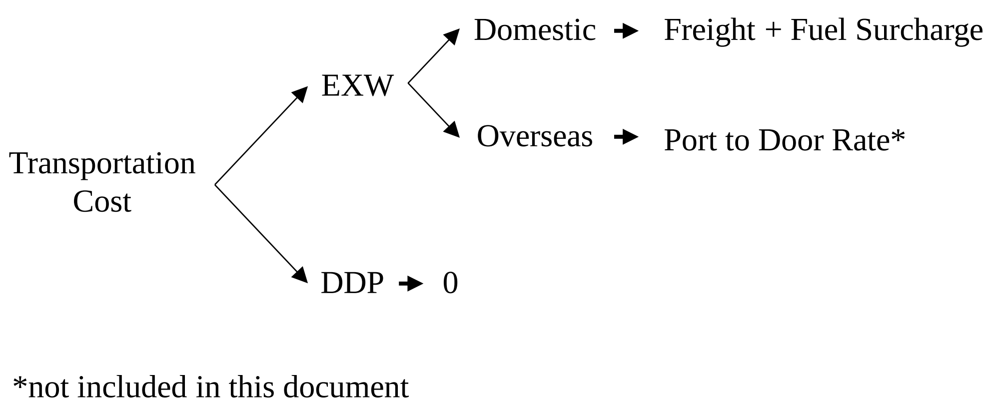

Figure 4-2: Schematic of Transportation Cost

Going forward, the focus of this section will be the transportation cost for domestic parts sourced EXW as defined in in Equation (4-4).

$$Transportation\ Cost = Truck\ Freigth + Fuel\ Surcharge \tag{4-4}$$

Domestic parts sourced EXW, can be delivered in Truck Load (TL), where a one supplier is able to fill an entire trailer, or Milk Run (MR), where a trailer is filled with multiple suppliers. TL routes are used for parts and suppliers than have a large enough volume arriving continuously at the plant to justify a dedicated route. MR are used for parts and suppliers with smaller volume. The balance between MR and TL routes is constantly managed to respond to changes in production volumes or to improve the network. Figure 4-3 presents a schematic of a TL and a MR route.

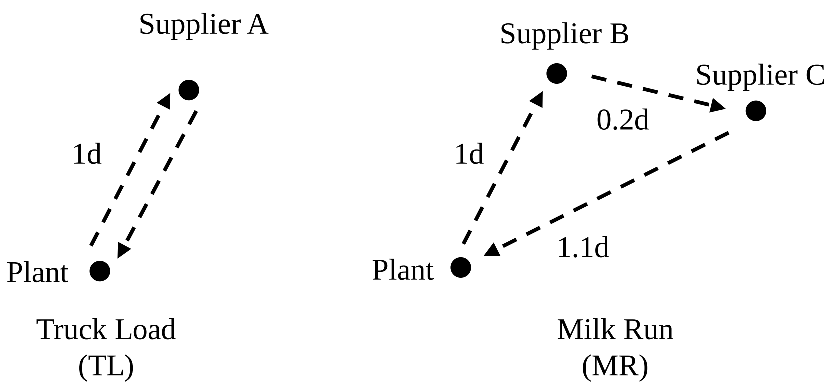

Figure 4-3: Truck Load (TL) versus Milk Run (MR)

Truck freight usage is typically measured in linear instead of volume based metrics. This happens because trailer filling is managed using available length and not volume. The traditional unit for freight cost is \$/m where the length, measured in meters, represents the trailer length. A typical trailer length is between 8.5m (28 ft) and 16.2m (53 ft). This means that for a hypothetical route with a freight cost of 50\$/m, using a meter of the available trailer length costs \$50.

An initial analysis of the Nissan TL and MR network was performed. This analysis included more than 300 suppliers that were connected using more than 220 TL and 160 MR different routes. Figure 4-4 presents freight cost in \$/m versus the supplier distance to the plant for both TL and MR routes, with the size of the circle representing the volume carried. The results clearly show that as expected freight cost in \$/m increase with supplier distance to plant. A linear regression with distance as the predictor was used in both networks, and as expected, the results show a better correlation for TL compared with MR with and R^2 of 0.87 and 0.40, respectively. The poorer performance in the MR case can be explained by the fact that MR routes are typically more complex with multiple suppliers in the same routes. To improve the results of MR, or to analyze networks with high cross-docking, a multiple linear regression with added categorical variables for location is used.

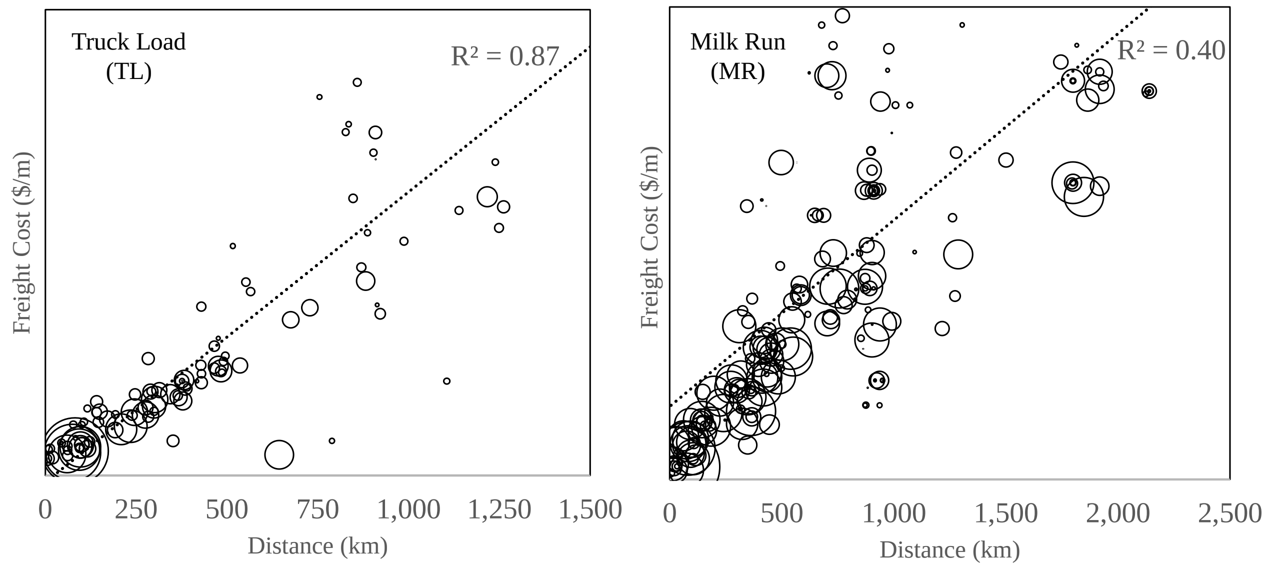

Figure 4-4: Cost of Transportation

As previously mentioned, truck freight cost is measured in linear trailer utilization using $/m units. However, these units are not suitable for direct use in TDC, the next step in the analysis is to transform linear cost into volume cost. To transform $/m into $/m^3 the concept of Truck Fill Ratio (TFR) is introduced. TFR represents the volume utilization of a trailer and is defined in Equation (4-9). The higher the TFR the better the trailer utilization and lower the cost in $/m^3. For practical reasons TFR target values typically do not exceed 90%.

$$TFR\ (\%) = \frac{Used\ Trailer\ Volume}{Total\ Trailer\ Volume} \tag{4-5}$$

Figure 4-5 presents the distribution of TFR values in the Nissan TL network. The results, which were based in 1 year of operation, show a highly left skewed distribution with approximately 90% of the instances occurring in the TFR interval between 75% to 85%. The high TFR average confirms the high performance of the Nissan TL network. However, the results also show a long tail of small TFR instances. Low TFR values can occur due to low truck filling performance but also due to the transportation of heavy parts. In this case of heavy parts, the trailer can reach its weight capacity before its volume and consequently the TFR value is low. To account for this effect, a Weight Factor (WF) is introduced as defined in Equation (4-6).

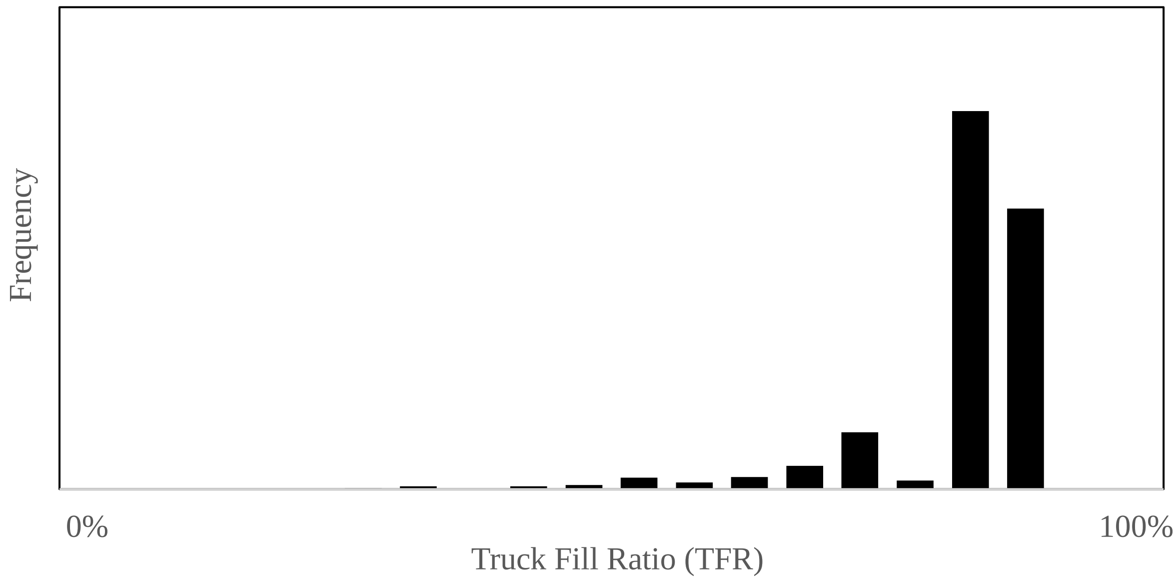

Figure 4-5: Truck Fill Ratio Histogram for Truck Load

$$Weight\ Factor = \frac{Part\ Weight/Part\ Volume}{Max\ Trailer\ Weight/Max\ Trailer\ Volume} \tag{4-6}$$

Based on the concepts of truck linear cost, TFR, and WR is now possible to define a generalized equation for domestic freight cost. Equations (4-7) and (4-8) provide the truck freight cost for Truck Load (TL) and Milk Run (MR), respectively.

$$Truck\ Freight_{TL} = Part\ Volume\ \times f_{TL}(distance) \times TFR \times WF \tag{4-7}$$

$$Truck\ Freight_{MR} = Part\ Volume\ \times f_{MR}(distance, location)\ \times TFR\ \times\ WF \tag{4-8}$$

With a formula for truck freight available, the last step in the analysis is to define a generalized equation for fuel surcharge. However, unlike truck freight, fuel surcharge is variable as it depends on current fuel prices.

Fuel surcharge is a function of distance traveled and fuel cost, and the calculation methodology depends on the route type. For TL routes, which have only one supplier, the distance traveled is simply the distance between the supplier and the plant, or in the case of a return route

2 times the distance. For MR routes, which have more than one supplier, the distance traveled depends on the distances of all the suppliers in the route. To address this issue a MR Distance Factor is added as defined in Equation (4-9).

$$MR\ Distance\ Factor = \frac{Milk\ Run\ Distance}{Average\ Supplier\ Distance} \qquad (4\text{-}9)$$

An analysis of the Nissan MR network was performed to define the MR distance factor. Figure 4-6 presents the MR distance factor as a function of supplier distance. The results show that as distance increases the MR distance factor decreases. This result is explained by the fact that MR routes are designed based on clusters and so for longer routes the MR distance is similar to the average supplier distance. Figure 4-7 provides a simplified illustration of this phenomenon. In the short MR, the total distance traveled is 1.8d and the average supplier distance is 0.4d, which results in a MR distance factor of 4.5. In the long MR, the total distance is 11.5d and the average supplier distance is 10.5 d, for a MR distance factor of 1.1.

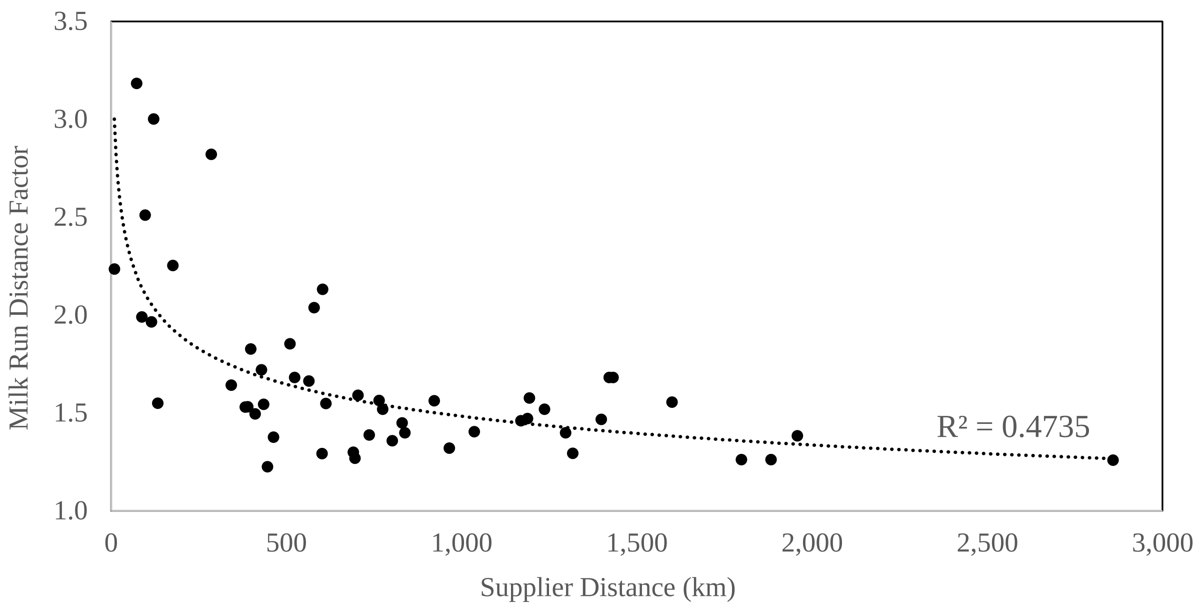

Figure 4-6: MR Distance Factor

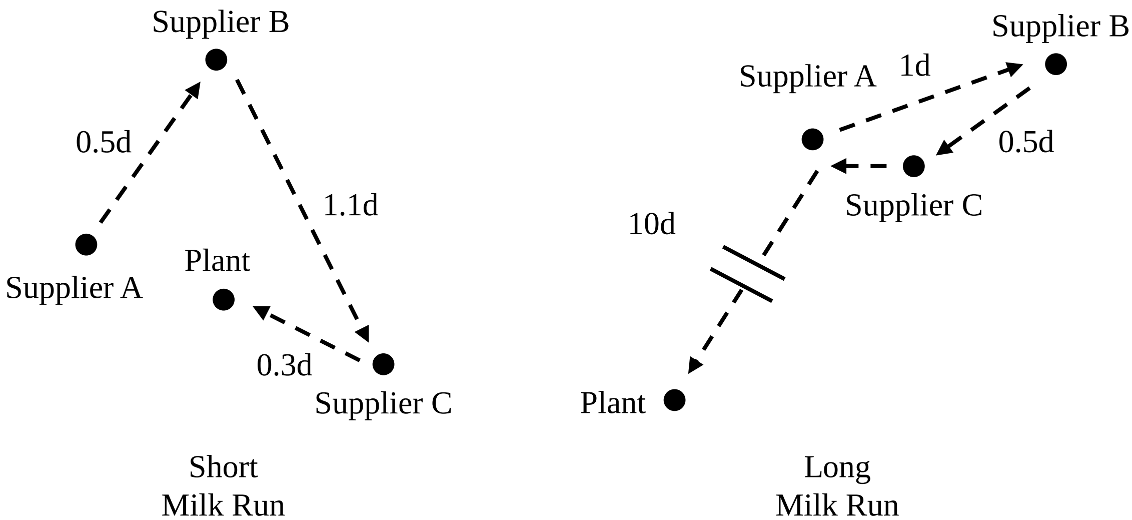

Figure 4-7: Short and Long MR Schematic

Equations (4-10) and (4-11) provide the generalized formulation for Truck Load (TL) and Milk Run (MR) fuel surcharge, respectively.

$$Fuel\ Surcharge_{TL} = distance \times fuel\ rate \times 2^{1} \tag{4-10}$$

1) Return route

$$Fuel\ Surcharge_{MR} = distance \times fuel\ rate \times f_{MR\ Factor}(distance) \tag{4-11}$$

4.4. Last Mile

Last mile, which is described in Section 3.5, refers to the internal movement of parts within the plant. Last mile is typically performed by switch trucks that move parts from building to building, including from the ILC to the sequencing center, or from the sequencing center to the assembly line. There are four possible last mile options, and for each part, the choice is performed based on diverse factors such as sourcing location, inventory quantity, and need for sequencing:

- Direct: Parts delivered directly to the plant inbound location (assembly line).
- Direct (Sequence): Parts delivered directly to the plant with pre-sequence.
- Non-Direct (ILC): Parts delivered and stored in warehouse (ILC).

- Non-Direct (ILC & Sequence): Parts delivered and stored in the warehouse (ILC) with pre-sequence.

An analysis of the operational costs associated with these four options was performed which included warehouse management, switch and shuttle trucks, and plant inbound costs. Figure 4-8 presents the operational cost in $\$/m^3$ for the four options normalized to the cost of Direct delivery. The results show that last mile cost is lowest for Direct delivery, which is expected as this option includes only plant inbound costs associated with switch trucks. Last mile costs are the highest for warehouse delivery with sequence which include multiple shuttle trucking and handling operations.

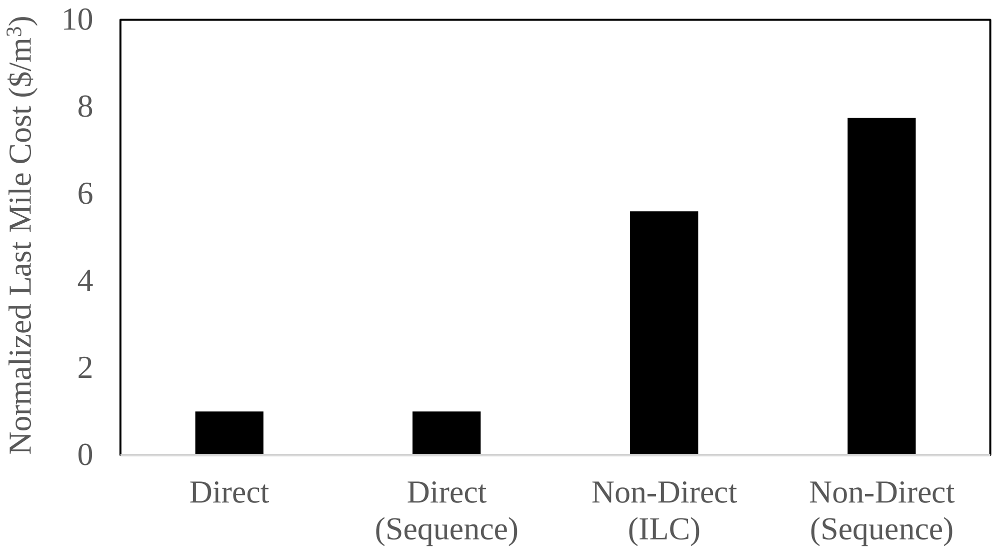

Figure 4-8: Last Mile Options Cost

Based on the cost provided in Figure 4-8, a generalized equation for last mile cost is developed and presented in Equation (4-12).

$$\begin{gathered} Last\ Mile\ Cost = part\ volume\ \times\ f_{Last\ Mile}(last\ mile\ option) \\ last\ mile\ option = \{direct, \ldots\ , non - direct(sequence)\} \end{gathered} \quad (4\text{-}12)$$

4.5. Storage and Inventory

Storage and inventory costs represent all the operational costs associated with keeping parts in the plant. Storage refers specifically to the cost of the space occupied by part and it is a function of the individual part volume, the number of parts in storage and the storage location. Inventory represent the financial cost associated with holding parts as an asset and it is a function of the individual part cost, the number of parts in storage, and the inventory holding rate. The inventory holding rate includes the interest discount rate and the spoilage/maintenance rate, and is defined internally be Nissan.

Because both elements are a function of the number of parts in storage, i.e., inventory, the first step in the analysis is to determine the required safety stock. This is performed using a standard inventory formula with lead time and demand variability as defined in Equation (4-13). The required service level is set internally by Nissan and it is a function of the part type.

$$\begin{gathered} Inventory = Z \times \sqrt{\mu_{LT} \times {\sigma_D}^2 + (\sigma_{LT} \times \mu_D)^2} \\ \mu_{LT} = Lead\ Time\ Average \\ \sigma_{LT} = Lead\ Time\ Standard\ Deviation \\ \mu_D = Demand\ Average \\ \sigma_D = Demand\ Standard\ Deviation \end{gathered} \tag{4-13}$$

The calculation in Equation (4-13) requires four elements: lead time average and standard deviation, and demand average and standard deviation. Figure 4-9 presents the average and coefficient of variation of lead time for the parts delivered to the Nissan Smyrna plant. The data includes 6 domestic regions that represent the Unites States, Canada and Mexico, and 5 overseas countries from Europe and Asia. The results show that, as expected, lead time is higher for overseas countries compared with domestic regions. Coefficient of variation, on the other hand, does not change significantly. Indeed, while the average lead time for overseas parts is approximately 5 times the average for domestic parts the coefficient of variation is only 42% smaller. As a consequence, all else equals, parts sourced overseas require additional safety stock.

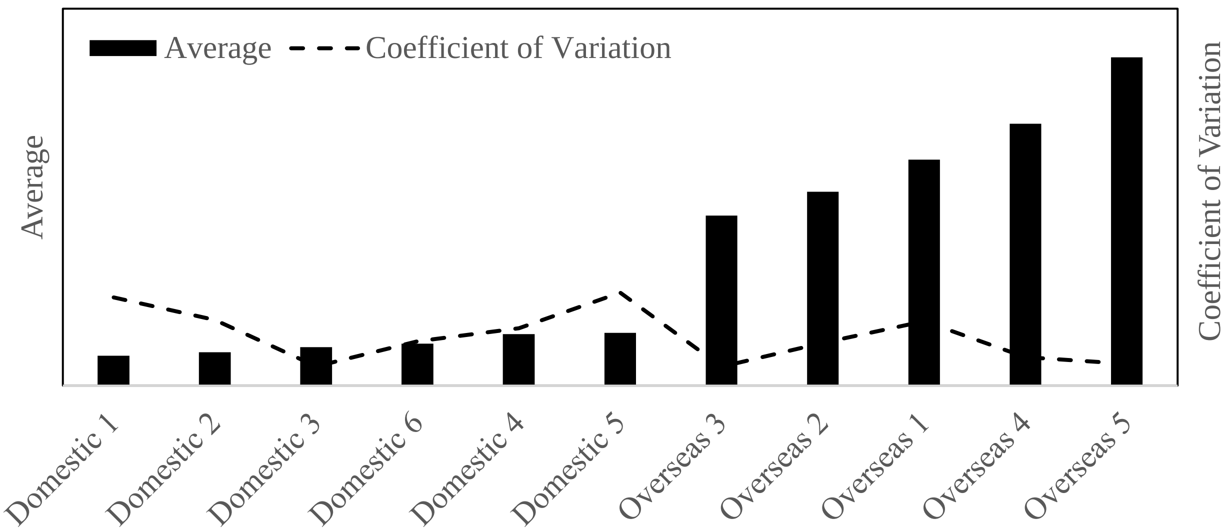

Figure 4-9: Lead Time Average and Standard Deviation

To complete Equation (4-13), it is required to obtain demand data. Demand at the Nissan Smyrna plant is determined by the production control group. This group works with the commercial sales and strategy teams and defines the daily, weekly, monthly, and 6-month production forecasts for the plant. Depending on the part type, the monthly or 6-month production forecast is used to determine the average demand. To define a methodology for the demand standard deviation an analysis of the plant production was performed aiming at examining a possible correlation between the average and standard deviation of demand. Figure 4-10 presents the relation between coefficient of variation (CV) and average demand measured in parts per day. The results show that the coefficient of variation of demand decreases with increasing average of demand. This behavior is explained by the fact that high volume parts are typically common across multiple vehicles and options (carry across parts) and therefore have small variability. Low utilization parts are typically restricted to a single vehicle or option and therefore are subjected to more variation.

A separate analysis of demand was performed to study the difference between parts sourced domestically and overseas. The results show that demand utilization for domestic parts is on average 83% larger than overseas parts, which means that overseas parts have on average higher CV. This is explained by the established preference to source parts with high demand domestically. Altogether, overseas parts have higher lead time average and standard deviation, and higher coefficient of variation. As a consequence, in the Nissan Smyrna plant, overseas parts typically require 8 to 10 times more inventory than domestic parts which means proportionally higher costs of storage and inventory in the TDC.

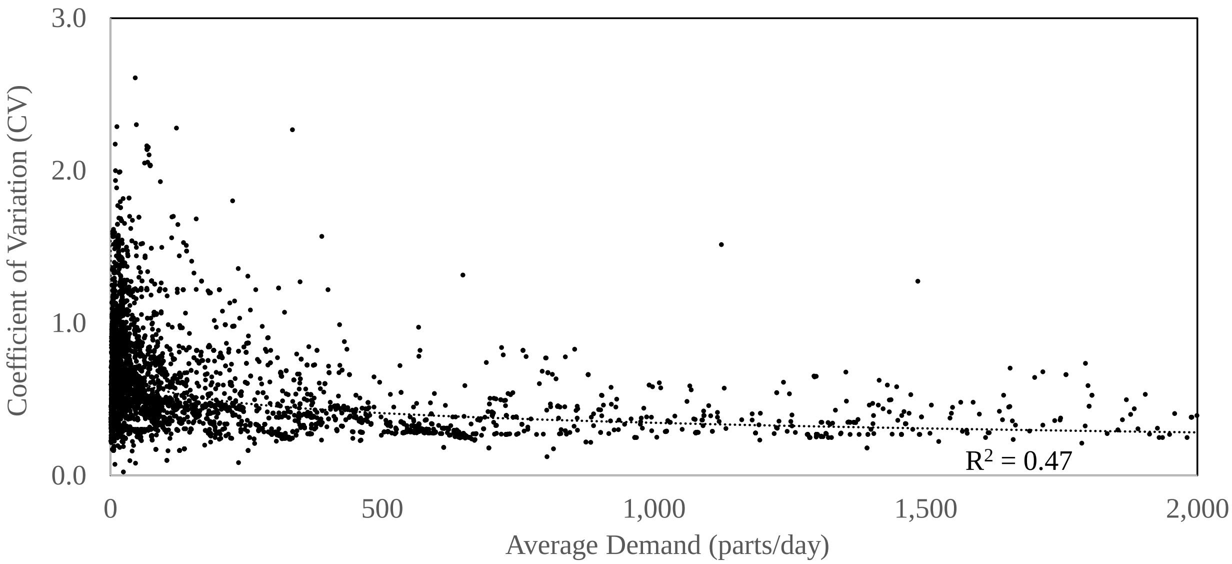

Figure 4-10: Coefficient of Variation (CV) versus Average Demand

Based on the data above it is now possible to define a general equation for inventory cost as presented in Equation (4-14).

$$\begin{gathered} Inventory\ Cost = \text{Part Cost} \times Inventory\ Quantity \times Holding\ Rate \\ Inventory\ Quantiy = f_{Inventory}(origin, demand) \\ origin = \{domestic\ 1, \dots , overseas\ 5\} \\ delivery = \{direct, sequence, warehouse\} \end{gathered} \tag{4-14}$$

Although, inventory cost requires only safety stock to calculate, cost of storage also includes the cost of storage location. In the Nissan Smyrna Plant, there are two main storage locations, depending on the last mile option as discussed in Sections 3.5 and 4.4. Parts that are delivered directly to the plant are typically stored in the plant inbound area and trailer park, and non-direct parts that require inventory are stored in the ILC warehouse. An operational cost analysis was performed to define the cost of direct and non-direct storage space. Figure 4-12 presents the operational cost of storage for direct and non-direct delivery on a volume basis using

$/m^3$/year, normalized to the storage cost of direct delivery. The results show that non-direct delivery has a storage location cost which is approximately 4 times higher than direct delivery, which reflects the additional cost associated with maintaining and operating the ILC versus the plant inbound trailer park.

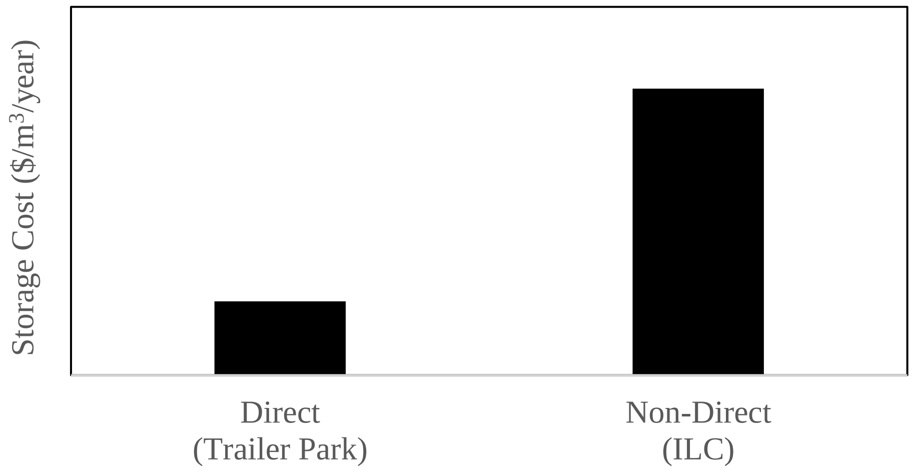

Figure 4-11: Storage Location Cost Direct and Non-Direct

A final analysis was performed to ascertain the possible impact of packaging type in storage cost for non-direct parts stored in the ILC. As described in Section 3.4 the two main types of packaging used are bulk and tote and its use depends mostly on the part size. An analysis of the storage cost within the non-direct parts split between bulk and tote is presented in Figure 4-12. The results show that tote storage cost is significantly more variable for tote compared with bulk which is explained by the higher diversity of tote geometries and consequently lower consistency of storage inefficiency. However, the median costs of both type of packaging are similar, and therefore for a preliminary analysis tote and bulk are considered to have the same storage cost in $/m^3$/year.

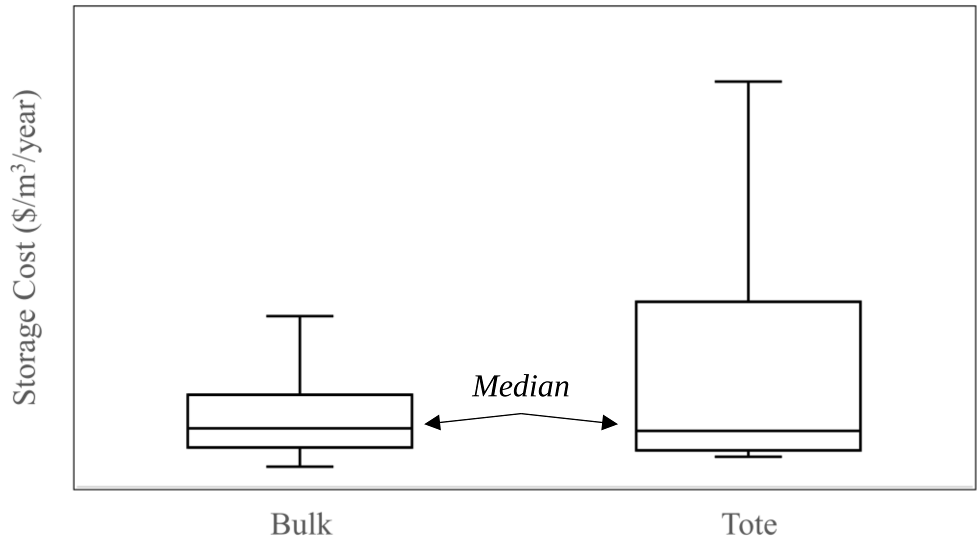

Figure 4-12: Storage Cost for Bulk and Tote

With this information it is possible to establish a general equation for the cost of Storage. Equation (4-15) provide the details for storage cost:

$$
\begin{gathered}
Storage\ Cost = Part\ Volume\ \times Inventory\ Quantity\ \times Storage\ Cost \\
Inventory\ Quantiy = \ f_{Inventory}(origin, demand) \\
Storage\ Cost = \ f_{Storage\ Cost}(last\ mile, packaging\ ) \\
origin = \{domestic\ 1, \dots\ , overseas\ 5\} \\
last\ mile = \{direct, non - direct\} \\
packaging = \{bulk, tote\}
\end{gathered} \tag{4-15}
$$

4.6. Obsolescence

When a vehicle ramps down production there is a risk of parts in inventory being left unused. To prevent this, production control and inventory management work together to define a inventory ramp down plan. However, despite these efforts many parts still end up left unused. The cost associated with these unused parts is defined as cost of obsolescence and it can be significant every year. Cost of obsolescence can be traced back to sourcing and therefore it is included in TDC methodology. Figure 4-13 presents the normalized risk of obsolescence for multiple regions. The results show that if a part is sourced from the Domestic 5 region its probability of going obsolete is half the average. On the contrary, if a part is sourced from the Overseas 1 region, its probability of becoming obsolete is four times the average. Figure 4-13 also shows a correlation between lead time and risk of obsolescence. This behavior can be explained by the effect of longer lead times in pipeline inventory that makes the supply chain less responsive. If there is a decision to accelerate the inventory ramp down plan, sourcing locations with longer lead times will have more difficulty in responding which increases risk of obsolescence.

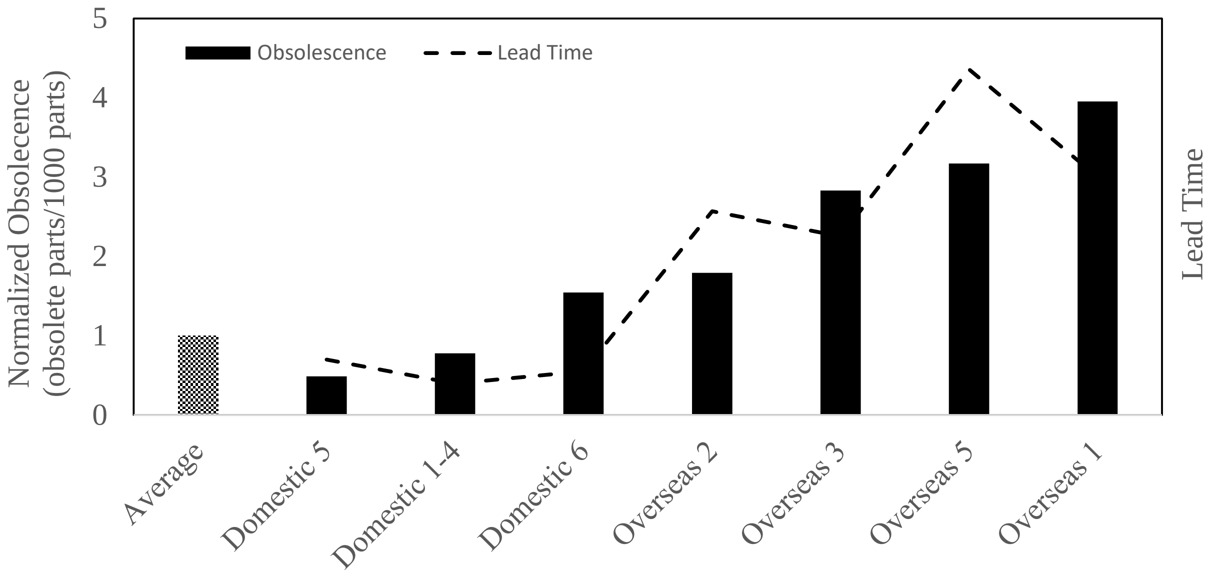

Figure 4-13: Risk of Part Obsolescence

Equation (4-16) presents the generalized formula for cost of obsolescence.

$$\begin{gathered} Obsolescence\ Cost = \ part\ cost\ \times f_{Obsolescence}(origin) \\ origin = \{domestic\ 1, \dots\ , overseas\ 5\} \end{gathered} \quad (4\text{-}16)$$

4.7. Quality

Section 3.6 presents a simplified overview of the Nissan quality system including the quality inspection process and the supplier score card. This overview aims at introducing the topic of cost of quality in the context of TDC. This section presents an introductory methodology to calculate cost of quality in the automotive industry. The methodology is limited to the direct cost of quality associated with warranty claims as explained in section 3.6.

An analysis of the warranty claims associated with supplier's quality defects was performed. The analysis was limited to part types that had more than 10 recorded claims in a period of 1 year and at least three different suppliers. Figure 4-14 and Figure 4-15 present the cost per warranty claim and the number of claims per 100,000 vehicles for a group of 40 different part types. More specifically, Figure 4-14 shows the 25% to 75% percentile range of cost that Nissan incurred to repair a claim made for a given part family. The results clearly show that, to solve a claim associated with a given part type, the maximum and minimum costs paid are similar. Figure 4-15 shows for the same group of 40 part types, the claim rate in number of claims per 100,000 vehicles. The results show the rate for the best and worst supplier as well as the average. The results show a clear variation of performance between the best and worst supplier which indicates that supplier selection has indeed an effect on cost of quality and therefore should be included in TDC. The following paragraph explains how to read Figure 4-14 and Figure 4-15.

Part type #5 in Figure 4-14 and Figure 4-15 represents the vehicle windshield. This is a glass part that all vehicles have, and it protects the occupants from the elements while giving visibility. In the case of the Nissan Smyrna plant the windshield is sourced from 3 different suppliers and installed in 6 different vehicles. The repair cost per warranty claim, which in this case is the replacement of the windshield, is shown in Figure 4-14. The results show that this cost is almost constant with a difference of approximately 15% between the highest and lowest cost repair. However, the warranty claim rate varies greatly between the best and worst supplier. In the case of windshields, the warranty claim rate measured in number of claims per 100,000 vehicles is 5.6 times higher for the worst supplier compared with the best.

The example above clearly shows that sourcing decisions can impact TDC through cost of quality. This impact is best measured by the cost per claim, which varies little, and the claim rate, which can vary greatly between different suppliers.

It is important to note that warranty cost is only a small portion of cost of quality. Suggestions for future work in cost of quality, which are detailed in Section 6.1, include incorporating in the analysis other costs elements such as cost of line repair, cost of inspection, cost of quality pipeline and cost of productivity loss.

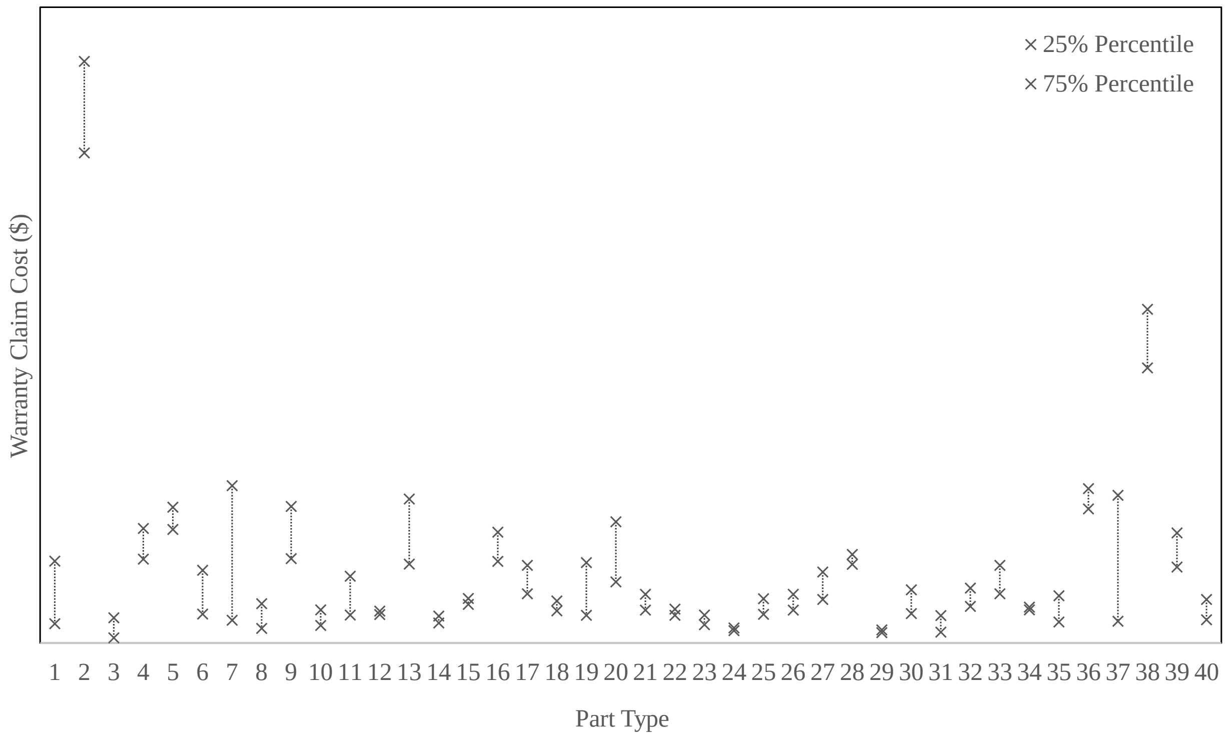

Figure 4-14: Quality – Warranty Claim Cost

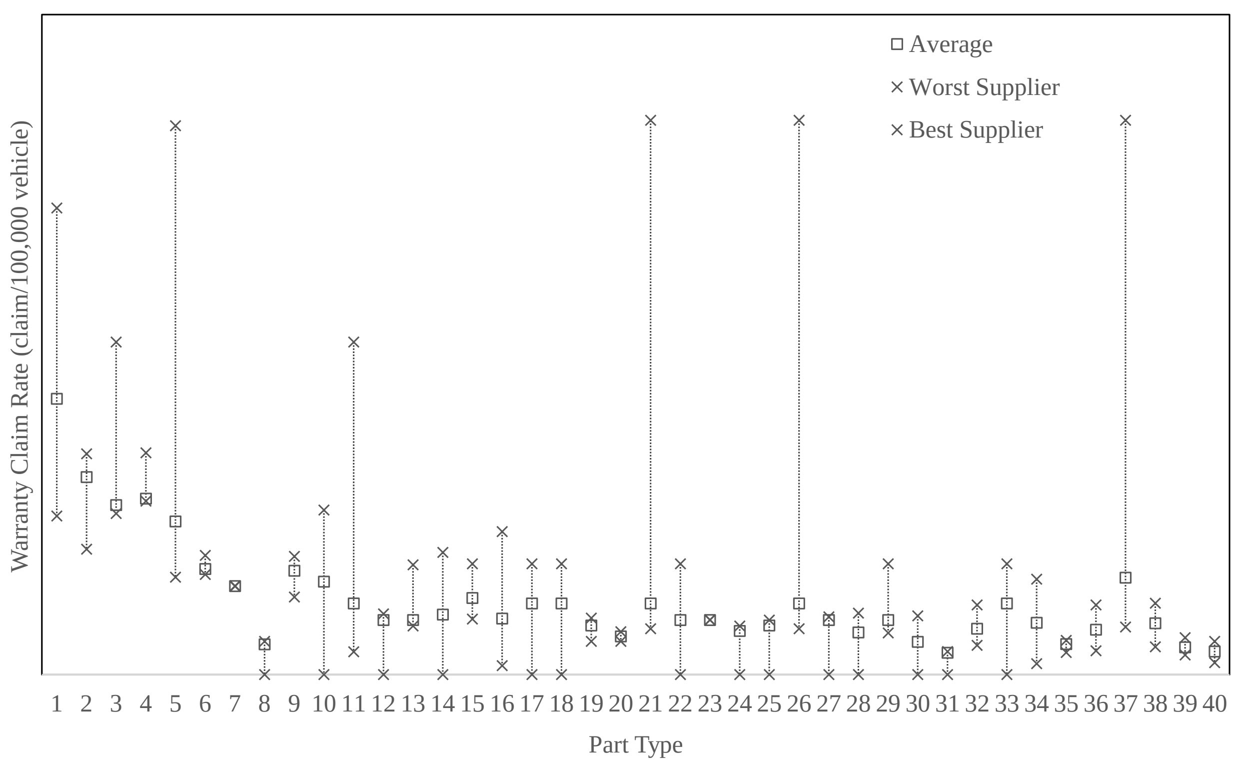

Figure 4-15: Quality – Warranty Claim Rate

Equation (4-17) presents the generalized formulation for cost of quality associated with supplier caused warranty claims:

$$Quality\ Cost = part\ cost \times f_{warraty\ cost}(part\ type) \times f_{warranty\ rate}(part\ type) \quad (4\text{-}17)$$

4.8. Tariffs

Taxes and tariffs have always been an important part of sourcing decisions, in particular in overseas sourcing. In recent years, the topic of tariffs has gained even more relevance due to changes in global trade policy. The application of tariffs naturally disincentivizes overseas sourcing. However, this is not the main challenge of implementing tariffs in TDC methodology, as the calculation method is simple as shown in Equation (4-18).

$$Tariffs\ Cost = part\ cost \times f_{tarrifs}(origin)$$
$$origin = \{overseas\ 1, \dots, overseas\ 5\} \quad (4\text{-}18)$$

The main challenge of implementing a tariff cost in a TDC methodology is related with uncertainty. Tariffs are typically a function of the relation between the country of origin and country of destination and these can often change due to reasons that are outside of the company control. To mitigate the impact of this uncertainty it is important to be internally consistent. Large companies, such as Nissan, typically have a legal department that is focused on operations and maintains an internal forecast of future tariffs risk. To make sure the TDC methodology is internally consistent within the company it is recommend implementing such a forecast in the TDC methodology and leave the responsibility to update it to the legal team. Nonetheless, it is important to review any sourcing decision that ends up being solely driven by tariffs forecast to make sure there is overall consensus from all stakeholders as discussed in Section 5.5.

4.9. Results Discussion

The objective of this project was to develop a TDC methodology for part sourcing. For that, an analysis of the operations at the Nissan Smyrna plant was performed. There are important results from this analysis that should be discussed. This section presents a brief discussion of these results.

The first observation to make is the compounding effect of TDC that occurs for some sourced parts, in particular overseas parts. The best way to visualize this is to compare the TDC of two parts, one sourced domestically and close to the plant, and one overseas.

The TDC for the domestic part starts with part, packaging, tooling, and transportation costs, with the latter small due to the proximity to the plant. Because the part is delivered directly to the plant, there is little inventory, and this inventory can be kept in the trailer park at the plant inbound location, which is cheaper. Therefore, last mile, inventory, and storage costs are low. Next are obsolescence and tariffs. Because the lead time is small, there is a small risk of obsolescence and low obsolescence cost. Tariffs in this case are zero because the part is sourced domestically.

The TDC for overseas parts starts in the same manner with part, packaging, tooling, and transportation costs, with the latter larger due to the distance to the plant. Because the part requires more inventory, this inventory must be kept in the ILC which is more expensive to operate. In this case, overseas parts require ≈ 8-10 times more inventory than domestic, and the ILC operation cost is ≈ 4 times larger than the trailer park. These two effects compound to increase last mile, inventory, and storage costs for the overseas part. Obsolescence, due to the larger lead time will be higher for the overseas part. Tariffs might apply depending on the country of origin and the part details.

One cost element of TDC that was not discussed yet is quality. In the methodology described in Section 4.7 there is no direct correlation between location of sourcing and quality cost. However, sourcing location can indeed impact cost of quality due to pipeline inventory. If a defective part is identified in the assembly line, the supplier is contacted to resolve the issue. If the issue is a dimensional problem or a local defect that requires a change in the supplier design or manufacturing the supplier fixes it. Once this happens, the supplier re-starts sending the new "fixed" part. However, Nissan still needs to continue to operate with the parts that are in the pipeline, otherwise the assembly line would have to stop. Naturally, the longer the lead time, the bigger this problem is. As a consequence, if cost of quality due to pipeline stock is considered, parts sourced overseas can have a higher cost of quality than parts sourced domestically. It is important to note that this concept of pipeline cost of quality was not studied in detail and it might be less relevant than the effect of supplier performance described in Section 4.7. If that is the case, overall cost of quality for overseas parts can be lower if the specific overseas supplier has a better quality performance.

The example described above aims to highlight the compounding effect of TDC, particularly in overseas parts, or parts sourced remotely. However, this does not mean that there should be a preference to source domestically over overseas, since in most cases, the dominant cost element of TDC is part cost. Figure 4-16 presents, for a CCM with approximately 1,500 parts, the proportion of TDC that is non-part cost. Approximately 90% of the parts in Figure 4-16, have a non-part TDC lower than 15%, which means part cost is dominant. Therefore, if an overseas part has a part cost which is significantly lower than a domestic part, it is likely that TDC will also be lower. Despite this, the example above illustrates the importance of considering the compounding effects of TDC in part sourcing.

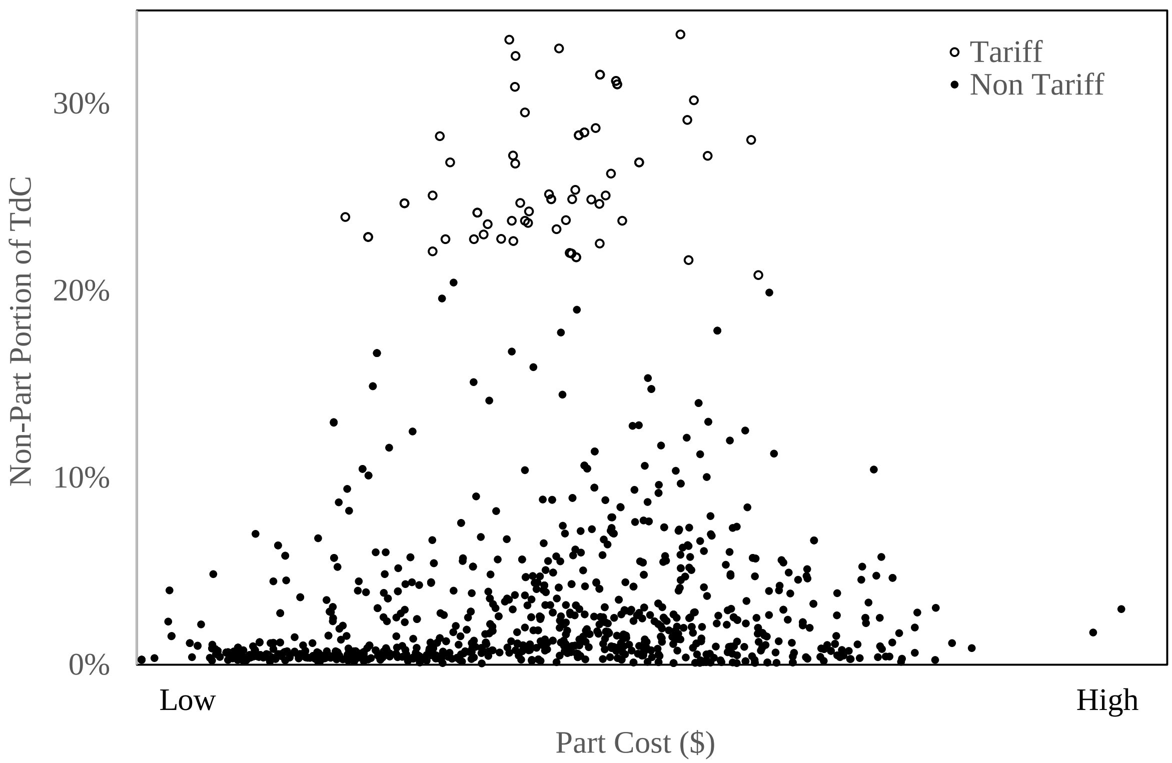

Figure 4-16: TDC – Distribution of Non-Part TDC Cost for a CCM

4.10. Other Cost Elements

This chapter presented a TDC methodology with 10 cost drivers focused on the operational costs associated with sourcing. While TDC methodologies should avoid excessive complexity by limiting the number of cost drivers, there are two aspects of TDC that are not detailed in this chapter but are worth discussing. These are cost of product complexity and cost of supply chain risk.

Addy (2020), in a study of the Nissan Smyrna plant operations, observe a negative correlation between product complexity and manufacturing quality [6]. A similar behavior likely occurs in TDC. In the context of TDC, product complexity is typically associated to part proliferation. Part proliferation is a growing phenomenon in the automotive industry and is caused by design and technological changes as the example below illustrates.

A new model of an existing vehicle is being launched. This model has a revised design and new technological features for safety and comfort. One of the parts that is revised in the new model is the side mirrors. In the previous model the side mirrors were black and had either manual or electronic angle adjustment for a total of 2 configurations. In the new model the side mirrors are offered in 8 different colors to match the car color, have standard electronic angle adjustment, and optional heating and blind spot detection system for a total of 32 configurations.

This part proliferation affects TDC in three different ways. First, a phenomenon of reverse pooling leads to less efficient inventory and storage cost as a high number of parts is required to be kept. Second, the higher number of parts requires more space in the plant and assembly line because each part requires a minimum amount of space in the plant even if its use is low. It is important to note that cost of complexity associated with part proliferation is not relevant when deciding to source from supplier A versus supplier B. However, cost of complexity impacts total vehicle TDC and therefore should be considered.

Another relevant aspect of TDC not expressively detailed in this chapter, is the impact of supply chain risk in TDC. Simchi-Levi et al. (2004), in a study of the automotive industry developed a new risk-exposure model that allows calculating the cost impact of a disruption in the supply chain without the need to estimate the probability associated with that disruption [4]. An equivalent approach can be included in a TDC methodology for sourcing. Such methodology would compare the cost of supply chain risk of multiple sourcing options and add it to TDC. In this case, the definition of risk should be expanded to include not only disruption to the supply chain but also other phenomena such as production volumes exceeding supplier capacity and double sourcing mitigation strategies.

Tool Implementation

The previous chapter presented the details of the TDC methodology developed for this project. However, the main challenge of implementing a TDC methodology in a company is not the calculation itself, but instead guaranteeing the methodology it is adopted and included in the business process. In this project, this challenge was addressed by developing a TDC tool based on the TDC methodology. This chapter presents an overview of TDC tool implementation process at Nissan. The content includes both lessons learned and future work recommendations, and the main topics covered include: a) how to design a TDC methodology and tool to deliver real business value; b) how to handle calculation uncertainty and estimation errors; and c) how to negotiate multiple implementation challenges and risks.

5.1. User Applications

The first step to design a TDC tool that delivers real business value is to understand the end user needs and the range of applications. As mentioned in Section 2.3, at Nissan, the buyers are responsible for part sourcing. Although this project is focused on new vehicle development, the range of possible part sourcing applications for buyers includes:

- Supplier selection for new vehicle parts.
- Make versus buy studies.
- Relocation studies involving onshoring and offshoring.

- Single versus dual sourcing analysis
- Cost analysis for parts with high supply chain risk

5.2. Approach and Design

The next step in the process is to define the appropriate tool design based on the user needs identified in Section 5.1. In this case, the main objective was to have a simple tool that is easily accessible across the organization. The tool interface was designed using Python® following the principles described below:

- Easy to use with focus on the buyer experience.
- Immediate results with best estimate of TDC.
- Flexible input and output manipulation

Figure 5-1 presents a picture of the TDC tool, with the interface divided in three sections that include the following:

- Initial input section: contains the basic sourcing data to be inserted by the buyer. Such as parts cost, part volume, supplier origin, plant destination, etc.…
- Preliminary output section: provides preliminary operational information to the buyer. This section was created to address the buyers' possible lack of operational knowledge. The following example illustrates how this section provides guidance to buyers and increase the tool usefulness:

  As described in Section 3.5, material handling and last mile costs depend on if a part is delivered direct or non-direct to the plant. Although this fact is common knowledge for a person in the plant, buyers often are not aware of this difference. To address this issue, using historical data the tool provides the buyer with the most likely last mile option for each part, based on the type of part and location of origin indicated in the initial input section. With this information, the buyer can adjust its calculation and obtain the most accurate TDC.

- Final output section that provides a cost summary and a waterfall chart for visualization. Buyers can adjust the cost elements included in the output to facilitate use.

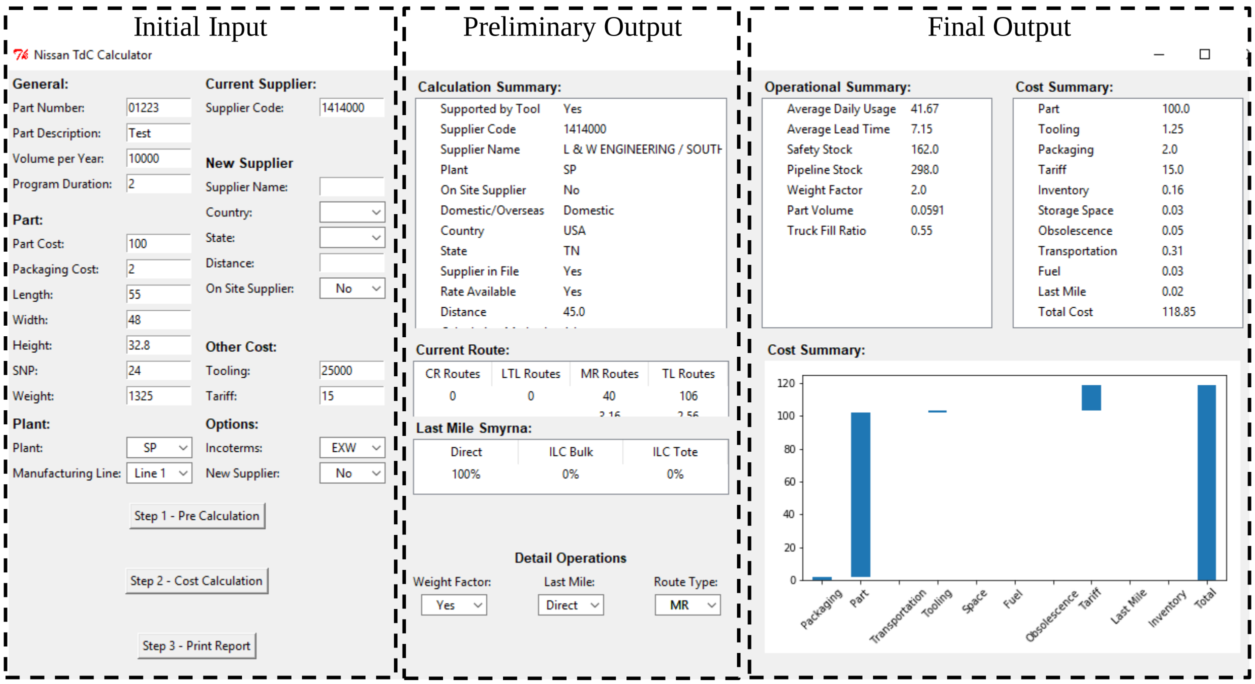

Figure 5-1: TDC Tool

In addition to methodology and user interface, the TDC tool also includes a long-term maintenance plan. This is essential to guarantee that the tool continues to be useful long after its release. The main maintenance activities include keeping the sourced data, which is used for the calculations, updated. The maintenance plan developed makes each operations team responsible for updating the data with a pre-established periodicity that ranges from once a month to once a year. Currently this process is performed semi-manually as Nissan is going through a transformation of its data storage system. However, in the long term the plan is to have the TDC tools directly linked to ERP system for automatic update.

5.3. TDC Accuracy and Value

Once the tool interface is developed, the following step is to assess its use and value to the company. One of the main challenges of implementing a TDC tool is to ensure the accuracy of the results. The higher the relative accuracy, the more value the TDC tool will bring to buyers which in turn increases confidence and adoption. However, if a TDC tool is not accurate, confidence will decrease which will eventually lead to abandonment. In this project, issues of accuracy were typically the consequence of two phenomenona which are hereafter described as information availability and calculation methodology errors.

Figure 5-2 presents a schematic of the relation between information availability, accuracy, and value of TDC methodology. At the start of the sourcing process, i.e., “Contract”, the information available is minimal as part design, part cost, manufacturing location, etc.… are all preliminary. With time, as the development work continues, available information grows, more or less linearly, until the maximum at the start of production. Accuracy increases as more information is available. This increase is initially faster as crucial data is determined such as which plant the supplier plans to use. Towards start of production, accuracy continues to increase, however, more slowly as more detail information is available. The value of the TDC tool behaves almost entirely opposite. At the start of a project, the value of a TDC tool is at its maximum. At this point most sourcing decisions are not yet confirmed and can easily be changed at minimum cost. As the main sourcing decision get confirmed, the value of the TDC tool decreases sharply because the cost associated with changing these suppliers increases. As start of production approaches the value of a TDC tool continues to decrease, however more slowly as less important source decisions are confirmed.

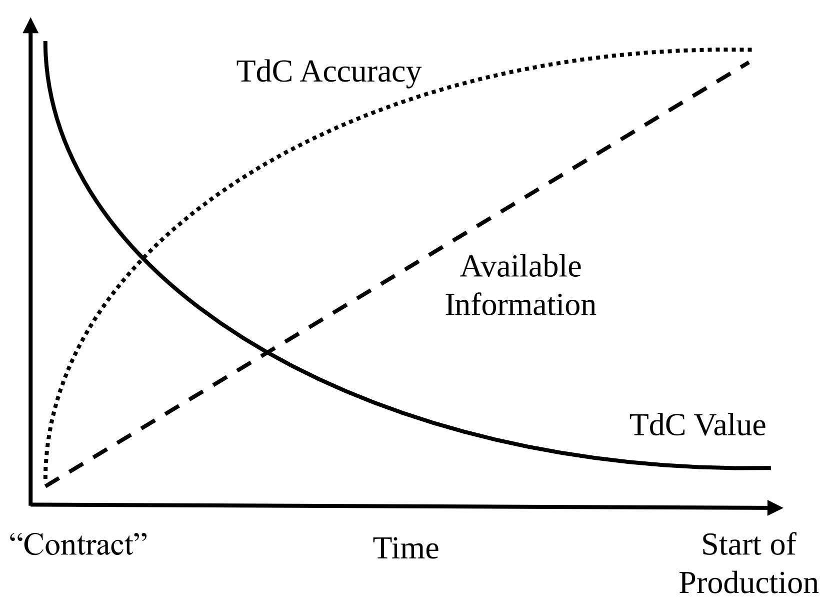

Figure 5-2: Information and TDC Value versus Time

Despite the approach or sophistication, all TDC tools will likely exhibit this type of relation between information, accuracy, and value. This behavior can prevent companies from implementing a TDC tool in their sourcing process, especially in early stages of sourcing as accuracy is likely low. However, companies should not be discouraged, and instead should understand these limitations and develop adequate processes around them [8]. Examples of these process are detailed in Section 5.5

The second source of accuracy problems is the calculation methodology. In this project, the calculation methodology was developed using a combination of operational data and data analytics tools. Because of data limitations and the application of simplifying assumptions, this methodology provides only the best estimate of TDC without a confidence interval. While the best estimate is important, it is incomplete as it fails to properly account for the uncertainty associated with TDC. This uncertainty can have a direct impact on a TDC decision as the following example explains:

> *Part A, currently sourced in country X (overseas), has a part cost of $50 and a transportation cost of $10, for a TDC of $60. The company is currently considering the option of changing sourcing to country Y (domestic), In country Y, the new part cost is $55, and the new transportation cost is estimated at $4 with a confidence interval of $3 to $6. Should the company change the sourcing location? Well, using the best estimate for transportation cost, the new TDC is $59 and the part should be relocated. However, if the higher estimate of transportation cost is used instead, the new TDC is $61 and the part should not be relocated. So, what is the right decision? And perhaps more relevant, is there a conservative decision?*

The example above serves to illustrates a problem that is particularly relevant in TDC tools applied to sourcing decisions. In many applications where uncertainty is present, its impact can be mitigated by designing a process that is based on a "conservative" choice. Unfortunately, as the example above illustrates, in sourcing there is no clear "conservative" choice as selecting the wrong supplier will result in additional cost either way. Although, there is no "conservative" decision, companies call still apply measures to reduce risk, including:

- Change sourcing only if the forecasted costs savings is below a certain threshold, typically defined as a percentage or an absolute savings value.

- In the particular case of domestic versus overseas sourcing, companies might also apply a rule to source form overseas only if the savings are above a similar threshold. This is to account for the possible hidden costs associated with overseas sourcing.

5.4. Other Challenges and Risks

There are other challenges and risks in the implementation of a TDC methodology that are not directly related with accuracy. This section presents some of them, namely the issue of incremental improvement, and the risks associated with using a cost control module methodology.

The issue of incremental improvement is described in the literature as a risk that companies take when decisions are taken in isolation. This can lead to making local incremental improving decisions might that end up detracting the company from an overall performance perspective [9][10]. This problem is illustrated in the example below:

> *A company has recently completed a TDC study for a part which compared two different suppliers, X and Y. Supplier X has a TDC of $50 and supplier Y has a TDC of $52. A simple analysis of the TDC results indicates that the company should source from supplier X. However, supplier X is located in a country where the company expects to source less in the future and supplier Y in a country where the opposite is expected to happen. Should the company source from X or Y? The answer will depend on the weight given to short-term gains versus long-term objectives.*

To prevent incremental improvement from negatively impacting a company's overall performance, companies that implement TDC methodologies should define an end state vision or strategy for sourcing. This vision will define priorities and ultimately guide the application of TDC methodologies.

The second challenge presented in this section is related with the use of Cost Control Modules (CCMs) that is first described in Section 2.2. CCMs are used in the development of a new vehicle to represent a "typical" configuration. For each vehicle, a small number of CCMs is selected, typically between 1 and 5, and studied in detail. While the use of CCMs has the clear advantage of reducing the work, it limits the depth of a TDC analysis. This phenomenon is particular important in case of significant TDC variation across configurations.

Figure 5-3 presents the aggregate TDC distribution for a vehicle program which has in total more than 70 configurations. The results include the cheapest configuration, and 5 other aggregated configurations, together with their production volume. The results clearly show that TDC varies greatly across configurations. As expected, the premium trim level configuration (Trim 5), has the highest TDC and the lowest production volume. On the other end, the lowest trim level, (Trim 1) has the lowest TDC and the highest production volume. This variation of TDC is important and should be considered when defining the minimum number of CCMs in each vehicle program together with sales forecast. Not doing so can hide significant TDC risks, especially in optional parts that are not included in the CCM or belong to small volume configurations.

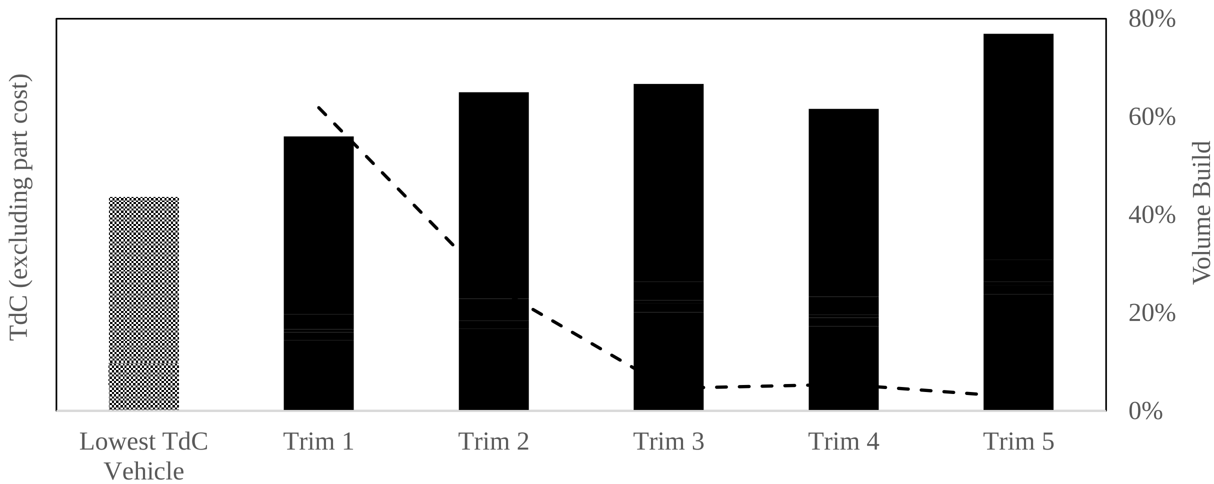

Figure 5-3: TDC for Multiple Trim Levels

5.5. Practical Considerations

The previous sections discussed the main challenges and risks associated with the implementation of TDC methodologies. This section presents practical considerations to mitigate some of those risks and overcome the challenges. The objective is to increase the value and adoption of TDC tools in business applications.

The first point discussed is how to manage the launch of a new TDC tool. When launching a new tool, it is important to properly manage expectations, especially when it comes to accuracy. Not doing so can lead to tool discredit and ultimately abandonment. As mentioned in Section 5.3 accuracy issues can be caused by data or methodology problems and these are likely to be bigger during the initial launch phase. Therefore, it is important to establish a proper adoption plan.

One of the most effective ways to handle issues of accuracy is to implement a gradual process of adoption. Before general release to buyers, the TDC should be launched temporarily to a test team that understands its limitations. In the case of Nissan this team is the Systems and Strategy group within sourcing which is responsible for assessing the total impact of sourcing decisions in new vehicles. Once enough confidence is built, the TDC tool can be gradually extended to buyers. This gradual adoption plan will ensure confidence in the tool's accuracy is not affected.

One other option to guarantee value and adoption while handling accuracy issues is to implement the TDC tool as a first filter in the normal sourcing process. One of the main advantages of the TDC methodology described in Chapter 4 is the ability to easily calculate TDC for a large number of parts with limited information. With this filter approach, the TDC tool is used as a first step to distinguish between "easy" and "too close to call" decisions. In this way, TDC tool can significantly reduce the amount of work associated with developing a new vehicle and create value to a company even if accuracy is not perfect. In this case accuracy refers to relative accuracy between two sourcing decisions. The following hypothetical example illustrates the value of applying a TDC methodology as a filter in the sourcing process:

> *A new vehicle program requires sourcing of approximately 2,000 different parts. Out of these, 400 parts are identified as COCA parts, i.e., parts that are currently used in another vehicle or model and are carried over or carried across. This leaves 1,600 new parts to source. Due to the high volume and limited resources in sourcing, the TDC tool is applied at this stage. Because relative accuracy is still a concern at this point a high threshold between "easy" and "too close to call" is defined. The results show that out of 1,600 parts, approximately 1,200 parts (75%) are "easy", i.e., the TDC results shows a significant difference between the cheapest sourcing option and all the rest. The remaining 400 parts*

(25%) are considered "too close to call" and a detailed study is performed with prioritization based on total cost impact.

The approach described above provides a way to implement a TDC methodology that brings value to a company even if relative accuracy is relatively low. As accuracy increases, the threshold is reduced which improves the tool use and value.

As mentioned above, after the initial release, the investment in improving the TDC tool should continue to increase its accuracy and functionality. To improve accuracy, it is recommended to implement a TDC monitoring system that compares actuals to forecasts. Actuals from operations should be measured and compared with the previous forecast used during the new vehicle development phase. Any discrepancy should be investigated and if required corrected through a change in the TDC methodology. This continuous improvement approach will guarantee the long-term value of the TDC tool.

5.6. Performance Incentives

Performance incentives are an efficient way to align individual, team and company goals. However, if not well designed, performance incentives can have a very negative impact on company results. This topic, which has been widely researched, also impact the application of TDC methodologies. Morita (2007) in a study of the impact of management incentives in sourcing decisions identified an issue when managers are requested to make decisions considering forward looking models that consider hidden costs but are evaluated based on backward looking models that ignore those same costs [5]. Quayle (1998) in a study of the drivers for sourcing decisions that involved 200 different industrial organizations identified eight statistically significant context variables that inadvertently affect sourcing decisions, including management incentives. [3].

The issue of performance incentives also impacts the TDC methodology developed in this project. Traditionally at Nissan, incentives are designed with at least a partial focus on individual and team performance. Using the example of the sourcing team, buyers' incentives are typically tied to the ability of the buyer to source a part at the lowest cost. However, this cost typically includes part, packaging, tooling, and tariffs only. For a TDC methodology to produce effective and positive change in a company, the system of performance incentives needs to be aligned with

TDC. In this case, the buyers need to be incentivized using TDC and not part cost only. This will in turn increase the adoption of TDC methodology generating a positive loop with overall cost savings to the company.

Conclusion

Sourcing strategies and processes are a significant source of competitive advantage in the automotive industry. The objective of this project was to develop a new TDC methodology to improve part sourcing at Nissan. The methodology was developed using operational data from the Nissan Smyrna plant and later integrated in a TDC tool for ease of use. The methodology includes 10 different cost drivers that aim to capture the main direct and indirect costs associated with sourcing, including part, tooling, packaging, transportation, last mile, storage, inventory, obsolescence, quality, and tariffs.

Once the development of the calculation methodology was complete, the TDC tool was used in a preliminary analysis. The results show that for the majority of automotive parts, part cost is the main driver of TDC, with 90% of the parts having a non-part cost lower than 15% of TDC. However, non-part costs can have a significant compounding effect on TDC. This behavior was illustrated by comparing the TDC for two identical parts, one sourced domestically and one overseas. The overseas parts not only had a higher transportation cost, but also higher storage, inventory, obsolescence and possibly pipeline quality cost, as these metrics are interrelated. Therefore, while part cost is dominant in TDC, this compounding effect should be recognized by anyone responsible for sourcing decisions.

Additionally, a review of typical implementation challenges associated with TDC methodologies was performed with the objective of identifying strategies that increase business impact. Two strategies were highlighted and investigated. The first includes adopting a gradual implementation plan to mitigate the negative impact of initial low TDC accuracy. The second discussed deploying TDC methodologies as a filter in the sourcing process to reduce workload and allow for better resource allocation.

This TDC project was the first of its kind within the Nissan Smyrna plant. The focus was to create a TDC methodology and tool that was simple and easy to use, while at the same time capable of providing immediate and accurate results with limited information. Ultimately, this project is expected to deliver both immediate results through direct cost savings and long-term benefits through sourcing process improvement, particularly in making better decisions about resource allocation.

6.1. Future Work

There is significant opportunity for future work in the application of TDC methodologies in the automotive industry. The three main areas of development include improving calculation accuracy, increasing calculation scope, and expanding tool application.

To improve accuracy, it is recommended to implement a TDC monitoring system that tracks actual TDC spending during normal operations. Once actual TDC data is available it can be used to compare with previous forecasts which is an enabler for continuous improvement initiatives.

The TDC methodology presented in this document includes 10 different cost elements that focus on the operational costs associated with sourcing. While it is important to avoid excessive TDC complexity by limiting the number of cost elements, it is recommended to consider adding cost of complexity and cost of supply chain risk to the current methodology.

In most cases, the most complex aspect of implementing a TDC tool in a business environment is not to develop the calculation methodology itself, but to succeed in making the tool a part of the normal sourcing process. An effective way to guarantee this outcome, is to continuously interact with the tool users to understand their changing needs. These are the needs that drive business value and guarantee long term value of TDC methodologies.

It is important to note that at the moment of this project, tariffs and a global pandemic were a major source of risk and uncertainty in manufacturing and supply chain. In the future, it is expected that automotive companies will continue to increase their focus on supply chain risk and resilience. The incorporation of these factors in TDC tools can be significant opportunity for future value and opportunity.

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