Modeling System Efficiency in Mixed-Model Assembly Lines

by

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Abstract

This thesis details the development of a system efficiency model at the Nissan Smyrna Vehicle Assembly Plant. System efficiency at Nissan is one measure of performance used to allocate new business to plants, and in pursuit of this new business, leaders at the Smyrna Plant maintain a continuous improvement culture where teams are regularly engaged in plant production improvement efforts.

Production improvements at the Smyrna Plant typically focus on fault reduction and line balancing. These efforts leverage either vehicle or process data, but none incorporate both, as no combined data system exists. One can overcome this disconnect by generating an integrated model that links the production sequence with assembly jobs using vehicle model and feature relationships. What results is a repository of work content on produced vehicles containing real and ideal production times, which can be used to measure system efficiency. Creation of such a system greatly enhances existing capabilities to identify bottlenecks in the plant, to improve system health, and to optimize the production sequence.

The completed research demonstrates the modeling capability to integrate product and process data and the use cases of such an integration in enhancing production improvements. The research also demonstrates how internal innovation can happen through the novel use of existing resources to unlock new capabilities. The recommendations focus on implementing the integrated system into stakeholder workflows, creating new data architectures to simplify data management and model development, and re-thinking plant performance models to incorporate current production data.

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List of Acronyms

AGV Automated Guided Vehicle. 25

CCM Cost Control Model. 11, 19, 30, 60, 71, 74

CFT Cross-Functional Team. 18, 19, 31, 69, 70

CPU Cost per Unit. 18, 31

DST Design Standard Time. 11, 12, 18, 38–40, 46–50, 52, 54–56, 60–64

DSTR Design Standard Time Ratio. 18, 31, 38–40, 56, 63

EIM End Item Model. 29, 40–42, 44, 46, 47

IE Industrial Engineering. 19, 30, 37, 60, 69, 70

KPI Key Performance Indicator. 18–20, 31, 38, 45, 68, 71, 73, 74

LGO MIT Leaders for Global Operations Program. 33

MHU Man Hours per Unit. 18, 31

NNA Nissan North America. 18, 19, 23, 26, 32

NRS Nissan Re-Balancing System. 37, 38, 40, 44, 46, 48–50, 53, 54

PBS Painted Body Storage. 27

PE Production Engineering. 19

PIG Product Information Guide. 42, 46, 53–55, 74

PQA Product Quality Assurance. 25, 28

SCM Supply Chain Management. 40, 46–49, 51, 53

SUV Sports Utility Vehicle. 18, 24

VIN Vehicle Identification Number. 29, 40, 41, 44, 46, 47

Chapter 1

Introduction

This thesis explores the methods used to model system efficiency in a mixed-model automotive assembly system and the use cases for such a model. The implications of this for the company include new or improved abilities to optimize assembly processes, to balance the assembly sequence, and to maximize system profits. This chapter describes the company, primarily in the context of the United States, as well as the motivations, problems, and objectives for the study.

1.1 Company Overview

Nissan Motor Co. Ltd. is an automobile manufacturer that was founded in Japan in 1933 [10]. Though still headquartered in Japan, Nissan grew its global presence in the ensuing decades through expansions into foreign markets and through partnerships, particularly major alliances with Mitsubishi and Renault [11]. Examining Nissan today, the company manufactures vehicles at assembly plants all across the globe, including in the United States and Mexico. In the United States, production occurs at three plants located in Canton, Mississippi and in Smyrna and Decherd, Tennessee [9]. This study focuses on the Nissan Smyrna Vehicle Assembly Plant.

1.2 Project Motivation

Decisions by Nissan to produce vehicles at any of its many plants are driven heavily by regional demand and by plant performance on Key Performance Indicators (KPIs), among other factors. Looking closely at how regional demand might drive production decisions using hypothetical examples, demand for mid-size Sports Utility Vehicles (SUVs) or trucks in the Americas may warrant production of these vehicles at Nissan North America (NNA) plants in order to minimize logistics costs. Similarly, South-Asian demand for electric vehicles may warrant production of new electric vehicles in the Nissan portfolio (e.g. the Nissan Ariya) at Japanese plants.

Historical plant performance on production metrics also has a considerable impact on strategic production decisions. Three of the many KPIs impacting these decisions (some which will be discussed in the ensuing sections) include: Design Standard Time Ratio (DSTR), the ratio of actual production time to Design Standard Time (DST); Cost per Unit (CPU), the average cost per unit produced; and Man Hours per Unit (MHU), the average labor hours per unit produced. These three KPIs, though not exhaustive, help characterize plant efficiency and thus are heavily considered when determining where to produce future vehicles.

Because KPI performance is critical to future production decisions at Nissan plants, each plant and region are continually identifying ways to improve on these metrics. At the Smyrna Plant, this has resulted in a continuous improvement culture, with regular implementation of targeted improvement initiatives. These include daily efforts, such as routine quality control meetings, as well as long-term efforts, such as the deployment of Cross-Functional Teams (CFTs), teams leveraging data analytics to investigate and improve problematic production areas. The motivation for this study is in that same continuous-improvement mindset with the principal intentions of generating insights about system efficiency and use cases from those insights in order to improve the system and create future business for the Smyrna plant.

1.3 Problem Statement

Teams at the Nissan Smyrna Vehicle Assembly Plant are regularly engaged in production system improvement efforts, whether through their own organizations or through diverse CFTs. For manufacturing personnel and CFTs, these efforts are focused on production health – investigations and interventions typically occur on fault metrics such as vehicle or part defects, system downtime, and line-stop pull cords. The ultimate goal of these investigations and interventions is to reduce said metrics and improve system health in pursuit of improved KPIs.

For improvements originating in NNA engineering organizations, such as Industrial Engineering (IE) or Production Engineering (PE), production system improvement efforts are focused on the jobs and areas that make up the production system – investigations and interventions typically occur via line-balancing or process redesign. The ultimate goal of these investigations and interventions is to reduce and/or balance assembly time in pursuit of improved KPIs.

Though the described production health and line-balancing improvement efforts do result in improvements to plant KPIs, the efforts (and KPIs themselves) lack sufficient vehicle granularity to appropriately design said improvements to maximize impact. Specifically, production health improvements by manufacturing personnel and CFTs typically examine the specific issues on the line and their associated trends, but these do not account for root cause as a function of the actual vehicles produced or the sequence of those vehicles. In other words, though a varying, mixed-model sequence may drive increased defects – a unique root cause potentially warranting a unique process improvement – this interaction mechanism is not currently considered.

Likewise, line-balancing efforts by IEs and PEs are typically performed using a Cost Control Model (CCM), an average vehicle produced over the life of a vehicle program. This does not account for actual vehicles produced or the sequence of those vehicles either, as in any given hour, shift, day, week, or month, production counts may actually average to a higher or lower-end vehicle, in lieu of a true CCM. This real-time variation in production may warrant alternate line balancing or process design, but this production reality is not currently considered.

The primary reason for omission of production count and sequence from the aforementioned process improvement methodologies is that no model exists to relate vehicle-specific production information with area-specific production information. This prevents Smyrna from understanding the underlying interactions between the actual vehicles produced in a specified time period and the area work content interactions associated with those vehicles. Understanding this work content and vehicle model-mix interaction can help drive more targeted, impactful process improvement, and it can help with better understanding how overall system efficiency changes as a function of model-mix. The formulation of a model informing this relationship between work content and vehicle model mix as drivers of system efficiency is the primary objective of this investigation.

1.4 Project Objectives

Data systems and models at the Nissan Smyrna Vehicle Assembly Plant currently lack the granularity necessary to capture the subtleties of vehicle model-mix interactions in different production sequences and production areas. In order to understand the impact of this model-mix relationship and drive better production improvement efforts, it is imperative to rethink existing plant data structures and the models that leverage that data. This culminates in two project objectives.

The first objective of this study is to develop a model that characterizes system efficiency as a function of the real-time production model mix and the area work content associated with that model mix. This requires investigation into data structures and linking of data in ways that are novel for the Smyrna Plant.

The second objective of this study is to develop use cases for the noted system efficiency model. This requires investigation into existing production improvement methods and KPIs and identification of novel ways these could be updated to reflect new understandings of vehicle model-mix work content interactions.

1.5 Thesis Organization

This thesis is organized into nine chapters that mirror the sequence of the underlying investigation. Chapter 2 details the background information related to the study, including information about the current production and layout of the Nissan Smyrna Vehicle Assembly Plant. Chapter 3 entails a literature review, detailing historical theses at Nissan and other material in the literature relevant to this study. Chapter 4 presents a thorough overview of the data sources used throughout this study, and Chapter 5 characterizes initial observations from said data. Chapter 6 documents the full model formulation process broken down into different model formulation phases with the associated phase learnings. Chapter 7 documents proposed model use cases and the implications for the company, and Chapter 8 details the recommendations for the company and generalized recommendations resulting from the developed models and use cases. Chapter 9 then concludes the thesis with final learnings and conclusions.

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Chapter 2

Background

This chapter provides the background information that is relevant to understanding this study and its place in the Nissan manufacturing ecosystem. The chapter covers several topics that are broken out by subsection, including information about the Nissan Smyrna Vehicle Assembly Plant, information about manufacturing at Nissan, and information about the plant area of focus for this study.

2.1 Nissan Smyrna Vehicle Assembly Plant

The Nissan Smyrna Vehicle Assembly plant is located in Smyrna, Tennessee and was the first Nissan manufacturing location in the United States. The first vehicle produced at the plant, a white pickup truck, rolled off the line in 1983, and as of 2021, the company has invested over $7 billion dollars in the plant [8]. Celebrating 40 years of production in 2023, NNA has produced several vehicle types at the plant under both the main Nissan brand and the luxury Infiniti brand [7]. The plant also plays an important role in the local community, employing more than 7,000 people and directly uplifting that community through frequent volunteering campaigns and site-wide charitable donations.

2.2 Vehicle Models Produced at the Plant

Throughout the first 40 years of production at the Smyrna Plant, Nissan produced various sedans, trucks, and SUVs under the Nissan and Infiniti brands. During this study, the models produced included the Nissan Leaf (Figure 2-1), Nissan Murano (Figure 2-2), Nissan Pathfinder (Figure 2-3), Nissan Rogue (Figure 2-4), and Infiniti QX-60 (Figure 2-5). The Nissan Maxima was also produced at the Smyrna plant during a portion of this study, but it ended production in Tennessee in mid-2023 [7].

Figure 2-1: A 2024 Nissan Leaf [3]

Figure 2-2: A 2024 Nissan Murano [4]

Figure 2-3: A 2024 Nissan Pathfinder [5]

Figure 2-4: A 2024 Nissan Rogue [6]

Figure 2-5: A 2024 Infiniti QX60 [16]

2.3 Plant Layout

Vehicle production at the Smyrna Plant is accomplished via five sequential stages. In order of production sequence, these include Stamping, Body Shop, Paint, Trim and Chassis, and Product Quality Assurance (PQA)/Pre-Delivery, as shown in Figure 2-6. Some of these stages consist of batched manufacturing processes with parts produced or assembled in coordinated groupings, and some consist of continuous assembly line production with vehicles produced or assembled in a pre-determined assembly sequence. Each of the major production areas are supported by sophisticated kitting and picking systems, by inbound and outbound transportation and logistics, and by a mixed internal network of forklifts and Automated Guided Vehicles (AGVs).

Figure 2-6: High-Level Plant Layout At The Nissan Smyrna Vehicle Assembly Plant

2.3.1 Stamping

In Stamping, individual part production begins as technicians load the stamping dies for a desired set of parts into one of many stamping presses. Raw sheet metal is then loaded into said stamping presses, and the dies are pressed together, forming the raw material into the corresponding part shape. Parts from each production run are then collated and taken either to a designated warehouse location, to outbound logistics, or to body shop for vehicle assembly. Production in the stamping shop is accomplished via a batched manufacturing process, given the timely nature of loading and unloading dies, and, because some of the described stamping technology is exclusive to the Smyrna Plant, the stamping shop often produces and ships parts for vehicles that are assembled in other NNA plants.

2.3.2 Body Shop

In Body Shop, a combination of parts produced in stamping and supplier parts are loaded into a series of sequential welding cells. In these cells, robots electrically weld parts together to create the substructure and outer enclosure of the vehicle. Sub-assemblies from upstream Body Shop processes are then fed into the ensuing cells to create increasingly complex assemblies. This culminates in the final line of Body Shop where the vehicle takes shape and where quality inspectors inspect welds and part surfaces for defects. These defects are then fixed either on or off line before transfer of the vehicle bodies to paint. Unlike in Stamping where production is batched, production in Body Shop and onward is completed in a planned, continuous sequence.

2.3.3 Paint

In Paint, finished vehicle bodies flow continuously through anti-corrosive baths and are then sealed; these measures are intended to prevent rust and moisture ingression during vehicle use. The vehicle bodies are then painted in a three-step process, including a base paint coat, a primary paint color, and a gloss finish. After bodies are painted, they are either loaded directly into Trim and Chassis or they enter a holding area called Painted Body Storage (PBS) where they are held until being loaded into Trim and Chassis. In addition to painting completed vehicle bodies, Paint also handles surface finishes for select exterior parts such as the front and rear fascia.

2.3.4 Trim and Chassis

In Trim and Chassis, painted vehicle bodies are loaded onto a moving line where technicians install parts through a series of sequenced assembly jobs. Trim and Chassis itself is comprised of several areas, including trim shops, chassis shops, final lines, and supporting sub-assembly, kitting, and picking areas. Within each area, production is divided into sub-areas, sub-areas are divided into zones, and zones are divided into pitches, as shown in Figure 2-7. These pitches are assigned jobs, which are comprised of several assembly steps. Each pitch is allocated a standard amount of space on the line and a standard amount of time for process completion, values that are pre-determined based on the size of the production area and rate of the line, respectively. Work completed in Trim and Chassis is a combination of manual and machine-assisted assembly, and the end result of the area is fully assembled vehicles rolling off the line.

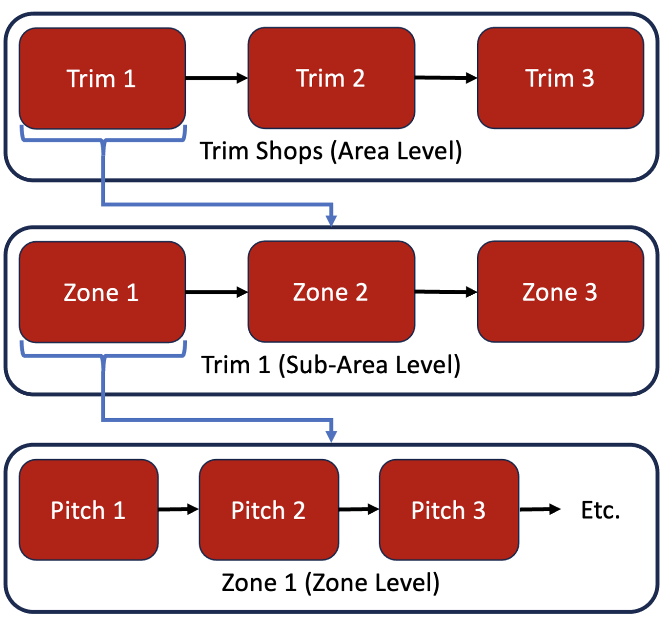

Figure 2-7: Breakout Of Trim And Chassis By Areas, Zones, And Pitches

2.3.5 Product Quality Assurance/Pre-Delivery

In PQA/Pre-Delivery, fully assembled vehicles exit the final lines of Trim and Chassis to begin functional tests and quality inspections. Functional tests in this area include brake tests, wheel alignment, and equipment checks, and inspections cover both the vehicle interior and exterior. The area also contains overflow space where any end-of-line assembly and rework can be completed. Once the required tests and inspections are complete, vehicles exit the plant for storage and coordination of finished-vehicle logistics.

2.4 Plant Assembly Systems

After completion of the stamping stage, the remaining steps of vehicle production at the Smyrna Plant happen in one of two parallel assembly systems (also known as assembly lines). These systems are independent and are differentiated by the models produced in each system and by the equipment and processes used to build those models. In addition to these manufacturing differences, the two systems run at different production rates and have different production model-mix ratios. Throughout the duration of this study, System 1 produced the Nissan Murano, Nissan Pathfinder, and Infinity QX-60, and System 2 produced the Nissan Leaf and Nissan Rogue. System 2 also produced the Nissan Maxima prior to its end of production in mid-2023.

2.5 Production Sequence

The sequence of vehicle production that begins in Body Shop and runs through Trim and Chassis is planned by a dedicated scheduling team using in-house optimization algorithms with inputs based on sales data and manufacturing constraints. Sales data is incorporated into this analysis using known historical sales and future sales forecasts that are communicated from Sales and Finance. This data informs the monthly demand, which is used to generate daily production counts that can adequately fulfill regional dealer quotas. Manufacturing constraints are incorporated into this scheduling process through the deployment of heijunka.

Heijunka is a methodology leveraged heavily within the Toyota Production System and involves level loading production across all business units and suppliers to smooth the value stream and minimize production disruptions [13]. For Nissan, execution of this technique from a scheduling optimization standpoint involves incorporating calculated manufacturing constraints and manufacturing constraints rooted in tribal knowledge that are both communicated from the manufacturing organizations and manufacturing leadership. Hypothetical examples of these types of constraints that could be built into this scheduling technique include:

- Only a fixed number of units containing a sunroof can be manufactured consecutively before a unit without a sunroof is required in the sequence.
- Only a fixed number of all-wheel-drive units can be manufactured consecutively before a front-wheel-drive unit is required in the sequence.
- Only a fixed number of high-end units can be manufactured consecutively before a low-end unit is required in the sequence.

2.6 Vehicle Model Codes

Among the five vehicle models assembled at the Smyrna Plant, there are countless variations that could be produced when taking into consideration the vast array of possible trim packages, options, and colors. Nissan selects subsets from these that will actually be produced at each factory, and these configurations are organized internally using a series of model codes. At an individual level, each vehicle is assigned a Vehicle Identification Number (VIN), which is communicated to the customer and used historically to identify that specific vehicle. Within the Nissan value stream, vehicles are also identified using 18, 21, and 25-digit End Item Model (EIM) numbers. These distinguish each vehicle in the production system by features such as model, model year, engine, drive train, trim package, options, interior and exterior color, and delivery destination. EIMs will be discussed extensively in later chapters.

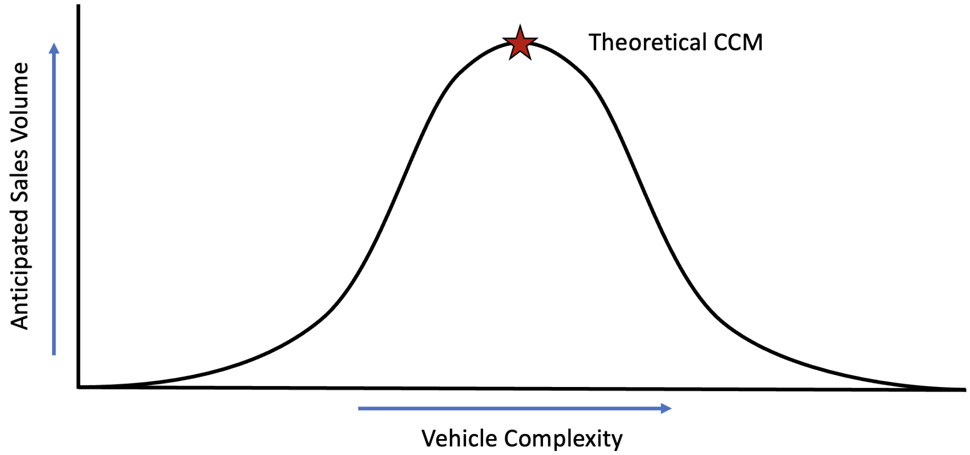

Figure 2-8: An Example Depiction Of A CCM In Terms Of Volume And Complexity

2.7 Cost Control Models

For each vehicle model produced at any Nissan plant, there exists a range of model complexities. At the lowest end, vehicles are the least complex and are of the lowest trim grade with no options included, and at the highest end, vehicles are the most complex and are of the highest trim grade with all options included. Somewhere between these complexities exists a CCM. A CCM is defined as a specific model within a vehicle program that is typically anticipated to be of average complexity and to have the highest projected sales volumes. CCMs are used extensively throughout Nissan to plan a program's value stream; example usage scenarios include influencing a program's make-buy decisions and supply chain structure in the supply chain organizations, as well as influencing a program's manufacturing process design in the IE organizations, as noted previously. Figure 2-8 shows an example depiction of a CCM in terms of anticipated sales volume and product complexity. It is relevant to note that Nissan CCMs do not necessarily fall at the peak of a bell curve and that volume itself does not necessarily resemble a bell curve. Figure 2-8 is simply intended to help illustrate the general definition of a CCM to help contextualize CCM use cases.

2.8 Key Performance Indicators

Several KPIs are used to measure performance of the Smyrna Plant. A few of these were noted in the Introduction: DSTR, CPU, and MHU. Other metrics that are used to evaluate factory health and efficiency include measurements such as: how closely the plant matches the planned production sequence; how many vehicles roll off the line fully assembled and defect-free; and total downtime, defects, and pull cords in designated production time frames. Each of these KPIs are impacted by both the production sequence and by production improvement efforts and play a critical role in determining which Nissan plants are selected for future vehicle manufacturing.

2.9 Production Improvement Efforts

Teams at the Smyrna Plant are regularly engaged in cross-functional production improvement efforts as part of a leadership-driven continuous-improvement culture. These efforts take many forms but most frequently involve working to improve factory health or to balance assembly processes. Factory health improvement efforts are usually driven by the manufacturing organizations or by CFTs and leverage improvement frameworks such as DMAIC [15] or root-cause corrective action. These are generally intended to help reduce assembly system downtime, chronic defects, or chronic pull cords, and they involve cyclical interventions, production trials, and data reviews. Line balances are usually driven by the engineering organizations and involve improving jobs or relocating jobs in order reduce and level load process time across pitches, zones, and areas. Recommendations for how to improve on these efforts using the models developed in this study will be discussed in later chapters.

2.10 Plant Focus Area

The primary focus area for this study is Trim and Chassis in System 1 of the Smyrna Plant. Trim and Chassis was selected because it is the area with the highest process variability between assembly systems and because it is a key contributor to overall plant performance. Other shops, such as Body Shop and Paint, have more consistent processes across systems, regardless of the vehicles being produced. System 1 was selected as the primary focus area because it consists of pure mixed-model assembly with continually changing production ratios between the Nissan Murano, Nissan Pathfinder, and Infiniti QX-60. System 2, though also a mixed-model line, is dominated by production of the Nissan Rogue, as production rates of the Nissan Leaf are comparably low. Though the model formulation in this study is focused on Trim and Chassis for System 1, the methodologies and use cases are intended to be applicable to all production shops and NNA plants.

Chapter 3

Literature Review

This chapter briefly presents research in the literature that is relevant to the methods, use cases, and underlying Nissan processes that are presented in this study. The primary focus of this literature review is on past theses completed at Nissan by former students of the MIT Leaders for Global Operations Program (LGO). Other research areas also covered in this literature review include: process flow analysis, capacity utilization, and mixed-model production schedule optimization.

3.1 Process Flow Analysis and Capacity Utilization

Process performance in any process or production flow can be measured by throughput time and cycle time. Throughput time is the time it takes to go from the start of the process to the end of the process, and cycle time is the time between successive departures from the process [17]. Cycle time is an important input to understanding capacity and capacity utilization, which can be used to identify bottlenecks and improvement areas in the system. Capacity itself is a representation of resources in a process. Capacity required represents the amount of resources needed to perform a process, and capacity available represents the the resources actually available to perform that process. From this, it follows that capacity utilization represents the ratio between capacity required and capacity available, as noted in Equation 3.1.

$$\text{Capacity Utilization} = \frac{\text{Capacity Required}}{\text{Capacity Available}} \tag{3.1}$$

Capacity utilization can be thought of in terms of either time in a shift or units produced (jobs performed). These are noted in Equations 3.2 and 3.3.

$$\text{Capacity Utilization} = \frac{\text{Number of Jobs} * \text{Cycle Time}}{\text{Time Available}} \tag{3.2}$$

$$\text{Capacity Utilization} = \frac{\text{Number of Jobs}}{\frac{\text{Time Available}}{\text{Cycle Time}}} \tag{3.3}$$

When analyzing a serial line system like Trim and Chassis, the stage, step, or job with the highest capacity utilization is a bottleneck in the system; bottlenecks will be discussed more in the next section. There exist many ways to lower capacity utilization, including: increasing resources in the system, such as time or production resources; working faster in the same amount of time; or shifting the demand on the process. These strategies represent opportunities for intervention in a system once a bottleneck or area of high capacity utilization has been identified.

3.2 Bottlenecks

In a manufacturing system like the Nissan Smyrna Vehicle Assembly Plant, bottlenecks are the rate limiters of the system [17]. In a more generalized sense, bottlenecks are resources in the system that have less capacity than the demand placed upon them, and non-bottlenecks are resources that have more capacity than the demand placed upon them [2]. Lux K. found that one could identify bottlenecks at the Nissan Canton Vehicle Assembly Plant by examining the consistency of process assembly times and, more specifically, by identifying the longest, most consistent, repeatable process in the system [12]. Once identified, these serve as optimal intervention points to improve the overall capacity and efficiency of the system.

3.3 Transition Complexity

In a mixed-model assembly system, transition complexity represents the complexity associated with transitioning from assembly of one complex product to another. At the Nissan Smyrna Vehicle Assembly Plant, Addy R. theorized that transition complexity is influenced by a number of factors including technician familiarity with products and processes, differences in parts on assemblies produced, and differences in assembly processes [1]. Addy then demonstrated that transition complexity is a byproduct of the production sequence and that high transition complexity in a system likely results in an increased defect rate. From this, it follows that when areas of high transition complexity can be identified, these represent high-impact intervention points to reduce defects and improve overall quality in the system.

3.4 Mixed-Model Production Schedule Optimization

Numerous studies exist in the literature pertaining to mixed-model production schedule optimization. Given that the demand placed on a system via the production schedule can result in process bottlenecks and defect spikes, arrangement of the sequence is of great importance to the health of a system. Guo G. and Ryan S. proposed using risk-averse stochastic mixed-integer programming to plan mixed-model sequences with model formulations including elements such as job sets, part sets, job allocations to stations, and job completion times [14]. As noted in the previous chapter, Nissan deploys its own optimization algorithm to plan the production sequence, but this is rooted in the deployment of heijunka using constraints communicated from manufacturing. If one were instead able to identify all of the elements making up the system and use these as the basis of a sequence planned via mixed-integer programming, this may help prevent sequence-driven disruptions to the system.

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Chapter 4

Data Sources

This chapter outlines the different data sources that were investigated and used throughout this study. These include data pertaining to the Smyrna Plant, such as area information, production rates, and production sequences, as well as data pertaining to manufactured vehicles, such as finances, parts, and configurations. These data sources are all exportable and exist in many forms, such as Microsoft Excel sheets, Snowflake data tables, and internally-developed Nissan web tools.

4.1 Nissan Re-Balancing System

The Nissan Re-Balancing System (NRS) was one integral source of data throughout this study, providing the necessary work content information for System 1 of Trim and Chassis at the Smyrna Plant. NRS itself is an internally-developed, web-based tool at Nissan that is actively maintained by IE and regularly used by manufacturing. NRS contains process-level information for the assembly line and is primarily used to study and balance processes in different areas of the plant. The system allows for simple extraction of data frames containing this information - two of these that were used extensively throughout this study were analysis sheets and process sheets. These contain a combination of assembly area information and assembly time data and, when combined, characterize all possible work content on the line.

4.1.1 Assembly Area Data

Data governing the configuration of the line was extracted from NRS as elements of analysis sheets and process sheets. For Trim and Chassis, the extracted data consists of the zones, pitches, and jobs used to install parts to vehicles or to operate on said vehicles. In this work hierarchy, the Trim and Chassis area is broken out into zones, zones contain a fixed number of pitches, pitches are assigned jobs, and jobs are broken out into work steps. These steps are assigned based on installation sequence requirements and as a part of ongoing line-balancing efforts. All told, this data characterizes where work content occurs on the line for each vehicle model.

4.1.2 Assembly Time Data

Time elements for the line come in multiple unique forms and were also extracted from NRS as part of analysis sheets and process sheets. The two time elements used in this study were Design Standard Time (DST) and time in pitch. DST is the theoretical minimum required assembly time to complete a particular process, and time in pitch is the time it actually takes to complete that process within the process pitch. Total actual production time encompasses the sum of time in pitch for each vehicle as well as the time to move between pitches and between areas, which are known based on the rate of the line. DST is estimated for each assembly process at the inception of a particular vehicle program, and in sum, the total DST represents how long it should take to build a particular vehicle in a best-case scenario. The KPI DSTR compares this total DST with real production time to reflect the build efficiency per vehicle produced, as shown in Equation 4.1.

$$\text{Design Standard Time Ratio} = \frac{\text{Actual Time}}{\text{Design Standard Time}} \tag{4.1}$$

Examining DST and time in pitch more closely as extracted from NRS, both are comprised of more granular time elements associated with the tasks in each job. In total, these time elements consist of a combination of value-added and non-value-added work. Value-added work is allocated a designated amount of DST, and non-value-added work is allocated zero DST. This aligns with the definition of DST in that DST itself should only consist of value-added work contributing to a theoretical minimum assembly time. Both types of work, however, contribute to the real process time for assembly on the line. In other words, the non-value-added work results in more assembly time but not in allotted DST, thereby worsening the vehicle DSTR, or assembly efficiency.

An example part installation is shown in Figure 4-1 to demonstrate this underlying nature of time in pitch and DST for the steps in a job. In this job, a theoretical wire bundle is to be attached to an installation bracket, and this assembly is to be

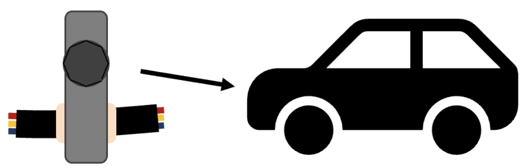

Figure 4-1: An Example Wire Bundle Installation Job On A Theoretical Vehicle Model

Step	**Description**	**Value-Added Time**	**Non-Value-Added Time**	**Total Time**	**DST**
1	Walk to picking location	0.0	3.0	3.0	0.0
2	Pick wire, wire clip, and fastener	0.0	1.0	1.0	0.0
3	Walk to vehicle	0.0	3.0	3.0	0.0
4	Attach clip to wire	1.0	0.0	1.0	1.0
5	Locate clip and wire to vehicle	2.0	0.0	2.0	2.0
6	Install clip and wire using fastener	4.0	0.0	4.0	3.0
7	Walk to starting location	0.0	3.0	3.0	0.0
Total Job Time = 17.0 Total Job DST = 6.0 Job DSTR = 2.83					

Table 4.1: A Breakout Of Possible Job Steps With Their Associated Time Elements For The Example Job Depicted In Figure 4-1

installed in the engine bay. Table 4.1 lists theoretical process steps for this job along with each step's value-added time, non-value-added time, total time, and DST. In this example, non-value-added operations contribute to total time but are not allocated DST. Value-added steps, however, contribute to total time and are also allocated DST, which can be higher or lower than the corresponding actual time depending on the efficiency of the step. At the job level, times and DSTs are summed to get a total job time and total job DST, which can be used to calculate the job DSTR. These total job times and total job DSTs are what were extracted from NRS as a part of analysis sheets and process sheets, and, when combined with area information, this data collectively depicts where work content occurs on the line and the magnitude of that work from a time perspective.

4.2 Supply Chain Management Data

Bill of materials data related to the vehicles produced at the Smyrna plant was extracted from Nissan Supply Chain Management (SCM) data systems. This data consists of the parts installed on each of the model EIMs in Trim and Chassis along with the jobs used to install those parts. On a parts basis, this data does not include parts stocked line-side, such as certain fasteners or standard parts, and it also does not include consumables. On an area and time basis, this data notably does not include installation locations, installation times, or installation DSTs for each job or part, as NRS is the primary repository of this information.

4.3 Production Sequence Data

Production sequence data for vehicles built in System 1 of Trim and Chassis was extracted from Nissan Manufacturing data systems. This data consists of the VINs produced in a specified time window and the timestamps of when those VINs reached designated milestones in the production flow. The most relevant timestamps used in this study pertain to when vehicles exit Trim and Chassis. These corresponds with the VIN sequence from beginning to end in Trim and Chassis overall, allowing for investigation into system changes under different sequences and model mixes.

4.4 Model Code Data

Model code data, like production sequence data, was extracted from Nissan Manufacturing data systems for each of the models produced in System 1. This data contains the relationships between the different model codes for all vehicles produced historically at the Smyrna Plant, and the most relevant piece of data extracted from this was the relationship between different VINs and their associated EIMs. This relationship links the features associated with each EIM to the actual vehicles produced, which helps inform the content of each vehicle from a parts and process standpoint.

4.5 Finance Data

Financial data pertaining to vehicles produced at the Smyrna plant was extracted from web-based Tableau dashboards developed by Nissan's finance teams. The primary metrics exported and used throughout this investigation included revenue, cost, and profit per vehicle produced at the Smyrna Plant. Unlike other data sources used throughout this study, which can reflect real-time production at the plant, Finance data lags in availability due to the underlying approximation methods required to generate said data. This impacted the selected time window of the full set of extracted data used in the model formulation phases of this study.

4.6 Fault Data

Data pertaining to faults occurring in System 1 of Trim and Chassis was extracted from Nissan Manufacturing data systems. Though not built directly into the models developed in this study, this data was extensively investigated to identify and explore the model use cases that are presented in later chapters. This fault data consists of the downtime, pull cords, and defects that occurred on the line during designated time windows. Downtime is a time measurement of when the assembly line is stopped. Because the Trim and Chassis portion of the Smyrna Plant is a continuous, moving line, when one portion stops, the entire line stops. Pull cords represent instances of technicians on the assembly line pulling line-side pull cords, which alert supervisors to a help-needed condition. After a set period of time passes following a pull cord, the assembly line stops, generating downtime. Defects on the line signify one of many non-conforming conditions with a vehicle. These can include (but are not limited to): defective parts, damaged vehicle surfaces, and incorrectly performed installations.

4.7 Product Information Guides

Information pertaining to the features contained within each vehicle model was extracted from Nissan Product Information Guides (PIGs). PIGs are created for each vehicle program and list the individual features associated with each possible trim configuration and option package across program models. These trim configurations and option packages, along with the features contained within them, vary across the many Nissan export regions, warranting unique PIGs for each region. The information contained within the PIGs is linked to each individual vehicle through the encoding in each vehicle's EIM.

4.8 Time Window of Extracted Data

The data extracted for use in this study was taken from October through December of 2022. This time period allowed for a common time window across all data systems, given the lagging nature of Finance data. The methods described in this study can be easily replicated with time windows beyond December of 2022 as new data becomes available, thereby enabling updated views of system efficiency that capture new vehicle model trends. Exploration of this for the sake of identifying factory improvement opportunities will be discussed in later chapters.

Chapter 5

Initial Observations from the Data

This chapter presents observations of the data that were collected during the preliminary data investigations of this study. These observations heavily influenced the model formulation methods covered in the next chapter and include information related to how data systems connect and to the quality of the underlying data.

5.1 Independent Nature of Data Systems

The data used in this study was collected from several different sources: internally-developed, web-based tools; web-based Tableau dashboards; Microsoft Excel sheets hosted on Microsoft SharePoint; and Snowflake data tables. Some of these sources contain the process information for the line, and some contain the attributes and production information of the vehicles produced. The data systems themselves, though frequently sharing a common data field with some other system, are completely independent in nature. In other words, they have different data entry rules and export methods, and they are not natively linked. This means that under the current data architecture it is extremely cumbersome to systemically view the process information for a specific vehicle being produced, and this challenge is greatly amplified when trying to view data for full production sequences. Production improvement methods are limited because of this, adding to the motivation for this study.

5.2 Identification of Data Linking Mechanisms

Investigation into the underlying data used throughout this study showed that common data fields exist across many of the available sources. This presented an opportunity to link the sources together to create a single model containing vehicle characteristics and vehicle work content, which can be used to model efficiency of the overall system. Examples of these linking mechanisms include that production sequence data and model code data can be linked using VIN codes, that produced vehicles and the bill of materials can be linked using EIM codes, and that NRS and the bill of materials can be linked using job numbers. These relationships will be discussed more in the next chapter.

5.3 Issues with Quality of Data Entry

Because the data sources used throughout this study are independent and have different data entry rules and methods, numerous data quality issues exist that are mostly a result of manual data entry. These include omitted data, which results in nulls in the formulated model, as well as incorrectly or inconsistently entered data, which compounds the difficulty of linking data sources and modeling the output. Incorrect or inconsistent entry takes many forms, but most frequently it involved misspelled words or phrases and inconsistent terminology (e.g. all wheel drive vs. four wheel drive and front wheel drive vs. two wheel drive). Many methods were used to overcome these issues including correction of data at the source and hard coding of rules to account for inconsistencies.

Chapter 6

Modeling Efficiency in System 1 of Trim and Chassis

This chapter presents the methods used to build a system efficiency model for System 1 of Trim and Chassis at the Nissan Smyrna Vehicle Assembly Plant. This process was performed with the intention of generating insights about system efficiency in the area, which can be used to drive more impactful production improvement efforts at the plant in pursuit of improved plant KPIs. Model formulation involved three cyclical phases of data linking, model validation, and output analysis, all which were performed using Tableau. This chapter focuses specifically on the methods used to generate the model, and the use cases and recommendations resulting from the model will be presented in later chapters.

6.1 Data Linking and Model Formulation Phases

The system efficiency model formulation process consisted of three iterative phases involving different novel approaches to data linking and modeling. The linking process itself involved grouping the outlined data systems using a series of joins across common data fields contained within those systems. This enabled collation of the important elements of each system, which are shown in Table 6.1, into one common system that could then be validated and used as an all-encompassing model for simulation

Data System	Inputs Extracted for Final Model
NRS	Jobs, Areas, Times, and DSTs
SCM Data Systems	EIMs, Parts, and Jobs
Manufacturing Data Systems	VINs, EIMs, Time Stamps, and Faults
Finance Data Systems	Vehicle Financial Data
PIGs	Vehicle Feature Data

Table 6.1: Data Systems Used To Model System Efficiency For Trim And Chassis Along With The Elements Extracted From Each System

and analysis. The model validation process consisted of comparing the output of the model with known production counts, times, and DSTs, and this was followed by new iterations of model formulation to improve the output. The different model formulation phases are described in detail in the subsections that follow.

6.1.1 Phase 1: Leveraging Operations, Vehicles, and Parts

Phase 1 of model formulation leveraged the relationship between parts that are installed on vehicles in Trim and Chassis and the jobs used to install those parts as the foundation in building a single, all-inclusive model. Because assembly jobs have associated areas, times, and DSTs, mapping parts for each vehicle to their associated installation jobs enables linking of the process and time data to those vehicles. This, in theory, results in a single system containing the work content for each specific vehicle.

Grouping Assembly Jobs

The first step of this model phase involved grouping assembly jobs using NRS Analysis Sheets and Process Sheets. These were joined using job numbers as a join clause, resulting in a combined data set consisting of jobs, production areas, times, and DSTs. When combined, this constituted all process information for Trim and Chassis, which could then be attributed to vehicles in the production sequence.

Grouping Produced Vehicles

The second step of this model phase involved generating the detailed production sequence using manufacturing data systems. Specifically, EIMs were mapped to the production sequence using VINs as a join clause, resulting in a detailed production sequence containing VINs, EIMs, and time stamps.

Linking Produced Vehicles to the Bill of Materials

The third step of this model phase involved associating parts installed in Trim and Chassis to each vehicle in the production sequence. In this step, parts and their associated installation jobs contained in the SCM Bill of Materials were joined with the production sequence using EIMs as a join clause. This attributed all parts and their job numbers to each vehicle, enabling a future linking with process data.

Linking the Produced Bill of Materials to Assembly Jobs

The fourth and final step of this model phase from a linking perspective involved joining the production sequence and its associated bill of materials with the process information for Trim and Chassis. These were joined using job numbers as the join clause, resulting in an all-inclusive model containing the vehicles produced, their assembly jobs, the locations their jobs are performed in, the amount of time it takes to perform those jobs, and the amount of DST allocated for those jobs.

Validating and Evaluating the Phase 1 Output and Results

Phase 1 of model formulation is depicted in Figure 6-1, which shows each of the native or combined data systems along with their associated join clauses. Validation of this model involved comparing calculated model outputs with known production information. Specifically, the count of unique VINs in the model output was compared with automated daily production reports to ensure counts were equal, and sums of individual vehicle production times and DSTs were compared with average monthly production times and DSTs to ensure they fell within known or approximated ranges.

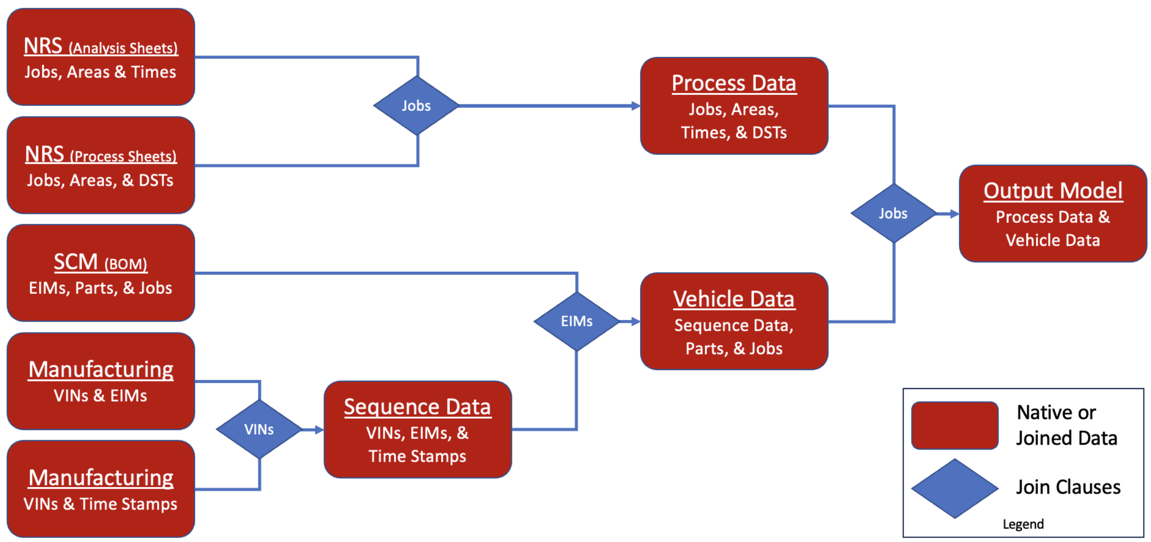

Figure 6-1: Outline Of Phase 1 Of Data Linking And Model Formulation

Additionally, each of the assembly jobs attributed to different vehicles by the model were collated and compared with the full collection of jobs contained within NRS to identify missing jobs and allow for investigation into their omission.

Evaluating the model results, the described validation method yielded production counts matching the automated daily reports, but times and DSTs did not fall into the expected ranges. An examination of the jobs captured by the model showed that only 72% of expected jobs were being attributed to vehicles in the model, which resulted in the inaccurate sums of time and DST for each vehicle. A closer look at the jobs omitted from the model demonstrated two primary root causes, which were both related to the model's inability to differentiate between jobs that should be applied on a parts basis and jobs that should be applied to every vehicle, regardless of parts.

Looking at the root causes of job omission more closely, the first was that jobs without a standard Nissan job number, such as jobs associated with kitting and picking, were being omitted from the model because they exist in NRS but have no counterpart in the SCM data system. Despite not being captured by the model, these jobs happen on every vehicle and thus should be attributed to every vehicle on a model basis. The second root cause of job omission from the model was that jobs associated with the handling of parts pre or post-installation were being omitted from the model because SCM only contains the jobs associated with part installation. To demonstrate this nuance using vehicle hoods, though NRS contains jobs pertaining to installation of hoods, opening of hoods, and closing of hoods, all which have their own times and DSTs, the SCM system only contains information pertaining to hood installations, thereby causing other part operations to be dropped in the model. Both of these underlying root causes revealed useful insights about the nature of the underlying systems and also demonstrated a need for a new model iteration for improvement of job capture by the model.

6.1.2 Phase 2: Incorporating Model Option Designations

Phase 2 of model formulation consisted of a similar methodology as in Phase 1 but included new job breakouts and the incorporation of a new data field intended to handle the missing job data identified in Phase 1 model validation. In terms of job breakouts, the new methods involved categorizing jobs in terms of vehicle applicability and applying them to vehicles in the most appropriate way for each category. In terms of a new data field, Phase 2 methods involved leveraging a previously-unused data field from NRS containing the vehicle feature or option associated with each job.

Grouping and Categorizing Assembly Jobs

The first step of this model phase involved grouping assembly jobs from NRS Analysis Sheets and Process Sheets per the same methods as in Phase 1. Upon obtaining a single system with all process data via this grouping, jobs were categorized by vehicle applicability in order to distinguish jobs that happen on every single vehicle and jobs that are part or model-specific. The first category of jobs are installation jobs that have a standard Nissan process number - these are model-specific and involve either installation of parts or work on a particular vehicle model. These jobs typically have both time and DST and are performed on the line for specific, applicable vehicles. The second category of jobs do not have a standard Nissan process number and involve reading information sheets for each vehicle to determine model manufacturing

Job Category	Job Characteristics	Location	Has Time?	Has DST?
1	Part installations or vehicle operations	On line	Yes	Yes
2	Reading of information sheets	On line	Yes	No
3	Kitting, picking, or inspecting	Off line	Yes	No

Table 6.2: Assembly Job Categories and Their Associated Characteristics, As Separated For Model Formulation

requirements. These jobs typically have time but no DST and are also performed on the line but for every vehicle produced in the plant. The last category of jobs also do not have a standard Nissan process number and involve kitting, picking, or inspecting. These jobs have time but no DST and are performed off the line in designated locations for each vehicle produced. Each of these categories are summarized in Table 6.2.

To further segment the first category of jobs - jobs that are model or option-specific - a new data field from NRS was used. This field designates the option or feature on a particular vehicle associated with a specific job. This field usually takes one of two forms: the first being an "All" designation, indicating that the job happens on all vehicles in a particular model regardless of trim or option packages, and the second being an option designation, indicating that the job only happens on vehicles of a particular trim or option package. These designations were used in conjunction with the other two defined job categories - information jobs and kitting and picking jobs - to create a set of option or model-specific process data and a set of base-model process data. Following the naming convention, the option or model-specific process data is vehicle dependent, whereas the base-model process data happens on every vehicle. The nature of this process relationship can be used to improve vehicle applicability in the model, as processes can be better attributed to the appropriate vehicles. The job breakouts as described are shown in Figure 6-2, and application of them will be described more in the sections that follow.

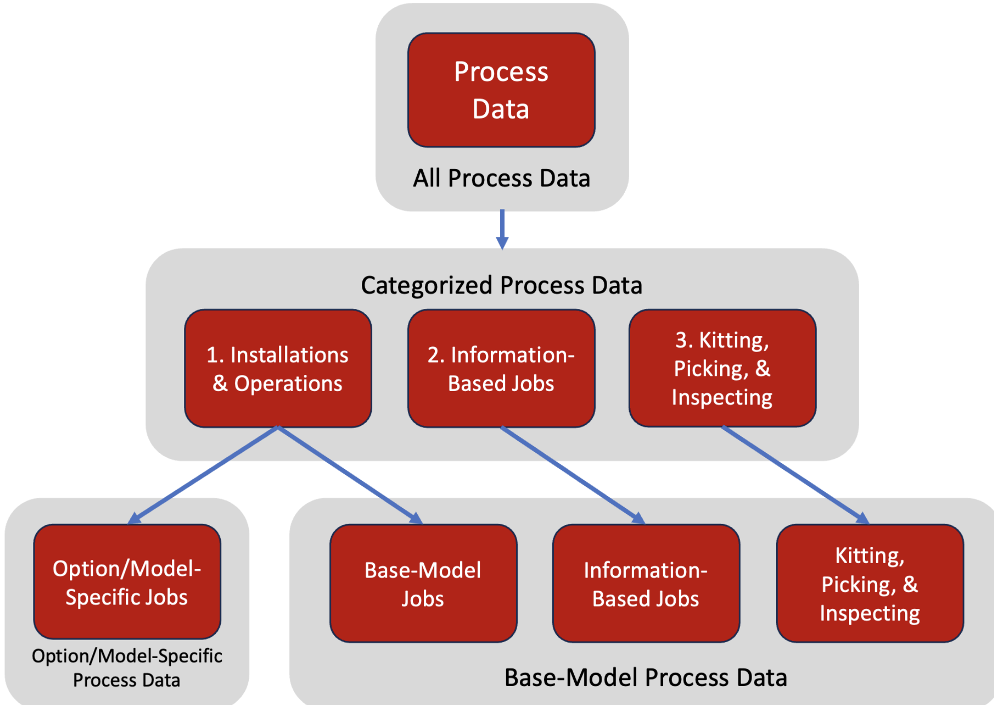

Figure 6-2: Assembly Job Hierarchy After Being Broken Out By Category And Model/Option

Generating the Production Sequence and Linking the Bill of Materials

The second and third steps of this model phase involved generating the production sequence using Manufacturing data systems and linking this sequence to the SCM Bill of Materials. This was done using the same methods as in Phase 1, thereby resulting in the same produced bill of materials.

Linking the Produced Bill of Materials to Option or Model-Specific Jobs

The fourth step of this model phase involved linking the produced bill of materials to the option and model-specific category of jobs. This allowed for associating the parts and processes for each vehicle in the sequence with their respective jobs in the process data. As in Phase 1, the jobs themselves were linked to the produced bill of materials using jobs as a join clause. Because base-model jobs were separated out from this step of the process, this greatly reduced the number of computations required to match the produced bill of materials with the appropriate production jobs.

Linking the Production Sequence to Base-Model Jobs

The fifth and final step of this model phase involved linking the base-model jobs to every vehicle in the sequence. These jobs were joined directly to the production sequence using the vehicle program model as a join clause - Nissan Pathfinder jobs were linked to produced Nissan Pathfinders, Nissan Murano jobs were linked to Nissan Muranos, and Infiniti QX-60 jobs were linked to Infiniti QX-60s. This output data was then combined with the option and model-specific output data from step four to create a final output model for validation, evaluation, and analysis.

Validating and Evaluating the Phase 2 Output and Results

Phase 2 of model formulation is depicted in Figure 6-3, which again shows the native or combined data systems along with their associated join clauses. As demonstrated visually and as described previously, the primary difference between this model phase and Phase 1 was in the segmentation and application of jobs. Validation of this model, like in Phase 1, involved comparing the output of the model with known production information. Evaluating the results of model validation, production counts again matched automated daily reports, and times and DSTs were much closer to expected ranges than in Phase 1. Additionally, with the segmentation of jobs and application to vehicles in base, option-specific, and model-specific groupings, jobs captured by the model improved from the previous 72% in Phase 1 to 96% in Phase 2.

Despite the substantial improvement in job capture in this model phase, investigation into the omitted jobs again revealed inefficiencies of the model. Specifically, among the jobs still omitted from model output, the majority were associated with trim or option content on different vehicle models. Because the trim and option content is what primarily distinguishes different trim levels within a vehicle program, the omission of these jobs made all vehicles across a program in the output appear to have approximately the same production time and DST. In other words, production times and DSTs for a low-trim Nissan Pathfinder were approximately the same as a high-trim Nissan Pathfinder, which is known to be inaccurate because of the work

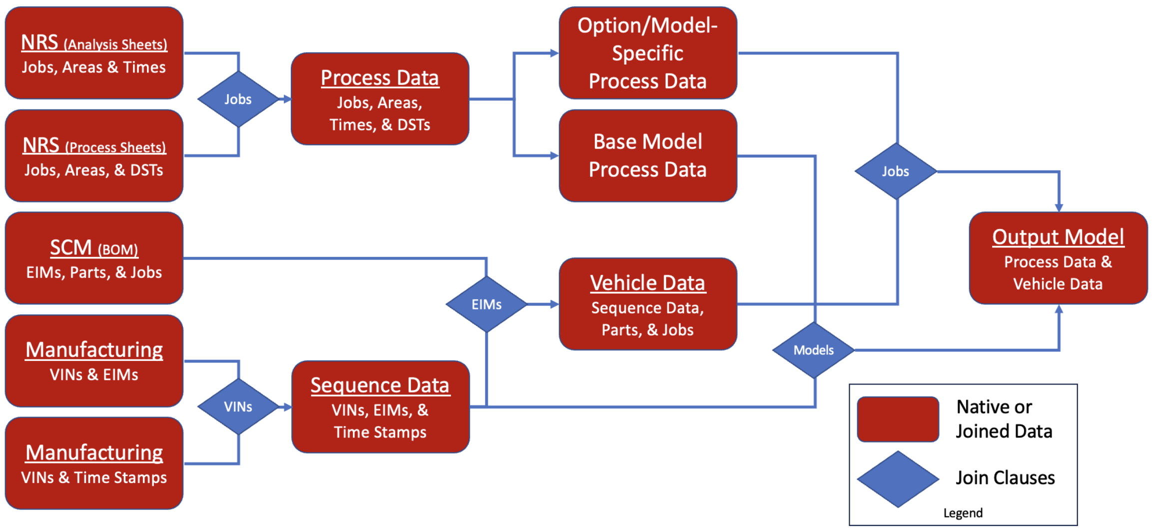

Figure 6-3: Outline Of Phase 2 Of Data Linking And Model Formulation

content differences across trim packages.

Further investigation into the root cause of jobs being omitted from the output revealed inconsistencies in the jobs contained within data systems. Despite the fact that some option or model-specific installation jobs existed within NRS, these did not exist within SCM data systems because of the nature of the jobs and because of the rolling nature of updates to what is contained within the SCM Bill of Materials. These inconsistencies warranted a new approach for job application to vehicles in the model to ensure full capture of the processes in NRS. A new methodology addressing this is presented in Phase 3 of model formulation, which is discussed in the next section.

6.1.3 Phase 3: Filtering Jobs with Product Information Guides

Phase 3 of model formulation involved a new approach to linking process data with sequence data in order to overcome the data structure challenges realized in Phases 1 and 2. This involved generating process data and sequence data using the same methods as in earlier phases and then attributing every possible job for a vehicle program to every one of those vehicles in the sequence. These jobs were then filtered out for each vehicle using model codes, NRS option designations, and PIG feature information to ensure every required process was attributed to the correct vehicles.

Grouping Assembly Jobs

The first step of this model phase involved grouping assembly jobs using NRS Analysis Sheets and Process sheets. This was done using the same methods as in prior model phases and resulted in a combined set of all process data for Trim and Chassis, including jobs, areas, times, and DSTs.

Grouping Produced Vehicles

The second step of this model phase involved generating the detailed production sequence using the same methods as in prior model phases. Though the sequence itself matched that of prior methods, a fundamental difference between this phase and prior phases was that this sequence was not combined with the bill of materials. Instead, processes were attributed directly to the sequence itself, forgoing the incorporation of parts; this will be discussed more in the next section.

Linking Produced Vehicles to Assembly Jobs

The third step of this model phase involved attributing process data directly to the production sequence. In lieu of segmenting jobs and applying them in a categorized manner, in this phase, every job applicable to a vehicle program was applied to every associated vehicle regardless of options or trim packages. This was accomplished using models as a join clause, thereby resulting in a sequence with every job attributed to every vehicle within each of the three vehicle programs.

Filtering Vehicle Operations Using PIGs

The fourth and final step of this model phase involved filtering the jobs associated with each vehicle to include only the jobs required for said vehicle's feature set, trim package, and option packages. To begin this process, vehicles were separated by delivery destination to mirror the structure of PIGs, given that there exist different configuration requirements for each of Nissan's delivery regions. Jobs were then systematically filtered from each vehicle in the sequence using true and false rules linking the requirements in the PIGs with the option designations associated with each job. Using all wheel drive jobs as an example, vehicles *with* all wheel drive were set to true on operations required for all wheel drive, and vehicles *without* all wheel drive were set to false on these same operations. Attributing jobs to vehicles using rule sets of this nature ensured that the jobs for every feature, trim package, or option package were appropriately linked to the required vehicles once false operations were filtered out of the model. The end result of this filtering process was an output of the production sequence with each vehicle correctly linked to its production work content, including jobs, areas, times, and DSTs.

Validating and Evaluating the Phase 3 Output and Results

Phase 3 of model formulation is depicted in Figure 6-4, which shows the native or combined data systems with their associated join clauses and the subsequent PIG filtering step. Validation of this model phase followed the same process as in Phases 1 and 2, yielding production counts matching daily automated reports and a job attribution rate of 100%. This is known to be 100% because jobs were attributed through the filtering step, ensuring that no jobs were missed due to the structures of the underlying systems or the methods used to combine those systems. This phase was the final phase of model development because of the quality of output achieved.

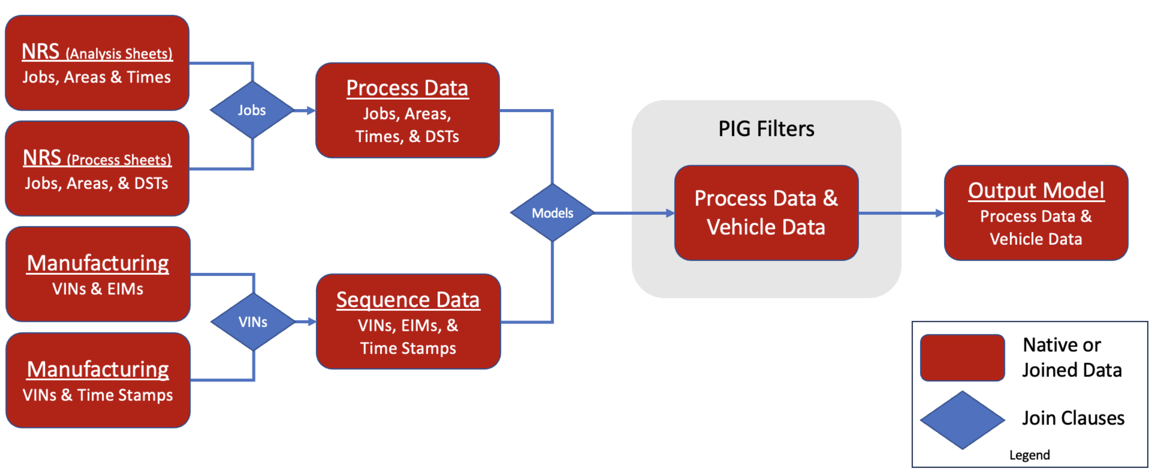

Figure 6-4: Outline Of Phase 3 Of Data Linking And Model Formulation

6.2 Calculating System Efficiency and Generating Model Use Cases

As described in the previous section, Phase 3 of model formulation enabled attribution of all required jobs in Trim and Chassis to all vehicles in a designated production sequence. Given that all jobs were successfully attributed, it follows that each vehicle was attributed its full production time and allocated DST across all zones and pitches. This allows for several new approaches to production system analysis that were not previously available at the company. Specifically, the model allows for generation of summary statistics related to time and DST for different time windows and areas of production, and it also allows for calculation of theoretical DSTR, or system efficiency, in those said time windows and areas for the sum of vehicles produced. Additionally, because the model generates area, zone, and pitch-level work content for each vehicle, this allows for simulation of the production sequence and analysis of the work required across all areas as that sequence changes. Many of these use cases and their implications for the company will be discussed in the next chapter.

6.3 Challenges Associated with Model Formulation

Numerous challenges were encountered throughout the different model formulation phases, and these were primarily related to the nature of the underlying data systems, to the complexity associated with vehicle configurations, and to the complexity of the production system. In terms of the data systems, many of the challenges have already been discussed; two examples are the lack of a native connection between data systems and inconsistent data fields across data systems. The different model formulation phases were novel attempts to overcome these challenges in pursuit of improved job inclusion rates in the model. These rates are re-summarized in Table 6.3.

In terms of vehicle complexity, only three vehicle programs are produced in System 1 of the Smyrna Plant, but these have a vast array of possible configurations. These are differentiated in several ways: by features, by delivery destinations, and

Model Formulation Phase	**Job Inclusion Rate**
Phase 1	72.2%
Phase 2	95.8%
Phase 3	100%

Table 6.3: Job Inclusion Rates From Each Of The Model Formulation Phases

by color combinations. Each of these unique configurations add to the element-wise complexity of the efficiency model, thereby increasing the challenge of actually generating that model. Vehicle configuration complexity for System 1 of Trim and Chassis is summarized in Table 6.4.

Possible Vehicle Configurations	**Magnitude**
When Including All Feature Options	10^2
When Including Delivery Destinations	10^2
When Including Interior/Exterior Colors	10^3
Monthly Total Production	10^4

Table 6.4: Magnitude Scales Of Possible Vehicle Configurations That Are Produced In System 1 of Trim and Chassis When Considering Vehicle Attributes

In terms of production system complexity, there exist several areas of Trim and Chassis, which are comprised of several zones, pitches, and jobs. This culminates in thousands of jobs existing for each vehicle program, all which require their own subsets of parts. These also add to the element-wise complexity of the efficiency model, necessitating countless model operations to generate the millions of data elements in the output. Complexity of these types of elements are summarized in Table 6.5.

Elements Incorporated Into Model	**Magnitude**
Models	3
Vehicle Configurations	10^3
Vehicle Parts	10^3
Assembly Jobs	10^3

Table 6.5: Magnitude Scales of Production Elements Being Analyzed And Joined During Model Formulation Phases

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Chapter 7

System Efficiency Model Use Cases

This chapter presents the realized use cases resulting from development of the Trim and Chassis system efficiency model. As described, the generated model bridges a gap between data systems by linking assembly jobs and their respective characteristics to vehicles in the production sequence. Using this model, one can advance production improvement and production planning techniques by incorporating data structures that are new to the company. This chapter focuses on specific use cases for Nissan, whereas generalized model outcomes will be discussed in the next chapter.

7.1 Incorporating the Model into Ongoing Production Improvement Efforts

Production improvements at the Smyrna Plant have historically centered on improving technology or process flows in the production system to reduce downtime, defects, and pull cords. Though these efforts have been valuable to the health and efficiency of the system, they have not taken into consideration the impact of the vehicle sequence. Incorporating this data into these processes - efforts like bottleneck identification and defect reduction - represents a significant opportunity to improve said efforts by examining order, frequency, and model-mix of vehicles produced.

7.1.1 Identifying Bottlenecks and Inefficient Areas

Bottleneck identification efforts at the Smyrna Plant typically consist of identifying and intervening on jobs that create the most downtime. IEs also work to prevent bottlenecks by balancing job operations using CCMs to spread out production times and keep them below the maximum allocated time in pitch for each job. These efforts, however, do not take into consideration the fact that the actual time in each job or pitch regularly varies as the production sequence changes and as the features on vehicles produced fluctuate up and down with different trim and option packages.

Using the developed system efficiency model, one can improve these methods by evaluating areas across Trim and Chassis using real production sequence data in order to identify the areas that consistently take the most time or that have the worst efficiency. Once identified, areas can then be broken down by mathematically examining their jobs at an individual level to identify those that also consistently take the most time and have the worst efficiency. These can then be intervened on using known problem solving methods regularly used throughout the plant.

Applying this methodology to example model data for Trim and Chassis, Figure 7-1 shows an area-level breakdown of times and DSTs for a specified time window of production across Trim and Chassis zones. This view enables identification of areas that take the most time (i.e. bottlenecks), and when comparing over different time periods, it allows for identifying the most consistent, time-consuming areas, similar to the bottleneck identification methods presented by Lux. This view also enables identifying the areas that are the least efficient, given that one can compare production times to DSTs across all areas. Once identified, inefficient zones can be broken down in a similar way to identify the most consistent, time-consuming jobs. Figure 7-2 shows a single zone broken out into its individual jobs, and within this view, one can immediately identify problematic jobs - jobs that take the longest and jobs with the worst efficiency ratio.

Building on this job-level analysis, the model can be used to examine each job in a zone to measure efficiency and to help identify root causes of inefficient processes.

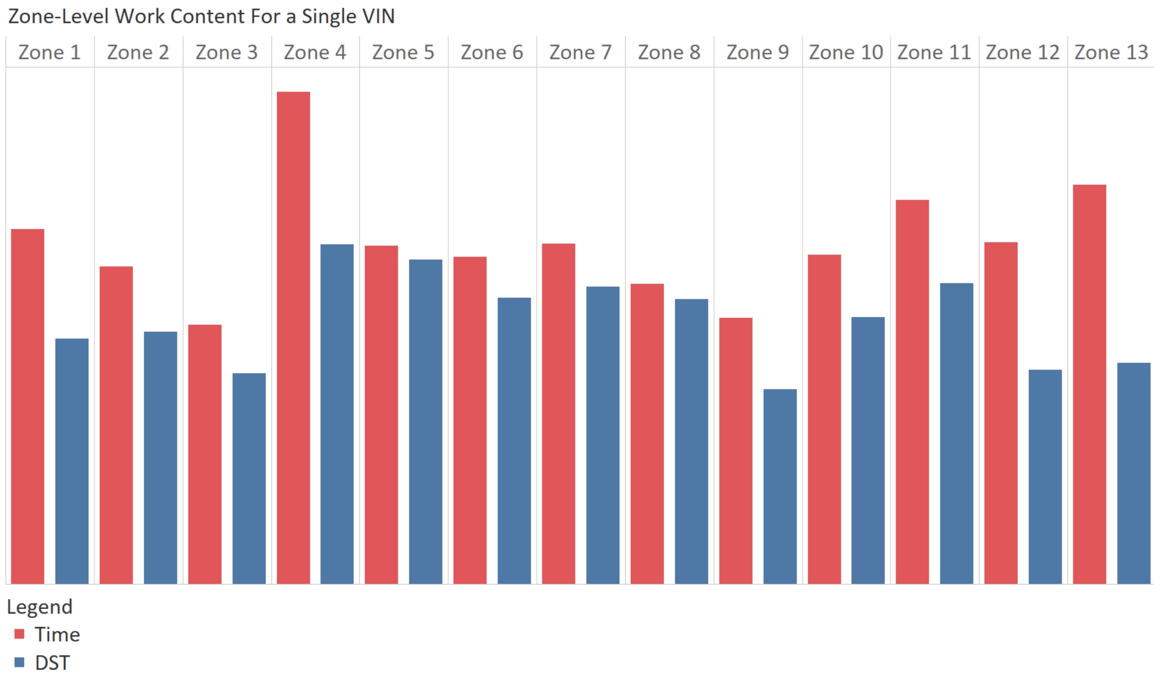


Figure 7-1: System Efficiency Model Data Showing Area-Level Times And DSTs Across A Set Of Zones In Trim And Chassis For A Specified Time Window of Production

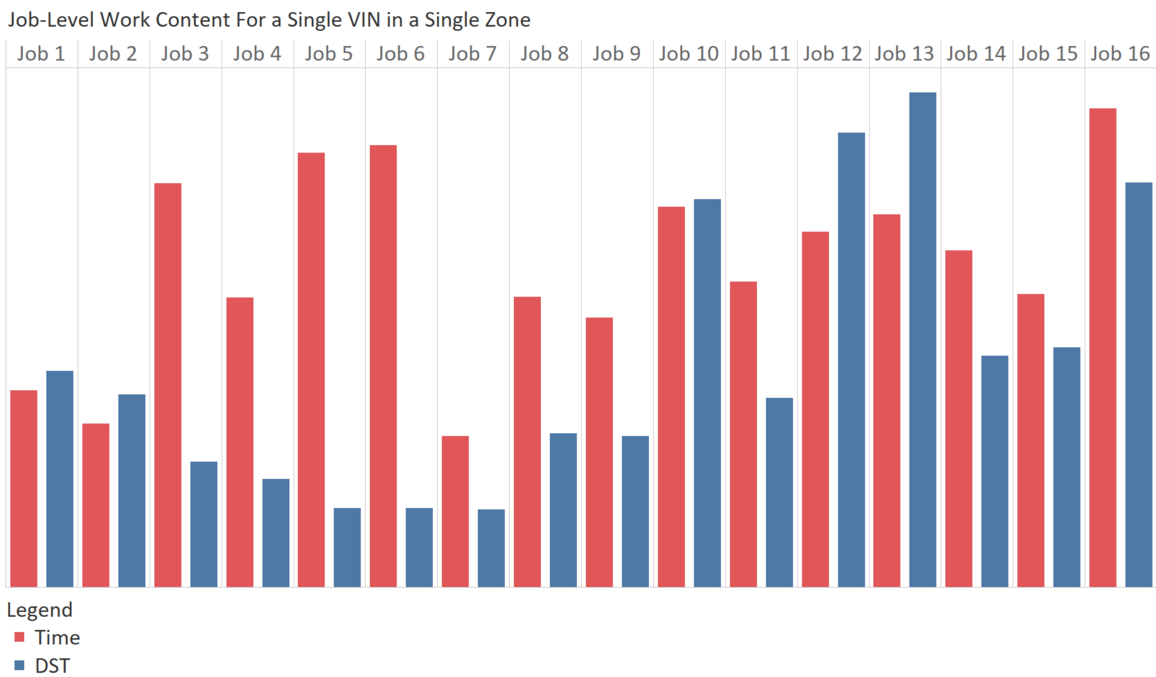


Figure 7-2: System Efficiency Model Data Showing Times And DSTs Across Jobs For A Single Zone In Trim And Chassis For A Specified Time Window of Production

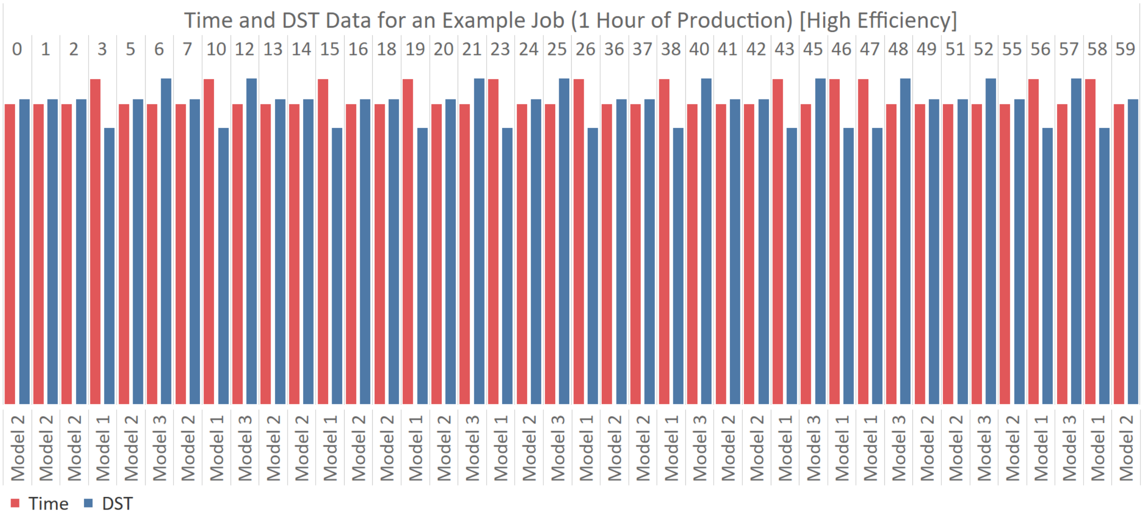


Figure 7-3: A High-Efficiency Job In Trim And Chassis As Demonstrated By Approximately Equal Time and DST For All Vehicles In One Hour Of Production

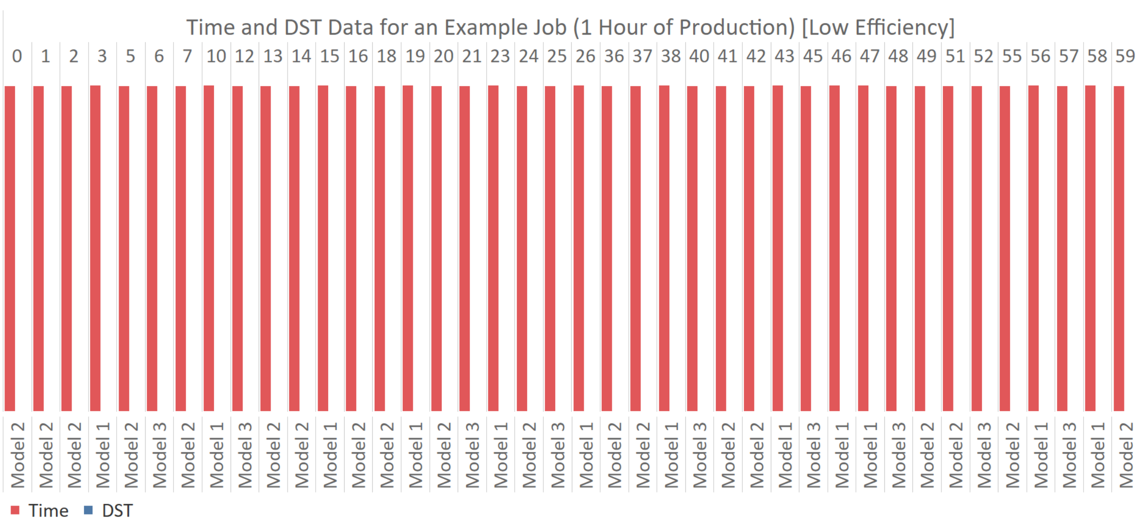


Figure 7-4: A Low-Efficiency Job In Trim And Chassis As Demonstrated By Consistent Times But No DST For All Vehicles In One Hour Of Production

Figure 7-3 shows an example job during a selected one hour production window. The three models produced in System 1 are identified on the x-axis in their designated sequence, and each vehicle's time and DST are shown for this specific job. From this data, one can see that this job is highly efficient with a theoretical job-level DSTR (efficiency) of approximately one. This means that the Smyrna Plant is executing this job as efficiently as possible, as designated by Nissan Japan during initial vehicle design. To contrast this, the same production sequence is shown in a different job in Figure 7-4. In this job, one can see that each vehicle requires production time for assembly, but the associated process steps are allocated zero DST. This means that this process is strictly providing a negative contribution to assembly efficiency, necessitating an investigation into possible ways to improve its individual efficiency.

7.1.2 Identifying Areas with High Transition Complexity

In addition to enabling identification of inefficient zones and jobs, the developed system efficiency model can be used to identify jobs with process-driven high and low transition complexity. Building on the results of the cost of complexity study completed at the Smyrna Plant by Addy, it follows that jobs with high transition complexity are likely prone to generating more defects and thus warrant investigation into ways the sequence or transitions can be smoothed to reduce said complexity.

Looking at examples from the model, Figure 7-5 shows the same production sequence from prior examples but in a job with high process-driven transition complexity. This is demonstrated by the fact that the sequence consists of alternating batches of vehicles with high assembly times and DSTs followed by vehicles with low assembly times and DSTs. In instances like these, the difference in time is likely part or feature driven: vehicles containing a set of parts or features take longer to assemble than vehicles without those features. Because transition points like these are prone to generating more defects and also bring with them a need for different production infrastructure, they represent significant opportunities to improve factory health.

Contrasting this example, Figure 7-6 again shows the same production sequence but in a job with low process-driven transition complexity. In this sequence, each vehicle requires approximately the same assembly time and is allocated approximately the same amount of DST. The similarity of times within this job likely means there are only minor differences for the technician when switching between models, making the job transitions less prone to defects and less in need of schedule smoothing. This does not mean that the job is without room for improvement though, as the consistent gap between time and DST likely points to a long process step that is inefficient and warranting investigation and intervention.

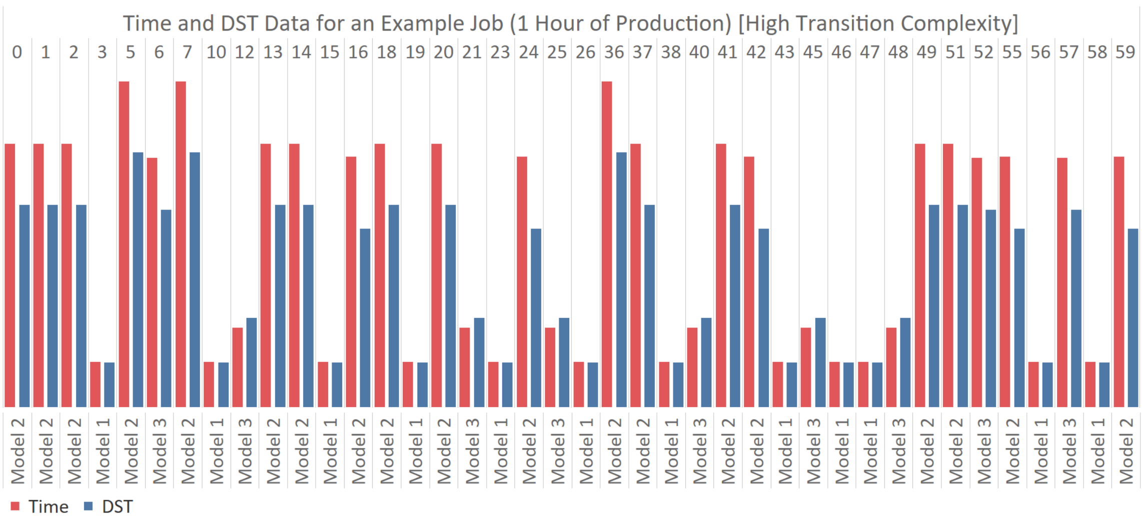


Figure 7-5: A Job With High Process-Driven Transition Complexity, As Demonstrated By Drastically Varying Completion Times And DSTs Across One Hour Of Production

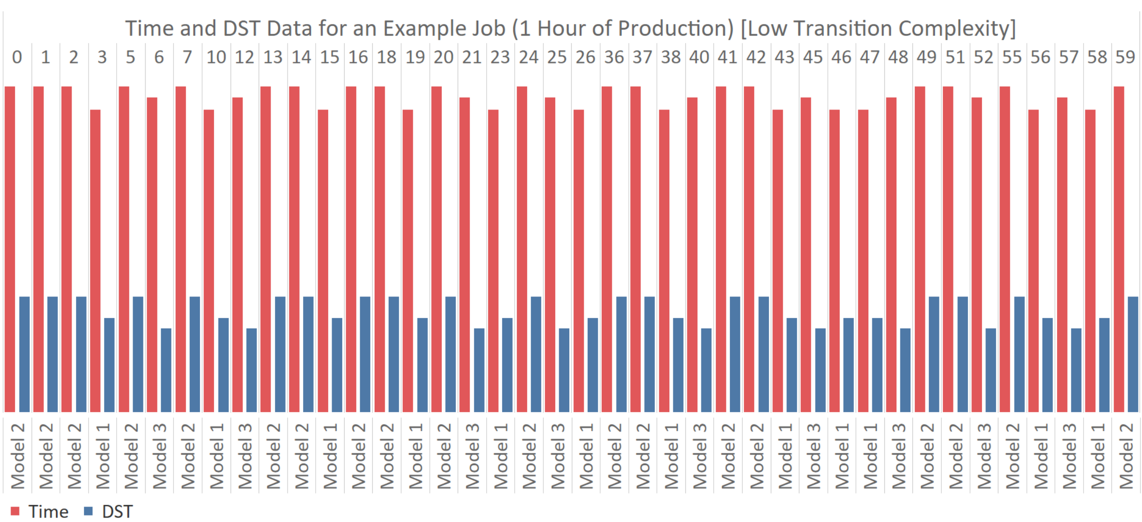


Figure 7-6: A Job With Low Process-Driven Transition Complexity, As Demonstrated By Consistent Completion Times And DSTs Across One Hour Of Production

7.2 Incorporating the Model into Ongoing Production Scheduling Efforts

Production scheduling at the Smyrna Plant has historically involved optimizing the production sequence using known manufacturing constraints. This is done to balance demand on the value stream and to satisfy sales projections, and the constraints used as inputs have typically been based on tribal knowledge communicated from manufacturing. Though these efforts ensure that demand is satisfied and that the communicated constraints are incorporated into the model, the methods used do not take into consideration how the schedule impacts the total work content required in each zone. Additionally, because the constraints built into the optimization methods are based on tribal knowledge, it is not known if all mathematical constraints are incorporated, as no system exists to identify these. This represents a significant opportunity to improve production scheduling efforts by using the developed system efficiency model to identify system constraints and optimal production sequences.

7.2.1 Identifying Over-Utilized Areas

The job-level constraints built into production scheduling optimization methods are usually intended to prevent over-cycling of the line. Specifically, these constraints prevent cycling too many vehicles in a row when doing so would repeatedly exceed the time capacity of each job, thereby leading to an over-cycled condition where technicians are working outside of their designated pitches. Some of the jobs that lead to this condition are known and validated via stop watch; when confirmed, they are incorporated into existing scheduling methods. The developed system efficiency model, however, allows for identification of *any* instance of over-cycling. This enables building a repository of all job-level constraints in the system so that they can be prioritized and built into ongoing scheduling methods.

Using production data from the model to exemplify this use case, Figure 7-7 again shows the same production sequence from the previous section, but in this instance,

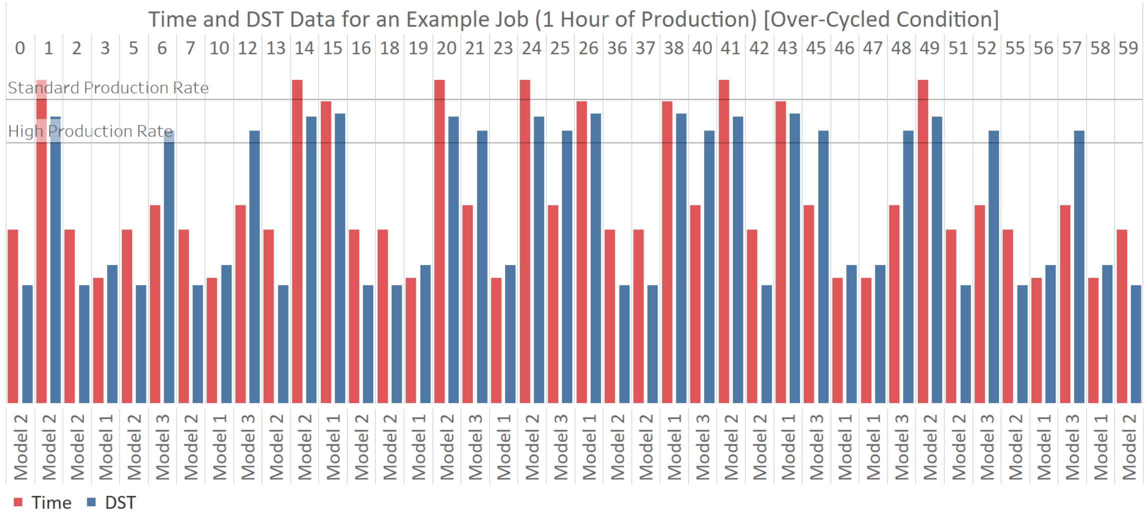
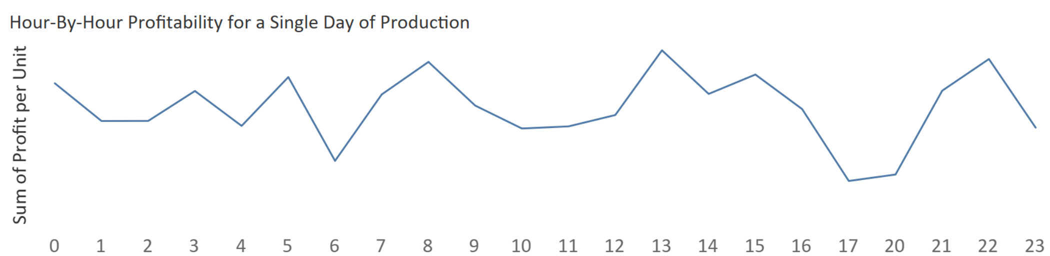


Figure 7-7: A Job With Varying Assembly Times Across Models Where Shorter Times Are Within Job Capacity and Longer Times Exceed Job Capacity

reference lines are added to show maximum time in pitch based on a standard or high moving line rate. In this example, one can see that the vehicles that take less time (and that likely do not have the feature installed at this job) are well within maximum time in pitch. These jobs would ordinarily be completed halfway through the designated pitch length, leaving the operator either sitting idle or free to move to the next unit. Vehicles that take more time (and that like have the feature installed at this job), however, exceed the maximum time capacity of the job. This means the the operators working on these vehicles - unless working in greater numbers or at a faster-than-average rate - will cycle out of the job's designated pitch location before completing their work. Though there do exist buffer zones on the line, repeated instances of this over-cycled condition would eventually lead the operator out of the buffer zone and into the next pitch. This is a constraint that must be accounted for to ensure vehicles with the appropriate features are sequenced together, and because the efficiency model can identify any instance of this condition, it represents an opportunity to formalize constraint identification in production scheduling methods.

7.2.2 Identifying Optimal Production Ratios

In addition to helping identify production constraints, the system efficiency model can be used to identify financial trends associated with the models produced. This allows for development of an understanding of which models in combination generate the most profit for the company, enabling prioritization of production ratios in Smyrna. Examining data of this type as generated by the model, Figure 7-8 shows one day of production in System 1, the ratio of models produced hour-by-hour on that day, and the profit generated each hour. This model-mix to profit relationship helps with decisions about what and when to produce in Smyrna, and when mapped with efficiency data, it can inform how efficient the plant is when generating certain profits. Though this particular example is broken out only by model, this can be taken steps further by breaking each model out by feature or trim package to understand the relationship between vehicle complexity and production profit.



Hour-By-Hour Model Mix Ratio

Model	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	20	21	22	23
Model 1	8	6	6	6	6	8	4	6	9	6	6	5	5	11	5	7	7	2	2	7	7	7
Model 2	22	17	18	20	18	24	12	21	22	19	17	17	18	23	23	22	20	10	10	24	25	14
Model 3	10	6	5	9	5	10	4	9	11	8	6	7	6	11	8	10	6	2	3	8	12	6
Grand Total	40	29	29	35	29	42	20	36	42	33	29	29	29	45	36	39	33	14	15	39	44	27

Figure 7-8: Hour-By-Hour Production Ratios For 1 Hour Of Production In System 1 Along With The Profits Associated With Produced Vehicles

7.3 Using the Model to Improve the Underlying Data

One major challenge with generating the described efficiency model was with the quality of the underlying data. Notably, there exist countless instances of nulls, typos, and misappropriations in the data. Given that the systems containing this data are used to balance the line and calculate system KPIs, data issues are detrimental to the efficiency and overall perceptions of the plant. That said, when using the developed model to simulate production sequences or evaluate the efficiency of processes, these data issues become glaringly obvious. Specifically, null categories appear throughout the model when the underlying data is null, and one can use basic vehicle and job intuition to discern if numbers in the data match expectation. To that end, the model can be used to improve the underlying data by correcting any discovered issues during use; this in turn improves the model and any other process methods that use the data.

Chapter 8

Recommendations

This chapter outlines the recommendations culminating from the methods and use cases that were presented in this study. These recommendations are primarily intended for Nissan but are also applicable to manufacturers who have data-rich production systems and who are engaged in or developing a continuous improvement culture.

8.1 Implement the Model into Existing Workflows

The system efficiency model use cases presented in this study are each aligned with a work flow that currently exists at the Smyrna Plant. Production improvement use cases are aligned with production improvement efforts, which are a regular part of the manufacturing, IE, and CFT work statements. Likewise, scheduling improvement use cases are aligned with production scheduling, which is a regular part of the scheduling team's work statement. Lastly, data improvement use cases are aligned with any team's involvement in data management, which is a responsibility of countless different teams, organizations, and plants throughout the company.

Any new data structure or model's ability to enhance multiple work statements in this way means there exists enormous potential for system improvement, but this relies on a willingness and motivation among each team to implement new models and levels of detail into their work. This is the basis of the principal recommendation from this study: to implement the methods and use cases into the noted workflows to enhance the continuous improvement culture that exists at the plant.

Implementation of the model takes many forms but aligns mostly with the noted use case applications. Specifically, implementation means sourcing defect and bottleneck reduction projects for CFTs and IEs using the zone and job views outlined in the model. Implementation also means identifying all Trim and Chassis production constraints in the model and incorporating these into a more sophisticated scheduling optimization process to drive efficiency gains and to improve profits. And finally, implementation means standardizing processes for data system upkeep and using the structure and output of the model to identify areas for data improvement. Implementation through these avenues, like with any model, requires diligence from the owning organizations but also represents a significant opportunity if implemented in the long term.

8.2 Develop New Data Architectures to Unlock New Capabilities

The major challenges encountered throughout this study centered around production complexity and data structure and integrity. In terms of data structure, the actual need for a new efficiency model stemmed from the fact that the required data systems do not connect but yet each contain vital parts of the full data picture. Namely, IE data systems contain the process data, manufacturing data systems contain the sequence data, and other miscellaneous systems contain vehicle data. Getting this data into one system is what enabled development of the use cases in this study and generation of novel information about Trim and Chassis. That said, the developed model has limitations for widespread use, as it is an offline system, it leverages data system exports as inputs, and it requires manual updates to remain current.

To overcome this need for manual updates and to enable better information use in general, another primary recommendation resulting from this study is to develop new data architectures containing unified information about both the production system and about the products produced. By combining data in this way, as demonstrated through the methods and use cases presented in this study, one can unlock new improvement capabilities that can help propel the company to new KPI targets. Additionally, creating this type of integrated data architecture enables standardization of maintenance practices and unifies all teams into one common system, thereby enabling collaboration and even more sophisticated model development beyond what was developed throughout this study.

8.3 Refine the Usage of Cost Control Models

Many systems, processes, and KPIs at the Smyrna plant leverage CCMs as inputs for analysis, reporting, and decision making. On the surface, this makes some practical sense, as a CCM is the expected average vehicle produced throughout the life of a program and should at least somewhat resemble the moving average represented in monthly production counts, regardless of time frame. That said, the average is the average because it is the average; otherwise, it would not be the average [17]. In other words, though a CCM might closely resemble a recent moving average, using that recent moving average as the representative value for production, supply chain, and KPI decisions in lieu of a CCM makes more intuitive sense, as it is more representative of what has recently been produced. This constitutes the final recommendation resulting from this study - to rethink the usage of CCMs and instead make production, supply chain, and KPI calculations and decisions using more recent recent production data. The developed system efficiency model captures the characteristics of vehicles produced for any designated time period and thus is one way to obtain this information for usage in more refined future decision making.

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Chapter 9

Conclusion

This thesis involved building a system efficiency model for System 1 of Trim and Chassis at the Nissan Smyrna Vehicle Assembly Plant. The investigation was successful in that it yielded new methodologies for structuring and modeling production data, and it also yielded use cases for this model within the various stakeholder organizations.

Decisions to produce vehicles at Nissan plants are typically based on regional demand and plant performance. Because of this, a continuous improvement culture exists at the Smyrna Plant where teams are regularly engaged in efforts to improve plant KPIs. Historically, these efforts have focused on reducing defects and downtime and on balancing the line, but because of the siloed nature of Nissan data systems, these efforts have not fully taken into consideration the impacts of vehicle sequence or features. This fact culminated in two objectives for this study - to develop a system efficiency model that characterizes both the production system and the vehicles produced, and to develop production improvement use cases as a result of this model.

The focus area for this study was System 1 of Trim and Chassis at the Smyrna plant. System 1 was selected because it consists of true mixed-model assembly with three models produced in an ever-changing model-mix ratio. Trim and Chassis was selected because it introduces product variation across trim and option packages, and this variation impacts production time and efficiency as vehicle features change. Several data sources were used to build the model developed in this study, including engineering, manufacturing, supply chain, and finance data systems.

Model formulation consisted of three phases all containing new ways to combine and model data systems. Phase 1 leveraged the relationship between processes and the bill of materials, Phase 2 utilized job option designations, and Phase 3 used PIGs as filters to attribute jobs to vehicles. Each phase resulted in more and more data being included by the model, with phase 3 incorporating all required jobs for the sequence of vehicles produced. This signifies a successful combining of process data and vehicle data, thereby unlocking several new production improvement use cases, such as bottleneck identification, defect reduction, and sequence optimization.

Three recommendations were identified as a result of the methods and use cases developed in this study. The first is to incorporate this model into stakeholder workflows in order to maximize model utilization. The second is to rethink data architectures by co-locating product and process information into one system in order to improve data accessibility and drive more efficient system management and model development. And lastly, the third recommendation is to rethink the use of CCMs when making production decisions or calculating KPIs, as using more recent data better represents the current state of the production system.

Nissan has an accomplished history in the automotive industry, and the Smyrna Plant is the foundation of that history in the United States. In spite of countless challenges faced over several decades of operation, including the data architecture challenges addressed in this study, Nissan and the Smyrna Plant have consistently accomplished remarkable production feats. To sustain such a legacy and achieve its ambitious goals for the future, Nissan must continue to foster innovation within and across its organizations. This thesis aligned with that internal innovation mindset and accomplished the desired research objectives by identifying novel ways to structure existing data systems to enhance existing processes. To that end, this study was a representative example for Nissan or any other data-driven manufacturer of how one can re-think the use of existing resources to unlock new capabilities and drive future growth through a continuous improvement culture.

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