Lean Product Development for the Automotive Niche Vehicle Marketplace

by

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Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Engineering and Management

at the

Massachusetts Institute of Technology

January 2005
[February 2005]

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ABSTRACT

The automotive low volume niche vehicle marketplace is growing, evidenced by increasing media coverage and fierce competition between original equipment manufacturers. Development of niche vehicles must be lean and therefore fast to beat competitors and keep customers interested.

This thesis case studies a niche vehicle product development organization which has survived within a major original equipment manufacturer for over 11 years. This work defines niche vehicles and presents process things gone right and things gone wrong which have been identified through detailed interviews. The organization's current product development enhancement strategy is also summarized.

Product development value stream mapping is used to identify process improvement opportunities for leaning the major engineering activities of the niche vehicle organization. Current state maps and desired future state maps are presented. Recommendations for approaching the desired future state are discussed. Process improvement opportunities outside of engineering are identified which work toward improving the cycle time of the overall product development process. Finally, all of the recommendations are summarized and rated on their difficulty of implementation and suggestions for future research are presented.

Acknowledgements

This thesis is dedicated to my mother and father whose encouragement, dedication as parents, and persistence made my MIT dream a possibility. Thank you for ingraining in me the importance of education and for sticking with it. I would not be where I am today if it were not for you.

I would like to express my sincerest gratitude to those that made the SDM program a reality. A great thank you goes to John Coletti for his support of me through the program, his guidance, and his mentoring. I thank him also for building the greatest niche empire of today and for giving me the privilege to be a part of it. I wish him health and happiness in his retirement, he will be missed. A thank you also goes to Tom Bochenek for believing that I have what it takes, for making the nomination, and for always offering an open door.

I must thank all of those who took time out of their busy schedules to work with me. A thank you goes to Chris Theodore and Hau Thai-Tang for agreeing to meet with me and providing valuable insight. Thank you to Dean Martin for being my confidant, listening to my ideas and being my sanity check. A thank you goes to all of those that I met with and work with, everyone contributed by providing comments, recommendations, interest and support. A special thanks to those that had to take over my work during the many weeks I spent on campus.

Finally I would like to thank my Advisor, Professor Deborah Nightingale, for her guidance on lean principles and support of my project. Her patience with my busy work schedule and ability to provide feedback despite her workload and travel schedule are greatly appreciated.

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1.0 Niche Vehicle Product Development Introduction

1.1 Motivation and Objective

Low volume niche vehicle offerings are a growing trend in the automotive industry. With so many products to choose from the traditionally large markets such as car, truck, and SUV are being subdivided into much smaller market segments with very specific needs. The performance car market, for example, has driven all three of the major U.S. automotive original equipment manufacturers (OEMs) to launch niche vehicle product development organizations for the purpose of delivering low volume performance vehicles. The oldest of these organizations has been operating for ten years and belongs to my employer who will be referred to as OEM-A. OEM-A's niche vehicle product development organization will be referred to as NVPDO.

With ten years of product design and development experience and a fierce increase in competition NVPDO has recently set out to enhance their product development and delivery. The generic product development process (PDP) used by OEM-A is not designed for niche vehicle products. Niche markets require new, innovative products to be brought to market quickly and often. The mainstream PDP is long and resource intensive. Niche vehicle development requires smaller, leaner teams with the ability to move fast and be creative; however, there is a fine line that must be walked to adhere to the PDP disciplines, delivering quality and affordability, without quenching the creativity of the team or bogging down the development timeline. Over the last year NVPDO has been working on developing a lean PDP specific to the design and development of performance niche vehicles. A strategy for niche vehicle product development has been developed and documented. However, this strategy is very broad and program specific details of implementation have yet to be developed. NVPDO is trying to follow this strategy but without the details the organization is learning as they go. This mode of operation is resulting in constant timing delays, missed milestones and budget overruns.

The objective of this thesis is to develop the details of the niche vehicle development strategy for NVPDO, identifying elements of a PDP that will deliver quality vehicles which meet all program targets in a compressed timeframe. This will be accomplished by meeting the following set of smaller objectives:

1. Identify things gone right that have kept NVPDO viable through 10 years of business
2. Identify things gone wrong at NVPDO (areas where significant improvement are required)
3. Look at the current PDP value stream and identify areas where lean principles can help improve the process
4. Define the desired future state
5. Make process improvement recommendations that work towards the desired future state

1.2 Approach

In order to meet the objectives of this thesis the current state of the NVPDO business was reviewed though detailed interviews with NVPDO personnel and management as well as senior management within OEM-A and some external consultants. The primary tool used in this thesis is product development value stream mapping. The current value stream of the NVPDO niche vehicle development process was studied and the desired future state was identified. This allowed a set of solutions to be developed that work toward achieving the desired future state. Finally, recommendations were made for implementing these solutions at NVPDO. The tools and methods for this thesis include case studies, interviews, value stream mapping and literature research.

1.3 Thesis Scope

OEM-A's generic PDP has 14 milestones where gateway reviews occur. These 14 milestones are described in the below table.

	Milestone	Description
Definition Phase	<1>	Beginning of program specific work
	<2>	Mission/vision and target customer defined
	<3>	Target ranges assessed
Design Phase	<4>	Initial program direction established
	<5>	Confirmation of strategy/viability
	<6>	Vehicle proportions frozen
	<7>	Program targets become objectives
	<8>	Interior and exterior surfaces are provided
	<9>	Designs are ready for first prototype builds
Prototype Phase	<10>	First prototype is available
	<11>	Commitment to production timing
	<12>	Engineering sign-off complete
	<13>	Ready to launch
	<14>	Start production

Table 1: OEM-A Milestone Descriptions

The front end of the process, Milestones <1> through <3>, concentrates on customer research and product definition. NVPDO has a loyal customer base that has been developed over the last 10 years. The wants and needs of these customers are well known and have been well documented. As a result, definition of the right product for these customers comes easy and happens quickly. The front end of the PDP for NVPDO is already considered lean. The middle portion of the process, milestones <4> through <9>, is where the product is designed in detail. This is the area where the most opportunity for improvement exists and, therefore, is the area of most interest for this thesis. Milestones <10> through <14> cover prototyping through production. The NVPDO strategy is to follow the generic PDP through these milestones and therefore this tail end of the PDP will not be addressed in this thesis.

1.4 Thesis Outline

Chapter Two describes the primary lean tool used in this thesis, product development value stream mapping, and summarizes the literature that was researched on the subject. It is meant to give the reader basic background information on the tool and how it is used. The reader should refer to the cited literature for detailed information on applying the tool.

Chapter Three summarizes the current state of the NVPDO business. First it presents a detailed definition of the niche vehicles that NVPDO is developing today. Then the current niche vehicle product development strategy is summarized. This is a brief description of the work done at NVPDO to date. Chapter Three closes with a discussion of lessons learned at NVPDO over the last 10 years. This discussion includes both things gone right and things gone wrong.

Current state niche vehicle product development processes of NVPDO are presented in Chapter Four. This is a discussion of the body, chassis and powertrain engineering value stream maps in the current state. The team is defined, the scope of the investigation is reviewed in detail and the engineering value streams are presented and discussed.

Chapter Five defines the desired future state. The desired future state maps of the body, chassis and powertrain engineering processes are presented. Differences between the current state and the desired future state are pointed out and process improvements which will work toward achieving the desired future states are recommended.

Chapter Six takes a look at all of the activities outside of engineering which support the engineering processes. Process improvement opportunities are discussed for the base program team, program management, purchasing, and manufacturing. Management and resource considerations are also presented. The challenges of implementation for each recommendation are noted.

Conclusions for lean product development in the automotive niche vehicle marketplace are presented in Chapter Seven. The 22 recommendations for improvement at NVPDO are summarized in a table and rated on implementation difficulty. Enablers and challenges of implementation are commented on for each recommendation. Finally, opportunities for further research are suggested.

2.0 Lean Engineering Tools

2.1 Product Development Value Stream Mapping Summary

Value stream mapping is a lean tool commonly used in the manufacturing environment to assist in the implementation of lean principles. There is plenty of literature available that describes value stream mapping and how it is applied to production processes. The reader is referred to Womack and Jones' *Lean Thinking* as well as Rother and Shook's *Learning to See* for background information on value stream mapping in lean manufacturing. There is very little published literature that covers value stream mapping of product development processes. The methodology is discussed in works such as Burton and Boeder's *The Lean Extended Enterprise* and Jordan and Michel's *The Lean Company, Making the Right Choices*, however, neither of these sources provide a "how to" like *Leaning to See* does for manufacturing processes. A product development value stream mapping (PDVSM) manual is being developed by Hugh L. McManus, PhD as part of the Lean Aerospace Initiative. A beta release of this manual came out in April of 2004. The purpose of the manual is to guide product development personnel in applying lean concepts to product development processes through value stream mapping. The major lessons from this manual are summarized here.

The manual is written to show the mapping and improvement of a single, very well defined, product development process. In this thesis the concepts presented in the manual are expanded to cover many of the sub-processes that make up a PDP. The manual shows the mapping of a process from beginning to end, showing how to find wastes, inefficiencies and non-value-added tasks. These things are then eliminated from the PD process to achieve a desired future state. The steps presented in the manual are followed in this thesis to identify contributions to a future state of the NVPDO process.

In the manual McManus first presents the three goals of Lean Engineering which are as follows:

1. Efficient engineering processes
2. Effective enterprise integration
3. Creating the right products

PDVSM is a tool used to achieve the first goal. This is where lean is applied to remove wastes from the engineering processes. This is intended to improve cycle times and increase quality levels. The second goal is where lean is used to create value throughout the enterprise and is outside the scope of the manual. The third goal communicates the need to not only do the job right, but to do the "right job", meaning that the products which are created should increase value for all of the stakeholders.

McManus then goes on to describe how applying lean to product development is different (versus application to manufacturing). He states three primary differences:

1. Product development processes contain high amounts of uncertainty. The output of the process is not exactly known at the start of the process.
2. Product development processes act primarily on information flows rather than physical material flows. The output of product development processes is the specification of a product and not the product itself.
3. Product development processes are applied to a mix of different jobs with varying degrees of complexity. This complicates the application of process improvements.

Despite these differences McManus does state one similarity between product development and manufacturing processes, and that is that in all cases the process should be repeatable.

In *Lean Thinking* Womack and Jones' present 5 steps to lean:

- Precisely specify value by specific product
- Identify the value stream for each product
- Make value flow without interruptions
- Let the customer pull value from the producer
- Pursue perfection

In the PDVSM Manual McManus applies these five steps to engineering. This is summarized in the below table.

Steps to Lean	Manufacturing	Engineering
Value	Visible at each step, defined goal	Harder to see, emergent goals
Value Stream	Parts and material	Information and knowledge
Flow	Iterations are waste	Planned iterations must be efficient
Pull	Driven by takt time	Driven by needs of the enterprise
Perfection	Process repeatable without errors	Process enables enterprise improvement

Table 2: Applying the Five Lean Steps to Engineering [McManus, p.18]

After this basic introduction on applying lean principles to product development processes the manual goes into the detail of PDVSM. The method is much the same as it is for manufacturing. The first step in developing a PDVSM is assembling the team of key stakeholders, defined as the people who derive value of any sort from the process. In PD this includes:

- Process executors
- Process output users
- Indirect users of process output
- Internal customers
- External customers
- End users
- Suppliers
- Management

A variety of these stakeholders should make up the team to ensure a balance of different perspectives from across the enterprise.

With the team in place the next step is to define the boundaries of the value stream. In manufacturing the value stream is easily bounded by the walls of the factory where a "door to door" value stream is easily seen. In PD the boundaries of the process must be defined and clearly understood by the team. The beginning and ending points of the process being worked on should be defined and the product that the process acts on should be specified. The owner of the process should be known, be it an individual or a group within the enterprise. The output of the process should be stated, this is the reason for which the stream exists. The customers that receive the output of the process need to be determined and all of the inputs to the process and constraints on the process should be recognized. All of these things together define the boundaries of the value stream under study.

Once the boundaries of the value stream are defined the next step in PDVSM is defining the value of the product development process. The team must work together to define the value created by the process and to understand how that value is created by the process. This understanding guides the process improvement effort. The output of the value definition step is a goal statement that clearly communicates what is required for the process output to be valuable. The sample goal statement given by the manual is: "Produce the required outputs, without defects, as efficiently as possible, and at the right time". The words in this statement should be replaced by words specific to the process being studied and the goal statement should be very explicit. An explicit goal statement allows for each individual task in the process to be evaluated on whether or not it contributes to the goal. Since most product development tasks cannot simply be considered value-added or non-value-added each task must be evaluated on what aspects of value it creates. The PDVSM manual presents ten aspects of value that were proposed by James P. Chase in his MIT Masters thesis entitled "Value Creation in the Product Development Process". They are as follows:

Task contributes to:

1. Definition of end product with desired functional performance
2. Definition of processes to deliver product
3. Reduction of risk and uncertainties
4. Forming final output
5. Facilitating communication
6. Enabling other tasks
7. Meeting or reducing cost and/or schedule
8. Learning or resource improvement

9. Enhancing employee job satisfaction
10. Other

The key value aspects for the process under study should be selected by the team and used later to evaluate the tasks that make up the process.

The next step in PDVSM is mapping the current state value stream. The manual presents the three basic steps to doing this:

1. Arrange the tasks and information flows
2. Collect performance data on the tasks and flows
3. Evaluate how value is created by each task and flow

The first step is completed by following the work through the process and asking process participants "Where does your task output go?" and "Where does your task input come from?". The team must decide what level of detail will be meaningful to the process improvement effort. The second step requires that the team determine what metrics of the process are important. For example, if the goal is to reduce cycle time then the team will want to collect data on time to complete each task. Teams are warned to avoid bias and normalize data if possible. Any data that provides insight into the process should be included on the current state map. The third step is where the team compares each task to the aspects of value previously chosen. The manual explains how most non-value-added activity is hidden in value-added tasks and states that the team should not expect to find any non-value-added tasks right away. Each task must be evaluated for how it adds value, how much value is created and how well that value is created by that task. The information flows between tasks should be ranked on quality of information as part of the task value assessment.

With the current state map completed the team can begin the difficult work of identifying waste. The goal of this step is to eliminate waste from the process in all forms. The manual presents seven concepts of info-wastes in product development processes:

1. Waiting – late information

2. Inventory – too much information or obsolete information
3. Over-Processing – unnecessary iterations
4. Over-Production – unnecessary data
5. Transportation – information incompatibility
6. Unnecessary Movement – lack of direct access
7. Defective Products – lack of interpretation, lack of knowledge

Examples and causes of each info-waste concept are presented in the PDVSM manual. Each task should be evaluated on whether or not it contains or produces an info-waste.

The final step in PDVSM is improving the process. The PDVSM manual presents best practices for reducing info-wastes and clearing bottlenecks to flow. Wait time is pointed out as the leading category of waste in product development processes. The best practices are taken from lean manufacturing and modified for application to product development processes. They are summarized here.

1. Establish a takt time

   Takt time is defined as the number of units of work demanded by the customer divided by the available time. Pseudo takt times can be set in product development based on the timing needs of the enterprise. The tasks that must be improved are the ones that cannot meet the determined takt time. The goal is to have all of the tasks being completed at takt time and the output information handed off to the next task at known intervals.

2. Assure the availability of information

   Most wait time wastes are due to missing information at the needed time. One way to avoid waiting waste is to store information neatly and simply to reduce searching time. Another tool is to make information visual in environments like "war rooms" where key information is posted on the walls. E-rooms where the team can access information on the web also work. Lastly the manual recommends making information flow physically by placing all pertinent information in a folder or binder that moves through the process with the work.

3. Clear external constraints

Waiting can be caused by external constraints such as lack of resources or authority to proceed. These external causes of waiting must be cleared wherever possible.

4. Eliminate unnecessary or inefficient reviews and approvals

Evaluate reviews and approvals in the system based on output value. These should be held when maximum value is created at minimum cost. Waiting for approvals that are ultimately granted is a pure form of waiting waste that can be eliminated from the process.

5. Break down monuments

Monuments in PD processes are defined by Murman *et al.* in *Lean Enterprise Value* as "assets, processes or mindsets that were originally created for good reason but which have not adapted to changing circumstances". Monuments in the process should be identified and eliminated as long as the original intent of the monument is still delivered by the process as necessary.

6. Eliminate unnecessary motion

This best practice refers to the unnecessary motion of people looking for information. The best way to eliminate this is to implement co-located integrated process teams (IPTs) when possible.

7. Eliminate unnecessary documents and formatting

Here the goal is to eliminate all non-value-added documents or information that is created which has no user. Often times email, phone calls or instant messages can be used to transmit information that is currently contained in a formatted document. The PDVSM manual states that "efforts expended on creation of information exchange systems should be proportional to the expected gains, and they should be regularly updated to avoid becoming 'monuments' themselves".

8. Eliminate unnecessary analyses, exploit underutilized analyses

   Here the thoughts are the same as above. Analyses should only be carried out if they contribute to the goal of the process. Analyses that are carried out should be utilized to their full value. They should feedback into the process and not just be used to confirm checkpoints. There are many missed opportunities resulting from this type of use of analyses.

The final step in PDVSM is using the above practices to improve the value stream and redrawing the map with all of the identified wastes eliminated. This new map is the "Future State Map". The PDVSM manual presents additional ideas which can be applied beyond the future state map to create the ideal state map. The ideal state map shows the vision of a perfect process but is, however, outside the scope of this thesis.

3.0 Current State of the Business

3.1 Definition of a Niche Vehicle

The terminology "Niche Vehicle" is used widely throughout the automotive industry and means different things to different people depending on the application. In all cases the term refers to vehicles that were developed with a specific niche market in mind. Niche markets are smaller sub-sets of market segments that have been identified by an enterprise for its products. For example, products such as the Honda Accord or the Ford Taurus are high volume mainstream products. They are not designed for a market niche. In an article for Forbes.com Jerry Flint sites several examples of niche vehicles such as the Volkswagen Beetle, the BMW Mini, and the Ford Thunderbird. All of which were designed to be attractive to a small segment of buyers seeking nostalgia. Niche products are a "love it or hate it" proposition that appeal to only a small segment of buyers that will pay a premium for the product. In his article, Jerry goes on to state the rules for a successful niche vehicle:

1. The vehicle should be developed at a low cost and be a derivative off of an existing platform.
2. The niche product shouldn't cannibalize too many sales of existing products.
3. The niche product must have some shelf life.
4. If the product doesn't make money, it makes it up with buzz and excitement and gets people into showrooms.

NVPDO develops niche vehicles for the high performance market niche. The work in this thesis is applied to one of NVPDO's niche vehicle programs which was used as a case study, this program shall be code-named ProgramX. It is important that the reader understand fully the scope of niche vehicles developed by NVPDO while the work in this thesis is being presented. The following details define an NVPDO niche vehicle:

- The product customer is highly researched and therefore very well known. The product is designed to meet a specific need of this customer. In the case of NVPDO this need is performance which translates to high power and superior handling and braking. The product, therefore, is highly developed in these areas. Other attributes of the product such as ride and fuel economy are traded off, as necessary, to fill the performance need of the customer.
- The product is a derivative of a higher volume product produced by OEM-A, called the mainstream vehicle. The platform architecture is well established and currently in production.
- The product development program contains less than 200 new-tooled end-items. These are components and assemblies that are new to the assembly plant, and are designed specifically for and used only on the NVPDO niche vehicle, and get shipped directly to the plant location.
- The product design has specific areas where it is highly unique from the mainstream vehicle. These are as follows:
    - **Powertrain** – The niche vehicle engine assemblies are unique and are designed to deliver highly increased horsepower and torque levels. These increases can be as much as 150% of the mainstream vehicle levels.
    - **Driveline** – The driveline components of the niche vehicle such as the drive shaft, transmission, and rear axle assemblies must be upgraded to deliver the increased power levels provided by the unique powertrain.
    - **Chassis** – The niche vehicle suspensions are sport tuned with unique springs and dampers. The braking systems are upgraded and larger to stop the more powerful, and heavier, vehicle. The products also have larger wheels and tires to put the power to the road.
    - **Exterior and Interior Differentiation** – The above mentioned upgrades are expensive and as a result the NVPDO niche vehicle is priced at a premium. Customers, therefore, want to be noticed and want their vehicle to be recognized as something more special than its mainstream sibling. The appearance of the product is altered to make it unique. Outside the vehicle is given a lower stance and more aggressive "looks fast standing

still" look. Inside the materials are upgraded and controls and touch points such as steering wheels, shifters, and seats, are refined to appeal to performance drivers.

- The product is produced in low volumes. Typically NVPDO will produce 10,000 units per year or less. This is to maintain exclusivity of the product.
- The product is sold with a high margin. Customers of these products are not as price sensitive as they are on the higher volume derivative products. The customer is willing to pay for performance and exclusivity and the product is priced to reflect this.

3.2 Niche Vehicle Strategy

Work has been ongoing at NVPDO to determine an organization specific approach to niche product development and delivery. Clearly OEM-A's generic PDP was not created with niche vehicles in mind and is too complex a process to work efficiently on derivative product programs. In 2003 a team was formed to propose a strategy to upper management of OEM-A for buy-off. The team consisted of engineering personnel and management from NVPDO and interfacing activities within OEM-A such as manufacturing. The result of this work was a high level strategy that contains the overarching principles to be followed by all of NVPDO's niche vehicle product development programs. A brief discussion of this work is presented here. It forms the basis for the work presented in following chapters.

The NVPDO vision and guiding principles, as defined by the team, are as follows:

Vision: Deliver exciting niche products

- Quick to market
- Meet all objectives
- Lean and efficient engineering
- Innovation and technology leader, trickle down to mainstream

Guiding Principles

- NVPDO remains lean and cost-efficient
- NVPDO must be a mainstream PD partner
- Engineering disciplines must be maintained

In order to develop an NVPDO unique PD strategy the team benchmarked past NVPDO vehicle development programs to identify error states. In the recent past a number of NVPDO new vehicle programs were plagued with timing delays and the output products contained significant quality issues which were causing OEM-A to incur high warranty costs. The following error states were identified by the team:

- Unclear connection between niche vehicle organization and mainstream organization
- Unclear roles and responsibilities between interfacing activities
- Build from vehicle issues are inherited by niche vehicle organization
- Limited customer quality performance reporting
- Dealer and customer education missing

These error states have been identified to be the high level general causal factors of a number or smaller "things gone wrong" identified by the team. Examination of these error states led to identification of three key elements that must be incorporated into the new enhanced product development process. These key elements are:

1. Established formal communication interchanges between NVPDO and mainstream engineering
2. New defined roles and responsibilities interface with mainstream engineering
3. Established current model quality responsibility for NVPDO

Application of these elements should result in faster, more successful programs and since NVPDO produces niche vehicles off of existing platforms the development time can be shortened versus the generic OEM-A PDP. The team developed a timing strategy for the timing of program milestones when these key elements are incorporated into the PDP. The milestones discussed here are defined in Table 1. The highlights of this strategy are as follows:

- Milestones <1> through <3> remain as is for NVPDO. NVPDO utilizes a greatly reduced timeline and deliverables structure for these milestones which contain the product definition phase of the program development. Since the organization has a loyal and well established customer base the wants and needs of these customers are well known, well documented, and continuously evaluated. This enables the product definition phase of the program to be highly efficient. The team determined that these milestones should be left as is.

- Significant compression is possible between milestones <4> and <9> for NVPDO (versus generic OEM-A PDP).

- NVPDO is to follow the generic PDP for milestones <10> through <14>. These are the prototyping and production phases. It was found that when compressed timing was used on these phases of the program that the development team did not have sufficient time to react to product issues. It was therefore determined that compression of these milestones was another error state that was resulting in poor vehicle quality and issues in the field.

- There should be a minimum of 24 months between milestones <7> and <14>, the mainstream PDP requires 27 months between these milestones.

The first program that this timing strategy is applied to at NVPDO is code-named ProgramX and is used as a case study for the work detailed in following chapters. ProgramX is planning 8 months between milestones <4> and <9>. The generic OME-A PDP says there should be 22 months between these milestones. The strategy proposed by the enhanced product development and delivery team is not program specific. It is a very high level strategy that is meant to govern NVPDO product development. It, therefore, does not contain the program specific details of how to achieve such considerable timing compression on ProgramX. Herein lies the motivation for this thesis, to look at the tasks that must be completed between milestones <4> and <9> on ProgramX and through value stream mapping determine if the 8 month planned timing between milestones is achievable. Value stream mapping the NVPDO process through these milestones will identify the areas of waste where timing compression can be accomplished. The opportunities identified on ProgramX can then be applied to all of NVPDO's other vehicle development programs.

3.3 Things Gone Right

NVPDO has been a force in the automotive industry for over 11 years to date. Survival in such a competitive environment with small budgets and tight timing means that the right decisions are being made and appropriate actions are being taken. NVPDO's successes are attributed to the following things-gone-right:

Logistics

- Collocated team in a separate facility, NVPDO operates separate from mainstream
- On site prototyping capability, the dedicated facility has an onsite garage and fabrication shop

Engineering

- Streamlined program approval process has been successful
- Out of the box thinking by passionate engineers
- Elimination of prototype tooling wherever possible
- Surface Integration Supplier

Marketing

- Development of a loyal customer base
- Development of owners association (fan club), market research is compiled at club events, the organization has constant contact with new and old customers

- Small network of dedicated and highly trained dealers
- Customer info center (call center) provides good data collection and early issue recognition
- Collocation with engineering

Management

- Direct link to upper management through stakeholders group, very few "layers"

Program Management

- Administrative tasks have been limited to the vital few, time and resources are not wasted on documentation and report-out

Purchasing

- Outsourcing of some normally internal activities resulted in large time savings

Manufacturing

- Enthusiastic and involved manufacturing teams
- Dedicated plant liaisons

Culture

- Empowered personnel with high levels of responsibility
- Willingness to break the rules
- Teamwork with a "we can do it" attitude delivers the "impossible"

Resources

- "Jack of all trades" personnel
- passionate personnel from working level through management

3.4 Things Gone Wrong

As with any organization NVPDO has recognized lessons learned and opportunities for improvement. In the recent past vehicle quality has been declining and programs have been slipping milestone timing over and over again. These issues are attributed to the following things-gone-wrong:

Logistics

- Lack of communication and common documentation with platform development team
- Inconsistent organization of department results in missed opportunities for shared knowledge across programs and efficiencies

Engineering

- No planning for niche vehicle in platform teams. In addition to adding content to the vehicle engineers must resolve issues with the current vehicle which further increases the workload on an understaffed group
- Growing program complexity
- Inadequate number of prototype vehicles for proper development and verification
- Inadequate data to back up engineering decisions
- Testing
    - Suppliers do not want to run large prove-out sample sizes for low volume programs
    - NVPDO cannot afford large sample sizes
    - Real world usage profiles do not match usage of high performance customer
    - Durability testing cycle time does not support niche vehicle compressed timeline

Management

- Late direction changes with mandate that timing be held
- Drawn out decision making results in long wait times
- Emphasis on wrong areas at times
- Too many "what-if" requests

Program Management

- Lack of work planning
- Lack of pre-program target setting, the team did not have clear direction at times (lack of process)
- Prototype builds timed too close together

Purchasing

- No dedicated purchasing support, using mainstream purchasing resulted in getting mainstream suppliers
- Lack of interest on part of suppliers due to low volume of program results in slow response times
- The lowest cost supplier is not always the right choice

Manufacturing

- Special handling of parts during prototype builds – misrepresentative assembly process
- Complexity management – plants are not flexible enough and limit content of niche programs
- Low volume programs get low priority at plants
- Mainstream manufacturing processes are more expensive than outside alternatives

Culture

- "Us versus them", NVPDO and mainstream not playing nice

Resources

- The team is undersized to meet all design / release and testing requirements given the content and timing of the programs, no single component could be attended to with the depth and thoroughness required to ensure a good "quality of event"

4.0 Current State Niche Vehicle Product Development Process

4.1 Defining the Team

The first step of the PDVSM process, as discussed in Chapter 2, is defining the stakeholders of the product development process that will become the team. Since this study includes all of the major processes that take place between milestones <4> and <9> a sizeable list of stakeholders contributed to the effort as required. First of all, the project was presented to upper management of both NVPDO and OEM-A to ensure there was alignment with the needs of the enterprise. The project was supported by the Director of NVPDO, the Executive Director of the larger organization that NVPDO is a part of, and a PD Vice President at OEM-A. This provided the necessary "top cover" to ensure the rest of the team that management was behind the effort.

With management on board the next step was to identify the major process owners and participants within NVPDO and OEM-A which would become the primary sources of PDVSM data. This required a deep-dive into all of the deliverables from milestones <4> through <9> to identify the groups and people responsible for those deliverables. 8 primary areas of responsibility were identified and are as follows:

1. Marketing
2. Engineering
3. Manufacturing
4. Corporate Design
5. Finance
6. Program Management
7. Prototype Planning
8. Purchasing

NVPDO has its own internal marketing function that is not shared with any other organizations. The engineering area is a generalization of all the different engineering activities that contribute to the process deliverables; this includes chassis engineering, body engineering, powertrain engineering, vehicle engineering, test engineering and CAD/CAE engineering. The first three are internal to NVPDO. Testing and CAD/CAE are engineering services provided by activities internal to OEM-A. Manufacturing provides representatives to follow NVPDO programs. NVPDO has its own vehicle designers specific to the niche vehicle programs that are provided by Corporate Design. Finance is an internal NVPDO function as is Program Management and Prototype Planning. Purchasing, however, is a service provided by OEM-A's purchasing function. There are several individuals within each of these 8 activities that contribute to the deliverables and acted as part of the team, providing data as necessary. NVPDO's suppliers also have direct input into the milestone deliverables and were therefore also members of the team.

There were also some external consultants that proved to be valuable team members. These were engineers and managers within OEM-A that do not have direct input into NVPDO's milestone deliverables. Some of them were members of the platform team that the niche vehicle is derived from and provided valuable insight into the mainstream processes for means of comparison. Others were from outside functions of OEM-A such as Quality and Process Control that provided fresh eyes and sanity checks to the team.

4.2 Scope of Investigation

Once the team is identified the next step of the PDVSM process is bounding the problem. The desire of NVPDO's product development enhancement strategy is a significant compression between milestones <4> and <9>, the product design stage of a program. Milestone <4> will act as the beginning point of the process under study and milestone <9> will act as the ending point. NVPDO's ProgramX is being used as a case study and the performance niche vehicle that ProgramX delivers is the product that the process is acting on. OEM-A's generic PDP states that 22 months are required to complete the deliverables of milestones <4> through <9>. NVPDO is planning 8 months between these milestones on ProgramX, a compression of 14 months. This is illustrated below in Figure 1.

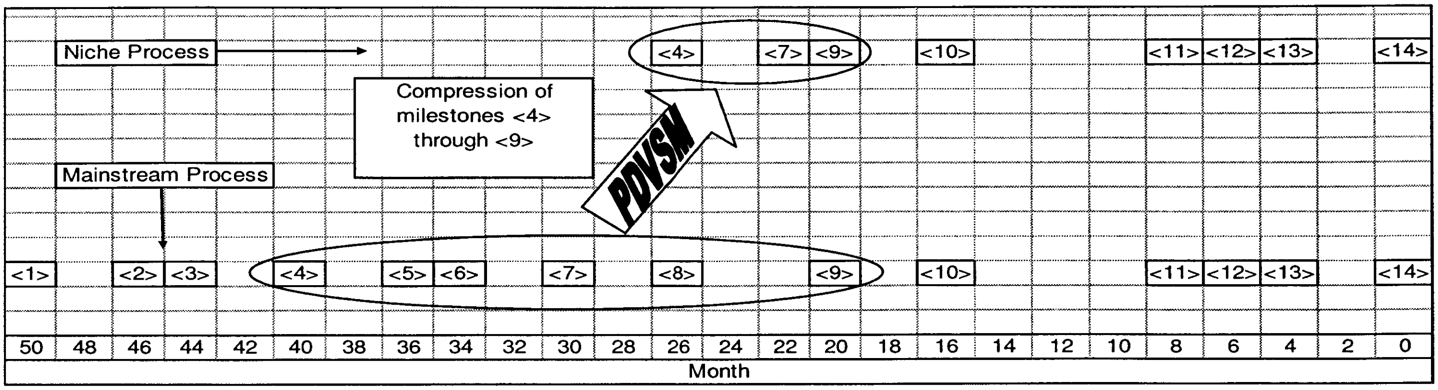

Figure 1: Compression of Milestones <4> Through <9>

To understand the magnitude of this challenge it is important to realize the number of deliverables that are required to pass through the gateways of milestones <4> through <9>. A breakdown of each milestone and its deliverables can be seen below in Table 3. The total deliverables are all of those specified by OEM-A's generic PDP. The "as defined" deliverables are those that NVPDO completes as specified by the generic process. "Non-required" deliverables are those that do not apply to NVPDO. In most cases this is because the output of the deliverable for NVPDO is the same as it is for the mainstream platform team and no additional work is required by NVPDO. In only a few cases it is because NVPDO has recognized the deliverable as non-value-added and has already removed the deliverable from the niche vehicle PDP. "Modified" deliverables are those that NVPDO completes but the process is modified versus generic. Table 3 shows that only 18% of the generic process deliverables are not required for NVPDO. With the desired 14 month compression between milestones <4> and <9> this means that NVPDO's goal is to do 82% of the work specified by the generic PDP in only 36% of the time. Table 3 is shown graphically in Figure 2 below.

Milestone	<4>	<5>	<6>	<7>	<8>	<9>	Total	% of Total
Total Deliverables	41	63	26	64	20	52	266	100.0
Total As Defined Deliverables	19	37	18	52	17	42	185	69.5
Total Non-required Deliverables	14	18	4	6	2	5	49	18.4
Total Modified Deliverables	8	9	4	6	1	5	33	12.4

Table 3: Deliverables by Milestone

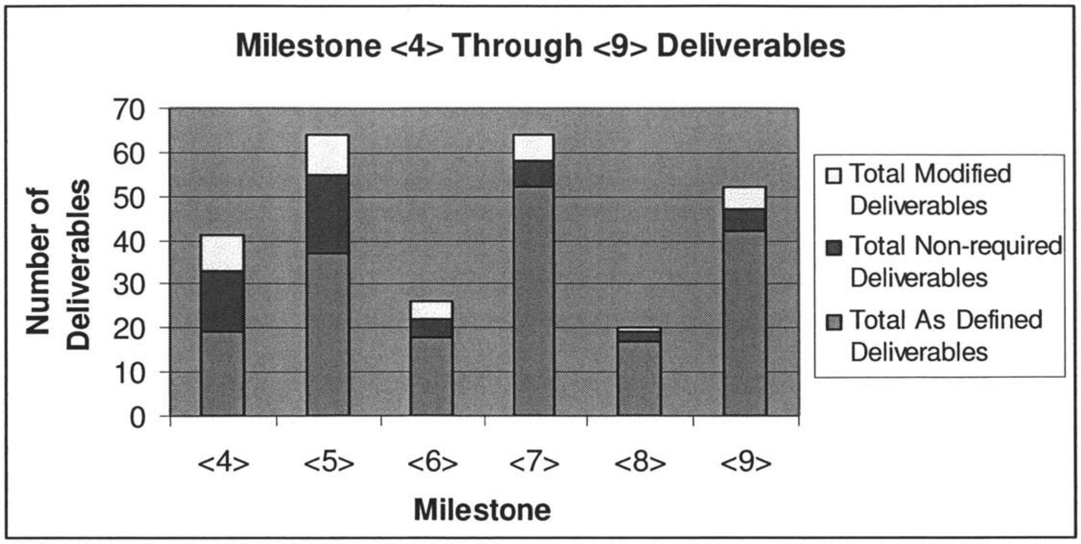

Figure 2: Deliverables by Milestone

From Figure 2 above it is easy to see that the percentage of modified and non-required deliverables declines as the program reaches later stages. This confirms that the current NVPDO niche vehicle PDP begins to look more like the OEM-A generic PDP as milestone <10> is approached. From that point on there is no unique NVPDO PDP. To further this analysis the "as defined" and "modified" deliverables required by NVPDO were categorized by which of the 8 areas of responsibility owns the deliverable. This can be seen below in Table 4.

Milestone	<4>	<5>	<6>	<7>	<8>	<9>	Total	% of Total
Marketing	6	0	0	2	0	0	8	3.7
Engineering	6	22	9	20	9	25	91	41.7
Manufacturing	3	0	1	10	0	1	15	6.9
Corporate Design	2	4	0	5	3	5	19	8.7
Finance	2	1	1	2	0	0	6	2.8
Program Management	7	15	8	12	6	13	61	28.0
Prototype Planning	1	2	1	5	0	1	10	4.6
Purchasing	0	2	2	2	0	2	8	3.7
Total	27	46	22	58	18	47	218	100.0

Table 4: Deliverables by Owner

Table 4 indicates that there are 218 total deliverables required by the current NVPDO PDP from milestones <4> through <9>. Since these are the design intensive milestones, almost 42% of the deliverables are owned by engineering. The second largest grouping, at 28%, is owned by program management. Each deliverable, of course, is made up of tasks to achieve the deliverable. There are literally thousands of tasks that make up the 218 deliverables. To keep things simple only the largest tasks are included in the PDVSM.

Understanding how much work takes place between milestones <4> and <9> is only the first part of bounding the problem. Following the steps of the PDVSM manual, the next step is identifying the process owner. The owner who has direct responsibility for this value stream is the NVPDO Program Manager for ProgramX. This is the individual who reports to the Chief Engineer of NVPDO and has the responsibility of managing and delivering ProgramX. Next, explicitly stating the output of the process helps the team to understand the reason that the process exists in the first place. The output is defined as the value generated by the process. In this case study, the most valuable output generated between milestones <4> and <9> is the final engineering release of the designs of the new tooled end items and components. This is basically a production tooling kick-off. Of course, there are other outputs of value such as the manufacturing launch plan, the vehicle analytical sign-off, completed 3D data, and important program evaluations such as vehicle performance versus objectives for each of the vehicle attributes. There are many customers of this data. The primary customers are the suppliers that receive the engineering releases to kick-off their tooling processes. OEM-A management is another primary customer. These are the vice presidents that review the launch plans, analytical sign-offs and vehicle evaluations to give ProgramX approval to proceed to milestone <10>.

Since the case study of ProgramX is beginning at milestone <4> there are, of course, many inputs into the processes that take place between milestones <4> and <9>. There is a vehicle design specification that gets cascaded to all of the teams which is a cascade of all of the requirements that the vehicle must meet. These are external government requirements and internal requirements decided by OEM-A. There is market research which defines the end user customer's must haves, wants and desires for the vehicle. There are target ranges which have been decided for each of the vehicle attributes, there are targets for vehicle investment and cost, and there is the pre-existing vehicle architecture background information which forms the starting point for most packaging and design studies. Along with these initial inputs generated from the milestones prior to <4> there is also existing knowledge that get pulled into the process such as the mainstream vehicle specifications, performance, and quality data. There are also lessons learned from the mainstream vehicle development that help improve the NVPDO design process.

As with any process there are many constraints placed on the vehicle development that occurs between milestones <4> and <9>. The first major constraint is manufacturing capability. There are constraints in the tooling and the materials that drive component designs and performance levels. There are also constraints at the final assembly plant that drives how much complexity can be introduced by the NVPDO niche vehicle. Often times the final assembly plant places limitations on vehicle content as a result of complexity issues. There are constraints placed on the development program by the affordable business structure of the program. This drives how much content can be afforded by the program. There are resource constraints placed on the development team. These are in the form of bodies and prototype properties. The NVPDO teams are much smaller than the mainstream vehicle teams and therefore there is a limit to how much work can be absorbed by the team. NVPDO engineering budgets are also much smaller than mainstream and this limits the amount of prototype properties that can be afforded by the program. This in turn limits the amount of work that can be accomplished in the given time and often results in teams waiting for vehicles to become available for testing designs. Government regulations place design constraints on the development teams and the existing vehicle architecture places packaging constraints on the design teams. Lastly, the OEM-A enterprise itself places timing constraints on the program team, dictating when the product is required in the marketplace which often limits the amount of development time available to the program team.

All of the elements mentioned above form the boundaries of the process under study. They are summarized below in Figure 3.

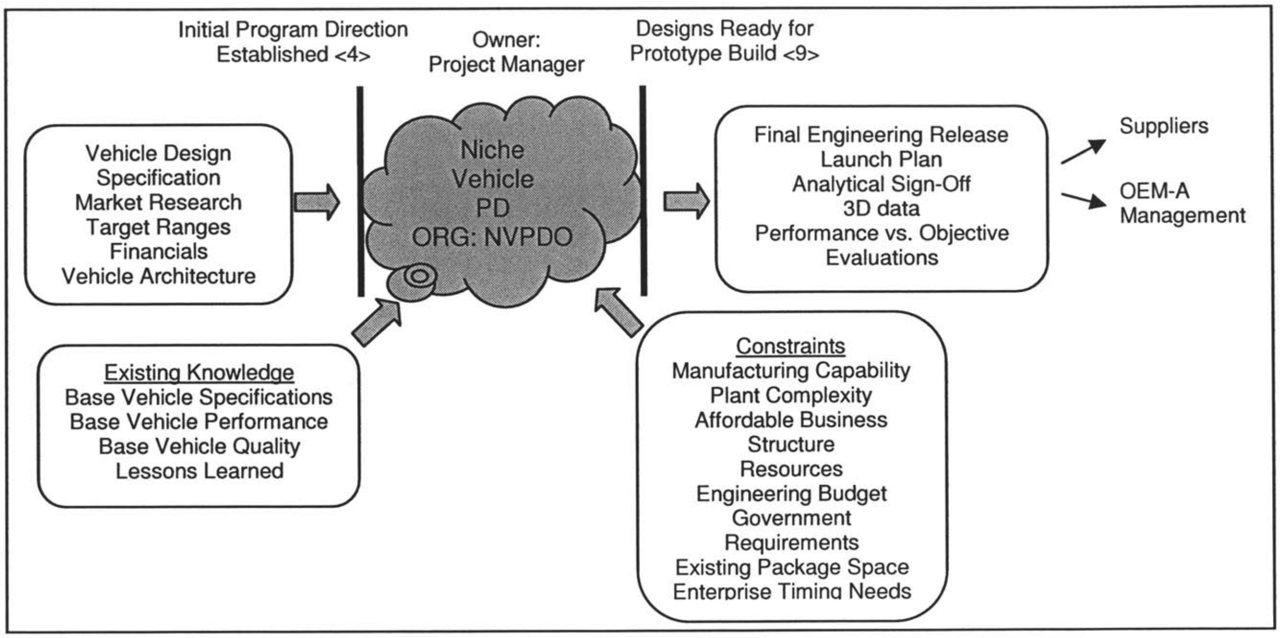

Figure 3: Boundary of the Process

4.3 The Current Process Value Stream

Once the boundaries of the process are identified the next step in the PDVSM process is to define the value created by the process. The value must be defined in a way that will allow each task to be measured by how it contributes to creating that value. The PDVSM manual recommends doing this by creating a goal statement for the process output. This way the process can be measured against whether or not it contributes to the goal. Tasks that do not contribute to the process goal are then easily identified and can be labeled as non-value added. The NVPDO PDVSM team decided to concentrate on Final Engineering Release, the major and most valuable output of the selected process. This was also because engineering has the most tasks to complete between milestones <4> and <9> and is believed to be the bottleneck to making the 8 month timing constraint. With these considerations, the team decided on the following goal statement for the process illustrated above in Figure 3:

Deliver Final Engineering Release of the right product that meets all of the input objectives (performance, cost, weight, quality, regulations) 8 months after initial program direction is established (milestone <4>).

Since the primary goal is to reduce the time it takes to complete the process the metric that was measured was cycle time for each task.

Each task in the value stream must be evaluated on how it contributes to the process goal. In order to do this there are aspects of value must be chosen by the team. These are aspects of the total process value that each task could contribute. The team's initial choice for the primary aspects of value to consider was:

V1. Definition of End Product with Desired Functional Performance

This was defined by the team to be any task that contributes *directly* to defining the form or function of the end product. Detailed design work in CAD would be an example of this.

V3. Reduction of Risks and Uncertainties

This was defined by the team to be any task that contributes to eliminating uncertainties in performance, quality, or robustness of the end product. Running component or system tests would be an example of this.

V4. Forming Final Output

This was defined by the team as any task that contributes to the final documentation necessitated by the process. Creating the drawings for Final Engineering Release would be an example of this.

V6. Enabling Other Tasks

This was defined by the team to be any task that is required for other tasks to proceed. Enabling tasks do not contribute directly to the design of the end product. An example of this would be some of the management reviews that must take place for the teams to continue working.

Choosing the aspects of value to consider completes the up-front work that must be done prior to drawing the actual value stream maps. Several iterations of the value stream maps were drawn by hand. The first attempt was to map the overall process that takes place between milestones <4> and <9>. This quickly became large and overwhelming with numerous parallel paths. However, the exercise was valuable in that it pointed out several large sub-processes that take place through the milestones which are highly independent. The engineering tasks were able to be separated into three distinct engineering sub-processes that take place in parallel. These are body engineering, chassis engineering and powertrain engineering. The other program tasks such as program management, finance and purchasing, could then be considered independent of engineering.

The first consideration in the value stream mapping process is how detailed to make the map. There were various schools of thought regarding complexity of the maps from participants in NVPDO. Some felt that a highly detailed map would reveal small pockets of improvement opportunities that would add up to large improvement opportunities. Others felt that given the magnitude of the task at hand only large improvement opportunities were going to make a difference and therefore the maps should be kept at a fairly high level. After attempting a very detailed map it became clear that looking at the higher level tasks and iterations would be enough to reveal the primary issues in the processes.

The information for each sub-process was collected through in-person meetings with the stakeholders of the processes. In most cases these were the design engineers themselves which were conducting the detailed engineering work that takes place between milestones <4> and <9>. These small team meetings would start with identifying the major tasks and then mapping the work flows and information flows. The engineers would then consult their personal records, internal service providers or external suppliers to determine the cycle time of each task. The cycle times collected were actual times to complete the tasks on ProgramX, therefore weekends and holidays are included in these cycle times. This process was completed for body, chassis, and powertrain engineering. Each mapped sub-process is presented here in detail.

Body Engineering

The body engineering value stream map is shown below in Figure 4. This process encompasses the exterior design and release of a new product. It starts in the clay studio and ends with the final engineering release of the body exterior components. The component that takes the most time to design and engineer was chosen as the case study for this map. The body engineering process was broken down into 18 major tasks, seen below in Table 5, and 3 major reviews that take place between milestones <4> and <9>.

Body Engineering Tasks	
1. Mill Single Clay Theme	10. Conduct Requirements CAE Study
2. Conduct Clay Feasibility Studies	11. Complete Design Phase 1 Data
3. Preliminary Surfacing in CAD	12. Complete Surfacing with Cheat Information
4. Mill Clay to Design Surface	13. Fabrication of Test Parts
5. Preliminary Design of Structure	14. Complete Surface Verification
6. Rework of Surface as Necessary	15. Complete Design Phase 2 Data
7. Final Surfacing in CAD	16. Testing of Prototype Parts
8. Cut Cube Model of Final Surface	17. Complete Final Design Data
9. Conduct Surface Cheat CAE Study	18. Engineering Release of Final Design

Table 5: Description of Body Engineering Tasks

Looking at the VSM, tasks are indicated by rectangles and reviews are indicated by ovals. Major program decision points are indicated by the diamond shapes. The small triangles are wait times. These are points in the process where information is stored in inventory until the receiving task is ready to use it. The solid arrows are major information flows and the thin arrows are minor flows, usually feedback flows. The rectangles with rounded corners indicate external factors that are inputs into the process. The different colors indicate the aspect of value that is contributed by each task and review. The red arrows indicate the critical path of the process; this is the longest path required to deliver the output. The bursts indicate areas of particular interest or concern. The "WFR" bursts indicate instances where the process is waiting for resources that are needed to continue. The bursts labeled "BAD" indicate tasks that provide incorrect information and often result in rework. The bursts labeled "LL" indicate tasks where particular lessons were learned for future process improvement. The tasks presented here are high level and each task has a sub-process to completing it. The "LL" indicates that there are areas of improvement evident in the sub-process behind the task.

As mentioned, there are 3 major reviews in this process. The first review is a decision point that takes place after task 4. This is where management must decide whether or not they approve the appearance model. If they do, the process flows to task 7. If they do not the process flows to task 6 which is a rework loop. There is a lot of uncertainty in the process at this point. It is unclear how many iterations of surfacing and management review will be required before approval is given to proceed to final surfacing. When the program does its work planning, program management has to assume that the design team will achieve "home runs" and no rework will be required, therefore no rework is included in the critical path. The second review takes place after task 8, cube modeling. There is a small wait between the two because the cube model review requires upper-management support and often at least a week goes by before all the right people can meet at the same time. This is a high level review of the surfaces modeled physically before they are released to suppliers for component design. This is the last opportunity to catch any errors or irregularities in the surface work. The third review is an engineering design review of the completed component designs before they are released for tooling.

The critical path on the body engineering value stream map indicates that the process is currently taking 47.5 weeks on ProgramX. This is approximately 11 months, not the 8 months desired by NVPDO. 3 months must be removed from the NVPDO body engineering process to meet the goal of the NVPDO strategy. Value stream mapping the body engineering process identified several points of interest where process improvements are possible and are as follows:

Task 3: Preliminary surfacing was identified as a task that often puts out incorrect information. The team felt that erroneous information was released by this task too often. In some cases the information did not match what was requested and in other cases the information didn't meet some of the program constraints such as packaging. Touch conditions or complete interferences were found when the data was imported and examined.

Task 8: Cube modeling was labeled as lesson learned. Here it was felt that the process of cube modeling takes too much time and could be shortened by use of new technologies. The team agreed to investigate this process further; however, this task is not on the critical path.

Task 13: Fabrication of test parts was also labeled as lesson learned. Once again the team felt that too much time passed before the parts were available. It was felt that alternative methods of part fabrication could be used to shorten this task. Because of the amount of time it took to make and test parts, the results of testing were not available to feed into the final design. If failures were experienced in testing this would require a rework to the design and would delay the final engineering release. This task is not on the critical path but could have a high impact on the critical path if a serious testing failure was experienced.

There are two wait periods in the VSM labeled as "wait for resources". The first is between tasks 7 and 9 and is on the critical path. Value stream mapping brought to the team's attention that the program waited 7 weeks for the information released by task 7 to go though CAE (task 9). A CAE analyst was not available to do the job and it sat until a resource became available after a lot of prodding by NVPDO management. There is a large opportunity for improvement here. The second "WFR" wait occurs between task 13 and 16. Here the parts fabricated in task 13 sit and wait for a car to become available for testing. The team discovered that the program waited for the parts to be finished before requesting a vehicle. This wait could have been avoided with better work planning. The body engineering VSM is seen below in Figure 4.

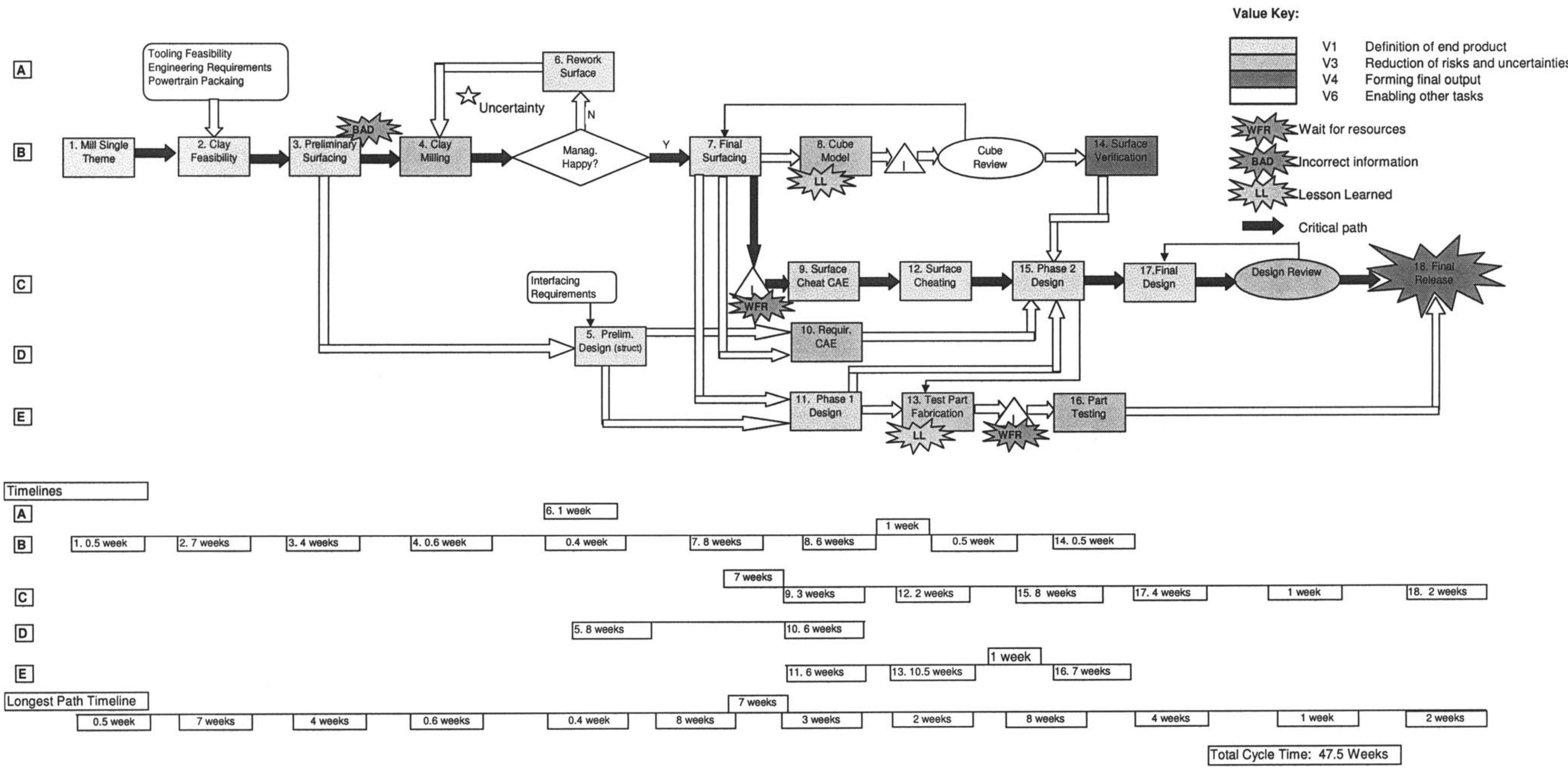

Figure 4: Body Engineering PDVSM

Chassis Engineering

Chassis engineering determines vehicle dynamics, the ride and handling characteristics of the vehicle. There are two parallel paths that feed into the chassis design, tuneables and road loads. Tuneables is the selection of components that tune the final ride and handling of the vehicle such as shock absorbers and springs. Road load engineering determines the forces that will be present under various conditions to ensure the strength and durability of suspension designs. The chassis engineering value stream map is seen in Figure 5.

The chassis engineering process was broken into 17 tasks, described in Table 6, and 2 decision points. The first decision point is regarding tuneables and takes place between tasks 6 and 7. This is a review where NVPDO management drives a vehicle with the selected tuneables for approval. If approval is granted the program proceeds to tuneable freeze and the selections are cascaded to design. If approval is not granted the process starts over at task 3. Once again it is uncertain how much rework will be required and rework is not afforded on the critical path.

Chassis Engineering Tasks	
1. Competitive Vehicle Drive	10. Process Phase 1 Test Data
2. Vehicle Dynamics Target Setting	11. Complete Design Phase 1 Data
3. Adams Dynamic Modeling	12. Release Long Lead Components
4. Order Tuneables for Testing	13. Retrofit Road Loads Vehicle
5. Tunable Testing Session	14. Complete Phase 2 Road Load Tests
6. Prepare Management Car	15. Process Phase 2 Test Data
7. Freeze Tunable Selection	16. Complete Design Phase 2 Data
8. Build Road Loads Test Car	17. Engineering Release of Final Design
9. Complete Phase 1 Road Load Tests	

Table 6: Description of Chassis Engineering Tasks

The second decision point is regarding road load data. Unfortunately NVPDO's "go fast" programs do not allow for all analytical analysis to be completed before long-lead tools must be kicked-off to meet prototype timing needs. Chassis engineering, therefore must start designs with road load data from mainstream that has been scaled for the increased weight and power levels of NVPDO's performance derivatives. These assumptions are then used to create initial designs for the phase 1 road loads car. The data from phase 1 road loads is then used to create phase 1 design data. Long-lead tools must be kicked-off from phase 1 designs due to timing constraints. The phase 1 designs are then retrofitted onto the road loads vehicle to run phase 2 road loads. Phase 2 is meant to be design verification before final release. When phase 2 road loads are complete there is a second decision point. This is where the data must be analyzed to ensure that the phase 1 designs are sufficient. If no changes are required the information flows to final release. There is, of course, a risk that changes will be required, indicated by the "RSK" burst on task 12 (long lead release). If something unexpected is identified in phase 2 road loads there is a chance that the long lead designs kicked-off 18 weeks earlier are no longer sufficient. This is a significant cost and timing risk to ProgramX that was identified though VSM.

The critical path on the chassis engineering VSM indicates that 50 weeks are required to complete the major tasks between milestones <4> and <9>. This is once again a little over 11 months and not the 8 months desired by NVPDO. The following areas of interest were identified through the VSM process:

Task 2: The team identified target setting as a process that results in "BAD" information. The targets that get cascaded out of this process are based on benchmarking and are usually incompatible with what is achievable by the vehicle architecture. The team also experienced a great deal of assumption changes along the way on ProgramX that resulted in the originally agreed upon targets being invalid.

Task 9: Phase 1 road load acquirement was identified as a lesson learned. The vehicle assumptions were changing rapidly and the team had difficulty putting a stake in the design and letting it go. This consequently held up all of the downstream tasks on the critical path.

Task 10: The data cascaded from phase 1 road loads was labeled as "BAD". As a result of the program assumption changes the data that was cascaded out of phase 1 road loads was no longer relevant to the program. This resulted in a great deal of retrofits for phase 2 road loads and made the phase 2 road load data required for final design, holding up the release of long lead items (task 12) and risking prototype build timing.

The chassis engineering VSM can be seen below in Figure 5.

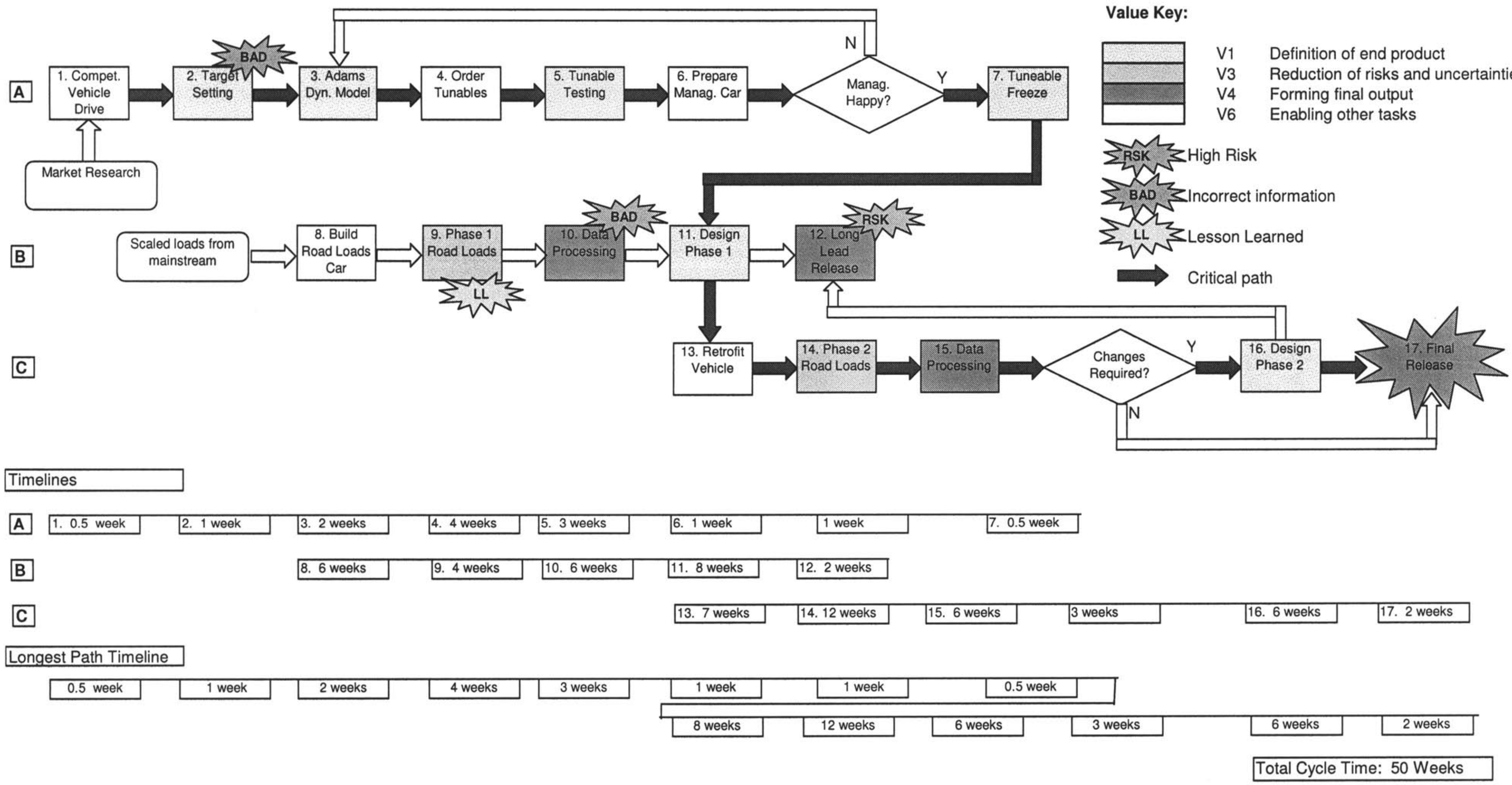

Figure 5: Chassis Engineering PDVSM

Powertrain Engineering

Powertrain engineering develops the unique engines for NVPDO's high performance niche vehicles. Their process includes packaging of the all new powertrain in the space defined by the mainstream architecture as well as development of the power, calibration of the powertrain control module (PCM), and detailed design of unique components. All of these activities are going on in parallel which makes the powertrain VSM complicated to draw. The version that the team felt best represents the process can be seen in Figure 6. Since there are so many activities taking place at the same time even more tasks were lumped together in this process. The powertrain VSM has 17 major tasks and a number of detailed reviews which are all indicated by one oval called "compatibility reviews". The tasks are listed below in Table 7.

Powertrain Engineering Tasks

1. Work Horse Lab Testing
2. Work Horse Dyno Testing
3. Detailed Hardware Design
4. Advanced Prototype PCM Devel.
5. Advanced Prototype (AP) Build
6. AP Power Sorting
7. Pass-By Noise Development
8. Refinement of Design
9. AP Dyno Mapping
10. AP Air, Fuel and Cooling Development
11. AP Lab Testing
12. Fall AP Development Trip
13. Release of Long Lead Components
14. AP Cold Development Trip
15. Final Engineering Release
16. AP Wind Tunnel Testing
17. AP Altitude Trip

Table 7: Description of Powertrain Tasks

The critical path of the powertrain VSM shows that the process from milestone <4> to milestone <9> took 56 weeks on ProgramX. This is more than a year and over four months more than the desired time of 8 months. The tasks in this VSM extend beyond the milestone <9> deliverable of final engineering release indicating that all of the development work is not complete when ProgramX requires designs to be released. The 10 week wait time shown between task 3 and task 5 is one large improvement opportunity. Since the chassis engineering assumptions were changing rapidly powertrain was waiting for chassis to freeze designs to build prototypes. This wait time resulted in powertrain missing a summer season for hot weather testing, adding risk to ProgramX. Other areas of interest on the powertrain VSM are as follows:

Task 5: The process of building advanced prototypes was labeled as a lesson learned. The powertrain team felt that the program waited too long for chassis to provide information, missing the valuable hot weather testing season as mentioned. Powertrain felt that an earlier prototype design freeze would have been valuable. Even if the prototyped designs were not entirely correct some powertrain testing could have been completed over the summer season. It was felt that some information, even if only directional, would have been better than no information at all. This task was also labeled lesson learned in a favorable regard. Powertrain engineering is outsourced at NVPDO and the advanced prototypes are built by the same source. Many of the same individuals that are developing the powertrain are also following the build activity. This is a large learning opportunity and provides the engineers with a great deal of hands on experience with the vehicles before the prototypes are delivered. This speeds learning as well as identification and resolution of issues allowing the overall process to proceed quicker than it would if the prototypes were being built by a unique source and delivered to the team when they are complete.

Task 13: Long lead release is once again labeled as a risk. Looking at the VSM it is clear that a great amount of development work and prototype testing is not completed when long lead tools need to be kicked off. Once again the risk is that something will be identified in later testing that forces a design change to components that have already been kicked off. This is a great timing and cost risk to ProgramX.

The compatibility reviews are also labeled lesson learned. These are detailed design reviews where each system is reviewed for conformance to packaging, regulations, and interface requirements. The process is required to meet the deliverables of milestone <9>. The ProgramX team learned a great deal going though this process for the first time. At first the meetings were long and there were many of them, one for each activity (body, powertrain, chassis). Eventually the teams worked together to have fewer meetings that deliver more results. This more efficient process will be cascaded to future NVPDO product development teams. The powertrain VSM can be seen below in Figure 6.

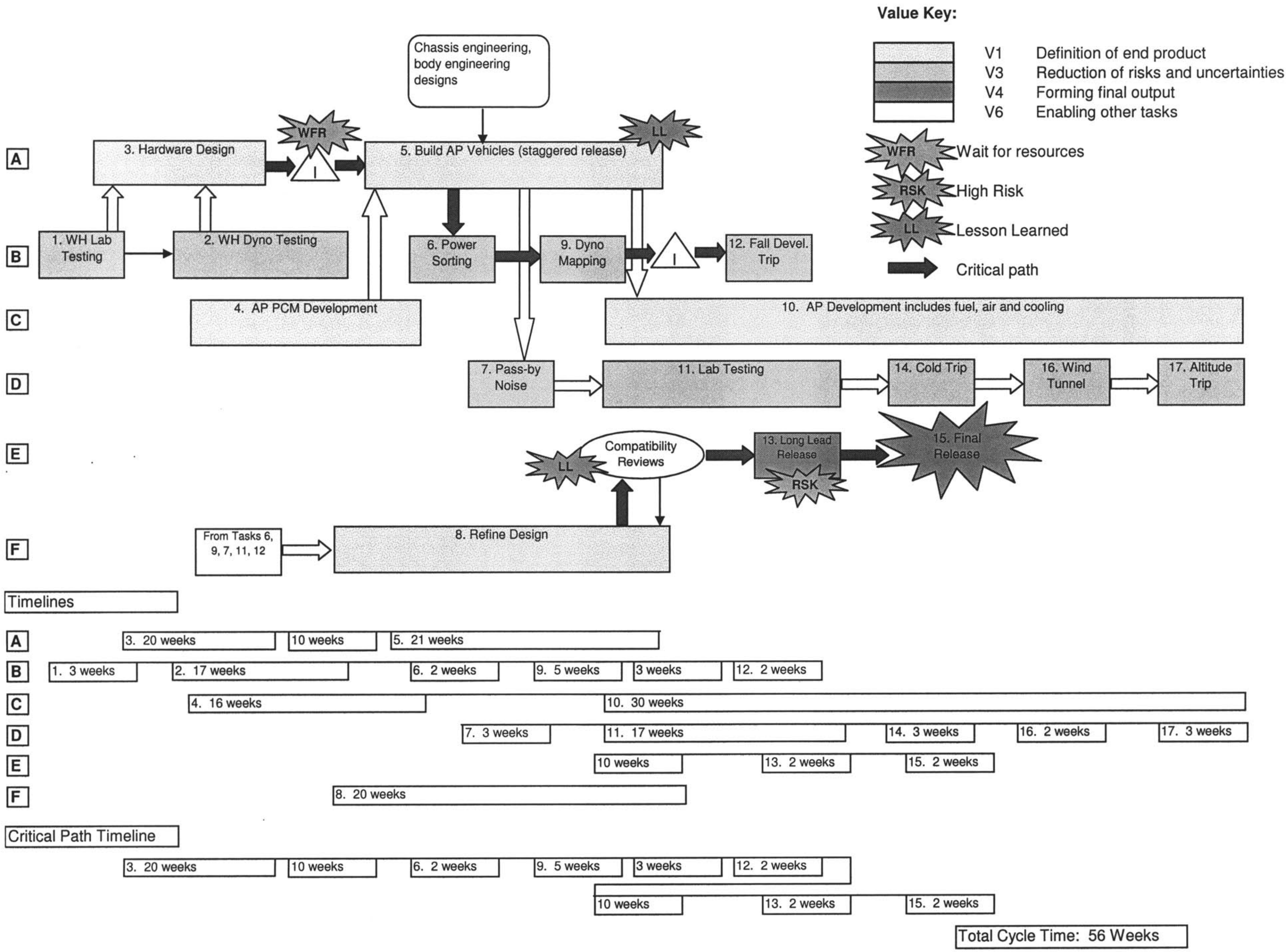

Figure 6: Powertrain Engineering PDVSM

5.0 Desired Future State Niche Vehicle Processes

5.1 Introduction of Desired Future State

Once the value stream maps are complete and the areas of waste are identified the next step is identifying ways to improve the process. Implementation of process improvements leads to development of a future state map. The body, chassis, and powertrain mapping exercise helped NVPDO to identify common and unique process improvement opportunities. To draw a true future state map, however, a deep dive into more detailed maps of each process would be required. The idea of the analysis completed by NVPDO was to identify the large opportunities first. These are things that can be done to close the gap between current process timing on ProgramX and the desired timing presented in the NVPDO enhanced product design strategy. Each VSM was revisited and a desired future state map was produced. The result is a process map which represents what the teams felt were achievable targets for process timing. Process improvements were then identified that would work toward achieving the desired future states, however, additional work at a more detailed level would be required to determine a true future state. The desired future state maps and associated process improvement recommendations are presented here for each activity.

5.2 Desired Future State of Body Engineering Process

The desired future state map of the body engineering product development process is shown in Figure 7. The desired process has been simplified and revised to contain 16 major tasks that take 40.5 weeks to execute. This is equivalent to 9 months and is the recommended process time between milestones <4> and <9> for programs with body exterior content similar to ProgramX. In the revised map the rework loop has been eliminated. The 7 week wait for resources between final surfacing and surface cheat CAE has also been eliminated. The cube model process is revised from an 8 week process into a single task called digital surface verification that takes no more than 1 week. The test part fabrication and testing is shortened and the wait for resources is eliminated. Together these actions save another 6 weeks. The changes to surface verification and part testing allow for part fabrication and testing to be moved onto the critical path. The test results are therefore obtained before completion of design phase 2, rather than at final release. This eliminates risk to the final release. In addition, final surfacing has been revised from an 8 week task to a 6 week task and 1 week has been taken out of final release. The following are considerations, lessons learned and recommendations that will work toward achieving this desired future state:

1. The root causes of the erroneous information coming out of task 3, preliminary surfacing, were lack of communication and late sourcing decisions. The exterior components on ProgramX are sourced to full service suppliers that have complete design responsibility for the parts. The studio surfacing comes from another supplier that provides surface data to each of the component suppliers and back to the studio for milling. There are also a number of other suppliers providing background information for packaging. There are numerous communication channels to manage. On top of that, some components were waiting for purchasing to agree on supply sources, leaving no one to do early designs and provide information back to the program. When interferences were found in the surfaces created by the surface supplier and sent back to ProgramX the root cause was almost always a missing piece of supplier information that the surface supplier did not have. Each of the suppliers was given a contact sheet that listed names and numbers for all of the interfacing suppliers and the surface supplier. At first they were expected to work amongst themselves to seek out the information required to ensure that their designs met all packaging constraints and program requirements. In hindsight this was not happening. The solution was implementation of a weekly team meeting that brought all the suppliers together to review the data that was being developed each week. In theory this meeting exists as part of the process however it was not implemented soon enough on ProgramX. Part of the reason for this was that engineering was waiting for all of the parts to be sourced so that all of the suppliers would be represented at the meeting. The process would have been better served to have the meeting start right away and to have each supplier join the meeting as they came on board. The best solution, however, would be collocation of suppliers.

Having a representative from each supplier onsite would enable real-time communication and eliminate defective data. Engineers would have more time to work, rather than attending frequent reviews and the supplier integration bottleneck would be eliminated. This, however, is difficult to implement because there are space limitations at NVPDO's facility and supplier reps are not dedicated to NVPDO programs. They work on mainstream programs and they also work on programs for other OEMs.

2. Styling changes drive rework into the process. Since exterior components are primarily cosmetic and low risk, up front work planning determines design freeze dates that are required to deliver production tools for first prototypes. This is a cost and time savings to NVPDO's niche vehicle programs. The timing for this is often very tight; the generic process that NVPDO works from is not designed for production tools at first prototypes. NVPDO applies lean principles to its tooling processes to achieve this. ProgramX had a studio design freeze date, determined through work planning that met the timing needs for production tools. The design freeze date was actually met on ProgramX and final surfaces were released on time. The appropriate reviews were conducted to get management's concurrence of the design freeze. Shortly thereafter an OEM-A executive walked through the studio and requested a surface change. The final surface had to be called back from the supplier and cube modeling put on hold while the surfaces were reworked. An abundance of late changes and late decisions resulted in exterior parts missing the first prototype build date or ProgramX paying tooling compression costs to meet timing. Addressing these issues, however, is a challenge. Frequent reviews ensure that everyone's wants are aligned and reduces late styling changes however no one can afford to spend all of their time in meetings. Management must understand the impact of the changes they enforce on the program and be willing to adjust program timing accordingly. Alignment upfront, however, would eliminate rework and work towards shortening the process overall.

3. Internal communication and strict work planning is required to ensure availability of resources on time. The 7 week wait for a CAE resource to complete surface cheat CAE was the result of a resource loss which was not communicated back to ProgramX. About the time that ProgramX was expecting to receive results they were informed that the work had not begun because a resource was not available. ProgramX had to work though OEM-A management to get the job prioritized and started. ProgramX did not have a good communication channel with support services within OEM-A such as CAE. NVPDO does not have internal CAE capability and must rely on the mainstream resources to complete jobs. Weekly timing reviews of program tasks versus work plan timing have since been implemented to catch these disconnects and resolve them sooner.

4. New technologies should be implemented. The current body engineering process includes 6 weeks for cube modeling. This is the physical act of cutting a property to the final surface release to ensure that no errors are present in the data. A digital process has been identified which eliminates the need for physical properties at a cost savings of $200,000 and a time savings of 5 weeks. The studios are equipped for digital surface reviews and verification but the equipment is under utilized. The cube model process could be considered a "monument" in this case. Things continue to be done the way they've always been done rather than adopting a new technology. The cube model monument should be eliminated.

5. Rapid prototyping should be embraced. Test part fabrication can be decreased to 4 weeks by utilizing rapid prototyping technologies where testing allows rather than costly and timely fiberglass parts. This is another case of a monument in the process that should be eliminated.

6. Final release is a process of feeding the system the necessary documentation and obtaining the appropriate sign-offs. Work planning enables the documentation to be prepared on time. Often the hold-up is in the sign-offs because they tend to sit in

people's cues. If the information is walked through the system and the appropriate resources are available this task can be reduced to 1 week.

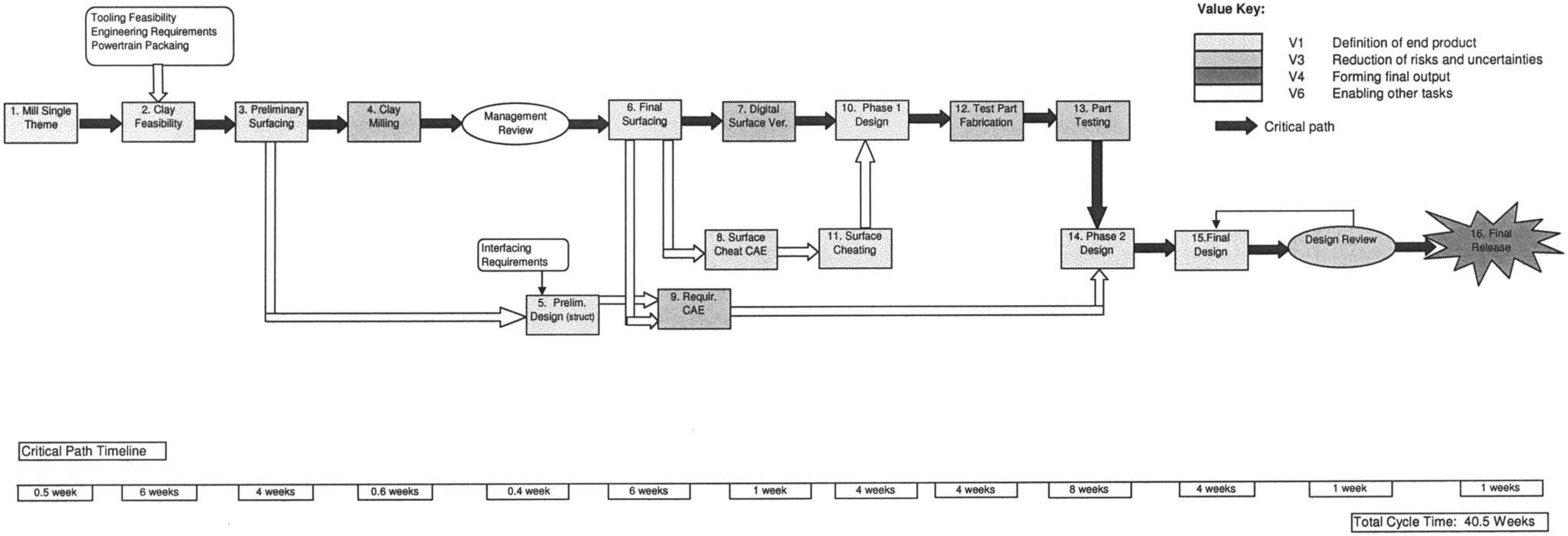

Figure 7: Body Engineering Desired Future State

5.3 Desired Future State of Chassis Engineering Process

The desired future state of the chassis engineering product development process is shown in Figure 8. The desire is to reduce the process from 17 major tasks taking 50 weeks to 14 major tasks taking 38.5 weeks to complete. This is 8.5 months and is only a few weeks off of the NVPDO product enhancement strategy goal of 8 months. The tuneables value stream is unchanged, the tuneable process is iterative by nature and the team did not have high confidence that it could be controlled better. There are, of course, opportunities to improve the quality of the analytical data and reduce the number of iterations. It is important to note that only one iteration through the process is shown on the critical path. The desired process runs road load testing once, at the right time and with the correct data, and therefore the output is good and feeds into long and short term designs and releases. Eliminating the need to rerun road loads puts the first series of testing on the critical path. Design phase 1 becomes dedicated to long lead designs and risk to the long lead releases is reduced. Design phase 2 becomes design completion and feeds into final release which has been reduced to a one week task as it was in body engineering. NVPDO can work toward achieving this desired process timing in the following ways:

1. Target setting drives the process. Setting unachievable targets results in program assumption changes which delay the process. ProgramX set upfront targets that engineering was not able to meet. Chassis engineering dedicated all of its resources to designing to the original targets. When management realized that the direction was not going to achieve the targets they decided to abandon the design effort, revise the targets, and change the program direction at great cost and timing to ProgramX. Time spent upstream in the process setting appropriate and achievable targets will save considerable time downstream in the process.

2. Test the right thing at the right time. Testing for the sake of doing something is a waste of time and resources. Road load data was generated three times on ProgramX. The first time the loads were generated analytically because it was too early in the program for a prototype to be available for testing. The loads from

mainstream test data were scaled to generate early assumptions of what loads may be acting on ProgramX. The scaled loads were "worst case" conservative loads which were later found to be high. Initiating designs with the higher load assumptions resulted in excessive engineering work. Then a certain set of program assumptions was used to produce the phase 1 road loads vehicle and generate the first set of physical road load data. Around the time that this data was being cascaded to the teams the program assumptions changed drastically and required that the prototype be modified and road load data be collected again. This is a common problem that is difficult to avoid. There is a fine line between "running with what you got" to keep the program moving and completing something that will likely need to be done again when more definition is available. Unanticipated assumptions changes driven by upper management cannot be planned for.

3. Improve prototype availability through early need recognition. Computer analysis is not always a suitable alternative to physical testing. ProgramX did not have a vehicle prototype available early enough to run phase 1 road loads at the needed time and therefore the scaled loads were used to keep things moving. The additional engineering work incurred as a result of the overly conservative load assumptions could have been avoided with the availability of physical data. Prototype requirements and the resources needed to deliver them need to be recognized early and contained in the program upfront. The desired future state process map moves phase 1 road loads up earlier in the process assuming that a prototype could be made available when required.

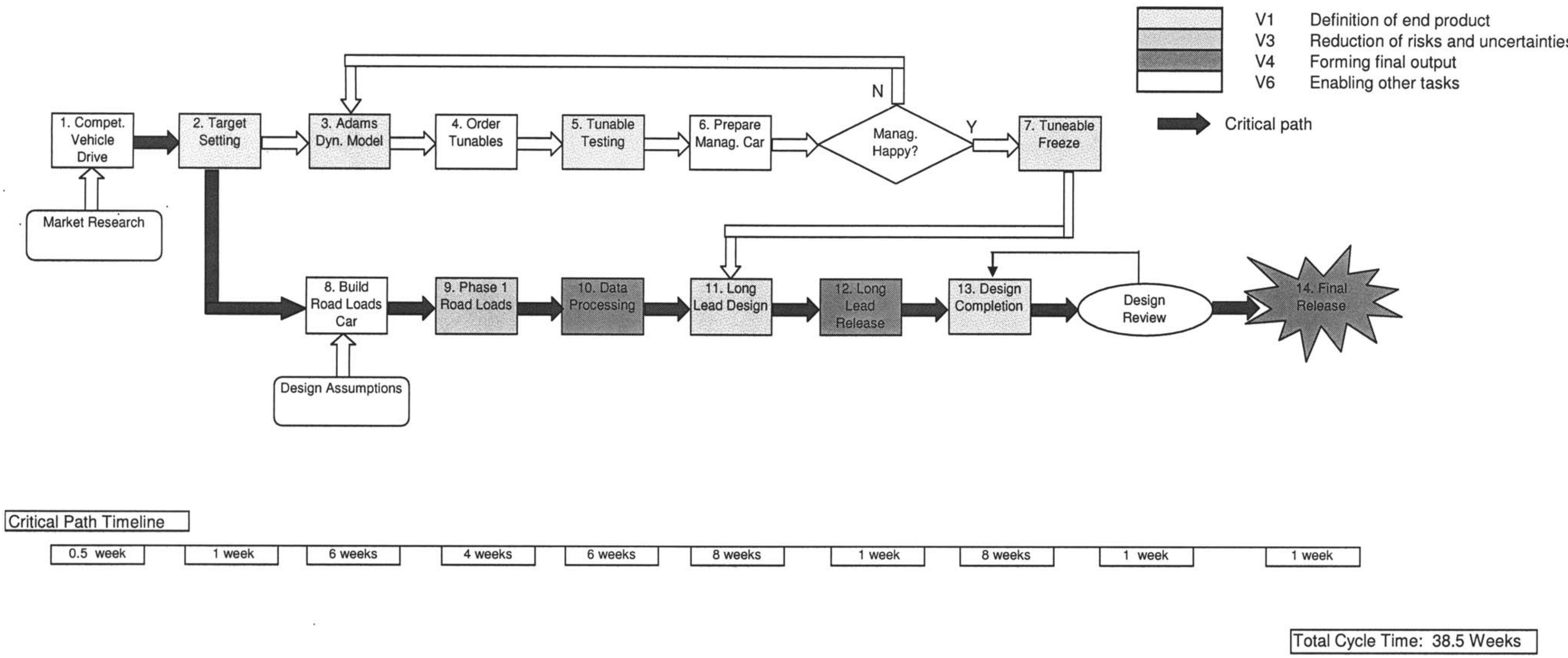

Figure 8: Chassis Engineering Desired Future State

5.4 Desired Future State of Powertrain Engineering Process

The desired future state of the powertrain engineering product development process is shown in Figure 9. The new process contains 17 tasks through final release which take 41 weeks to complete. The 10 week wait for resources between hardware design (task 3) and build AP prototypes (task 5) is eliminated in the desired process. This moves all other tasks upstream and allows more development and design tasks to be completed before long lead and final release minimizing risk. The development trip (task 12) is now called summer development trip and is extended to 3 weeks to allow for additional hot weather testing. Long lead release becomes concurrent with compatibility reviews and comes off of the critical path. The compatibility reviews themselves are reduced to a 2 week period in which all of the design reviews are conducted prior to final release. The desired process takes 9 months to achieve final release; however, there are still some development tasks that have not completed prior to final release. This is the nature of the powertrain process. Development is ongoing through all of the prototyping phases. Most powertrain components are small and have short tooling lead times. The objective of the process is to complete enough development between milestones <4> and <9> to kick long lead components off with high confidence and minimal risk. NVPDO can work toward achieving this desired future state by considering the following:

1. Working parallel paths takes resources away from the primary program direction slowing the overall process. Powertrain is an area where NVPDO can "what if" itself endlessly. The high performance business is highly competitive and there is always a desired to deliver more power and higher speeds. Powertrain is always being challenged to push design limits. Suppliers are constantly being asked what more they could do, even though program assumptions have been set and original targets have been met. At one point in time 3 different powertrain assumptions were being followed on ProgramX. This is normal during the program definition phase but it is a bottleneck beyond that. In order for programs to "go fast" assumptions must be firmly held otherwise rework is inevitable. NVPDO must limit the amount of extracurricular studies that they ask suppliers to perform.

2. Prototype intensive development processes such as powertrain stand idle when prototypes are not available. Meeting prototype timing is vital to delivering overall process timing. The desired future state of the powertrain engineering process has no slack for the prototype build task (task 5) to be waiting for parts from other activities. In the current state map the powertrain process sat idle for 10 weeks waiting for chassis to freeze their prototype designs. By not allowing ProgramX to adjust the overall program timing as a result of the unanticipated bottleneck the end product was put at higher risk. Designs were released with less development time leaving more opportunity for late changes.

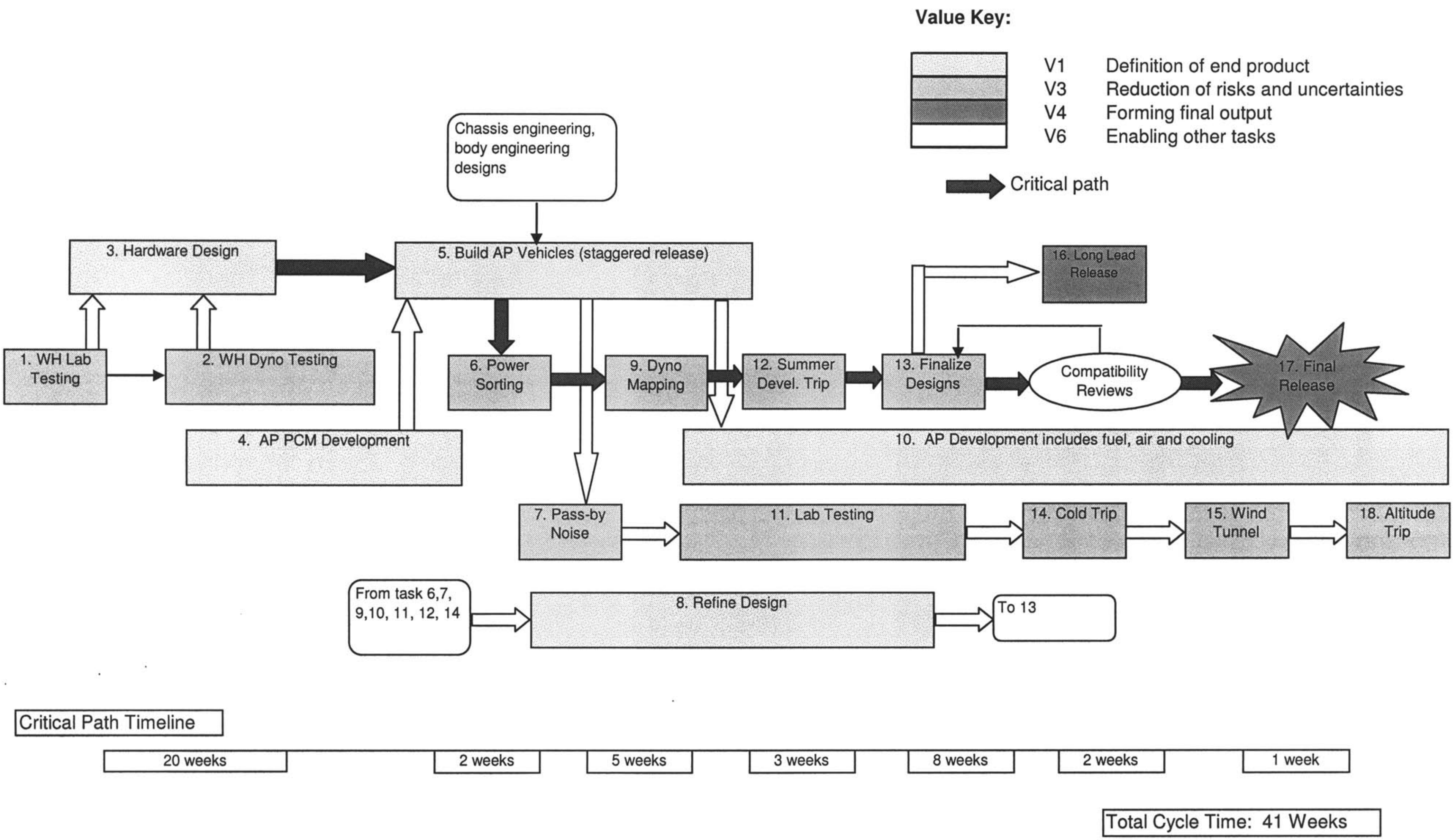

Figure 9: Powertrain Engineering Desired Future State

6.0 Other Considerations for Achieving the Desired Future State

6.1 Introduction

Chapter 5 presented the desired future state of the three primary engineering processes for NVPDO: body, chassis and powertrain. Specific areas where NVPDO could work towards achieving the desired future state for each process were pointed out. The three processes presented are only a snapshot of the work that goes into completing the 218 deliverables required by the NVPDO PDP between milestones <4> and <9>. The value stream mapping was completed at a very high level to point out fundamental process flaws and wastes in each value stream. Each of the tasks contains a process in and of itself that runs with support from numerous internal activities and external suppliers. The team meetings that were conducted to complete the VSM exercises brought to the surface many areas common across all processes where improvement opportunities existed. Improvements in the areas that support the tasks will work towards improving the cycle time of each task and therefore improving the overall cycle time of each process presented in Chapter 5. Without implementation and observation the effect of each opportunity is not directly measurable and is therefore not represented on the desired future state maps previously discussed. The recognized opportunities for leaning out and speeding up the overall NVPDO product development cycle are discussed here.

6.2 Base Platform Actions

NVPDO niche vehicle product development actually starts with the design of the mainstream vehicle of which the niche vehicle is a derivative of. Vehicle architectures are designed by mainstream engineering years before the niche derivative programs are kicked-off. Leaning of the NVPDO process should start with better alignment between NVPDO and the base program during the base program design stages. The NVPDO process study introduced two areas where alignment between the programs could be improved: target setting and knowledge sharing.

Target Setting

Cost and investment targets are set for the development of the base vehicle at program kick-off. These targets for vehicle architecture development do not include provisions for NVPDO derivatives. NVPDO unique powertrains and suspensions drive unique requirements, additional complexity, and additional material into the base vehicle architecture. The mainstream programs are usually struggling to meet aggressive targets and cannot incur any additional costs for a future niche program possibility. Alternatively when unique features are included in the base design for NVPDO future use they are first to get deleted when the mainstream program finds itself not meeting its targets.

For example, NVPDO must package larger powertrains and larger wheels and tires into the mainstream vehicle platform. When design considerations are not made for packaging these components in the base vehicle design it becomes challenging for NVPDO to design the unique components. Packaging requirements must be deviated which it makes it difficult for manufacturing to assemble the components. NVPDO incurs additional engineering costs and manufacturing costs as well as timing delays while trying to solve difficult problems.

The NVPDO process could be simplified if a few considerations were allowed in the mainstream platform development. The most common challenges are as follows:

- Engine decking of larger powertrains requires considerations in the front structure such as width between rails.
- Larger powertrains require more underhood package space.
- Larger wheel and tire packages require larger packaging envelopes in the wheel wells for clearance.
- NVPDO adds additional stress to the vehicle structure in the way of additional weight and higher forces which require structural upgrades for durability.
- The additional NVPDO content changes the crash characteristics of the vehicle which also results in changes to the vehicle structure.

- Upgrading materials on appearance items becomes simple if it is planned for. For example, a two piece door panel allows NVPDO to upgrade the insert material without tooling a whole new door panel; however a one piece door panel is less cost and less complexity for mainstream.

The recommendation is to allow for a piece price and investment provision in the base vehicle development targets. This provision would exist for use specifically on the elements of design required only for the NVPDO niche vehicles but which drive additional cost into the base platform. NVPDO would be required to work within this targeted provision. As long as NVPDO is within the target the NVPDO specific design actions can not be cancelled by the base program. Ultimately this saves OEM-A time and money. When designed upfront, many of the solutions to the above listed challenges faced by NVPDO are simpler to develop, less expensive to incorporate, and more elegant than when retrofitted into the base platform later. Implementation of this recommendation is feasible if political and cultural barriers can be crossed. Organizationally NVPDO has operated as a "skunk-works" operation completely independent of the mainstream vehicle teams. Because of the high amount of media coverage around high performance vehicles NVPDO keeps many of its plans secret from other organizations within OEM-A to avoid potential information leaks to the public. Upfront alignment with mainstream would require NVPDO to reveal its program assumptions early and would require both organizations (mainstream and NVPDO) to work as partners rather than separate entities.

<u>Knowledge Sharing</u>

The base platform product development team accumulates documentation and lessons learned which can speed NVPDO product development if properly shared. NVPDO shares many components with mainstream and modifies a lot of mainstream parts. Currently, with the separation between the base and NVPDO programs there is no formal process for knowledge sharing between programs for shared and modified components. There are e-rooms where documents are stored that are difficult to navigate if not organized and maintained well. NVPDO engineers reported that they waste a fair amount of time seeking out information that already exists to avoid rework. Time is wasted in finding the appropriate contacts, making phone calls and waiting for already busy people to respond to the request. NVPDO often finds itself reproducing the following types of information when it can not be located or is not provided when needed:

- Quality histories
- Robustness documentation such as P-diagrams
- Test plans
- Failure mode and effects analysis (design and process)
- Component target agreements
- Engineering statements of work

It is also beneficial for NVPDO and mainstream to share lessons learned. NVPDO can learn pitfalls to avoid by reviewing base program's test reports and vice versa. Sharing of documents such as milestone report outs is also beneficial. When going through milestone reviews it is helpful to upper management decision makers if the same types of information are presented in formats that are familiar. Less time is spent reviewing documentation in meetings when the information is recognized.

The recommendation is to implement a formal knowledge sharing procedure between NVPDO program teams and base platform development teams. Shared e-rooms used currently are a stepping stone to this process. No new costly systems are required, just more discipline in the management and organization of e-rooms and a common process that is used at both NVPDO and mainstream. Also, there is currently no formal requirement that information be placed on the e-rooms, it is simply a tool. NVPDO engineering is at the mercy of what mainstream has volunteered to make available. The information should be standardized and engineering must be held accountable to make the information available.

6.3 Program Management Actions

Program management is responsible for 28% of the work that takes place between milestones <4> and <9>. There is no formal process for the work that program management completes that could be shown in a value stream map. NVPDO is a product development activity where value is generated by delivering a vehicle to customers. The engineering activities are therefore the primary generators of value; however, program management performs tasks that ultimately work to keep the engineering processes moving forward. The 61 program management deliverables include development of program assumptions, work planning to develop program timing, documentation to support milestone reviews, process management, and tracking of metrics to keep management informed of program health. The case study of ProgramX has resulted in lessons learned regarding work planning, milestone management and process management which are discussed here.

Work Planning

One thing NVPDO has learned through the study of ProgramX is the value of work planning. Typically NVPDO programs do not have a dedicated work planner tracking overall program timing. The task is consumed by the program management personnel. Eventually on ProgramX program content grew to a level where the task was unmanageable by a shared resource and program timing was not being tracked to a level which sufficiently identified timing risks. Engineering was identifying risks however management kept getting surprised because the information was not being sufficiently collected and reported. NVPDO had to ask for help and borrow a skilled work planning resource from mainstream to dedicate to the task. This greatly aided risk identification as well as communication to management which resulted in quick response and improved time to resolution. NVPDO found that detailed work planning resulted in early identification of timing issues such as:

- High risk tooling kick-offs because insufficient analytical data was available when the tooling kick-off was required to meet manufacturing timing

- Tooling kick-offs too late to support manufacturing requirements for prototype builds
- Prototype parts late to prototype build
- Finished prototype not available for scheduled testing
- Scheduled milestone gateway review incompatible with completed deliverables

The recommendation is for each NVPDO program to employ a dedicated work planning resource at program kick-off (milestone <1>). On ProgramX the resource was brought in when the program was out of control. A lot of time could have been saved by having the resource on board from day one. Implementation of this recommendation requires that NVPDO have the available headcount and budget to bring in an additional resource on future programs. If program content is manageable one highly skilled resource could be shared between programs. NVPDO will have to negotiate with management and perhaps identify an offset to allow for the additional resource.

Milestone Management

Any process at OEM-A, be it at NVPDO or mainstream, operates through gateway reviews at each milestone. The required milestone deliverables are summarized to OEM-A management through presentation and written papers. If the deliverables meet management's expectations the program is given approval to proceed to the next milestone. Preparation for these milestone reviews is a work intensive program management and engineering task. After all, engineering is providing most of the information that goes into the reviews. Program management is collecting the information and putting it into the appropriate format for management review. These milestone reviews generate a tremendous amount of rework at NVPDO that takes time and resources away from the engineering critical paths.

NVPDO is plagued with milestone drift. The department prepares for a milestone review on a certain date and commonly finds a critical piece of information missing or deliverable incomplete. The milestone date is moved to the next available review usually two or three weeks ahead. All of the activities that generated information and documentation for the original review date are then asked two weeks later to update the work because progress has been ongoing. It is not unusual for this cycle of generating and regenerating presentations and reports to continue for months. Engineering has expressed a great deal of frustration with this mode of operation. It happens when program management sets overly aggressive targets for milestone review dates or when program assumptions are changed without allowing any timing changes.

Go fast programs require aggressive timing and there is always a risk of not getting everything done in time. There should therefore be a formal process within NVPDO for evaluating milestone readiness prior to the documentation requirement date. If the program desires the most up-to-date information in the documentation at the milestone review there must be a way to generate the information once, at the right time. Implementation of such a process requires appropriate reporting by engineering and communication with management.

Process Management

Consistent delivery of quality products requires a consistent and repeatable process. OEM-A and NVPDO strive for continuous improvement and therefore implementation of process improvements is expected. The process, however, should be in control and only value-added changes should be implemented. Typically NVPDO has had authority to delete non-value-added tasks from the PDP. On ProgramX, however, engineering reported numerous process changes, driven by management, many of which were considered non-value-added.

Over time the content and complexity of NVPDO vehicle development programs has grown. As this has been occurring the NVPDO PDP has grown to look more like the OEM-A generic process. More and more administrative tasks previously deleted from the niche process are being requested. Also systems that NVPDO were exempt from using have become mandatory. This has slowed down engineering considerably. Time is consumed in training on new systems that deliver the same results as previous NVPDO processes and more time is dedicated to non-value-added tasks. In some cases new processes requirements were mandated late requiring engineering to go back and make up the work. Ongoing process changes have cost ProgramX considerable engineering time.

The solution is to have the NVPDO program team and management agree on process elements at the beginning of a program and for all parties to stick with the agreement. Engineering must recognize that increased program complexity requires a more disciplined process to make sure nothing is missed; however, management must find a balance between adhering to the process disciplines and keeping the program "go fast". Changing the process along the way seems to breed frustration and generate more work for engineering activities and program management.

6.4 Purchasing Actions

NVPDO uses OME-A's purchasing services. Purchasing is one area where NVPDO does not deviate far from the mainstream process. Since the niche vehicles are produced at the same manufacturing facilities as their mainstream derivatives NVPDO works with the same buyers and suppliers as the mainstream programs. It is believed that NVPDO would benefit from having dedicated low volume buyers and in some cases unique suppliers. A case for each is presented below.

Material Buyers

NVPDO niche vehicle programs are low volume, typically 10,000 units per year or less. The mainstream derivatives are produced in volumes upwards of 150,000 units per year. The low volume business differs from the high volume business because low volume programs are more sensitive to investment and less sensitive to piece cost since the end customer pays a premium for the product. Also, the low volume programs have material upgrades which increase component piece prices over mainstream. OEM-A purchasing is accustomed to the high volume business where investments are high and prices are low. NVPDO loses time when mainstream buyers negotiate with suppliers for lower prices as a result of not understanding the low volume business. "Go fast" programs require quick purchasing response since there is a great deal of outsourcing and getting suppliers onboard quickly is a major process enabler. Sharing purchasing resources with mainstream is difficult because of the workload placed on buyers by the mainstream programs. Niche programs with low volumes and limited content do not take priority with mainstream purchasing and understandably so since much higher volumes are at stake when mainstream issues arise. NVPDO engineers spend time waiting for purchasing responses. All of these issues can be eliminated by developing dedicated low volume buyers. These resources would be knowledgeable of low volume business and available specifically to niche vehicle programs. NVPDO has been aware of this need but implementation has been difficult. OEM-A purchasing is not organized in a way which allows dedicated low volume niche buyers and NVPDO is too small to contain its own purchasing activity. There are political and cultural barriers that must be overcome. As NVPDO grows and partners more closely with mainstream this could become reality.

Suppliers

NVPDO currently has no choice but to use mainstream buyers and the same is true of suppliers. OEM-A purchasing has a very detailed and disciplined process for choosing quality suppliers for its products. Vehicle programs work with purchasing to choose a pre-approved supplier for each commodity. The way the process is set up now NVPDO must work from the same pool of pre-approved suppliers as mainstream. This works well in the case of modified mainstream components where the base design of the component is carry-over with the exception of small changes such as material upgrades. The current process should remain the same for modified components for the following reasons:

- Mainstream supplier has full knowledge of the part history and part interfaces and uses lessons learned to avoid issues on the modified components
- Design of the modified components is quick because the supplier owns the CAD data and all of the documentation of the mainstream part
- The existing supplier has already developed relationships with purchasing and manufacturing

There are some issues that arise with mainstream suppliers, however, on components that are all new and used only on an NVPDO niche vehicle program. Much like the buyers in purchasing, the mainstream suppliers are just that, mainstream suppliers. When mainstream issues arise the supplier must tend to them immediately and any NVPDO needs are put aside. Design reviews get skipped and NVPDO engineers are left waiting for information. NVPDO's "go fast" nature requires suppliers that will treat NVPDO programs as a priority. NVPDO would also benefit from being able to choose unique suppliers on low volume new tooled end items because mainstream suppliers build high volume tools which are capable of delivering hundreds of thousands of shots. NVPDO requires on the order of 40,000 shots for the life of a vehicle program. High volume production tooling for a hood, for example, can cost as much as $5,000,000 and take as long as a year to produce, a huge investment for a tool that will see only a small fraction of its useful life. A low volume supplier using low volume technology could tool the same part for $500,000 and approximately 24 weeks, however the piece price would be much greater because more labor is required to produce a quality part off of low volume tooling. Because of the growing popularity of niche vehicles new businesses providing low volume manufacturing are developing. NVPDO could save significant investment costs by using low volume specialty suppliers. Being able to use unique suppliers would allow NVPDO to deliver more content with the same investment budget, surely a strong program want.

Developing a unique low volume supply base for NVPDO programs poses many challenges. OEM-A incurs costs each year associated with maintaining suppliers and ensuring that each supplier is meeting the OEM-A requirements. For this reason OEM-A limits the size of the supplier pool overall and it is difficult to request that a new supplier be allowed in, especially one that will only be producing 10,000 parts per year. On top of that it is also very expensive for the business to be an OEM-A supplier. Many of the desired low volume suppliers are small businesses and cannot afford to go through the process. Bringing new suppliers into OEM-A final assembly plants is challenging as well. The plants are judged on their product quality and they must trust their supplier quality. They are reluctant to allow components to be manufactured by suppliers that they do not know and trust even if they are in the supply pool. Prior to new technologies low volume tooling was known for supplying low quality parts but this is changing with today's low volume tooling technologies such as kirksite injection mold tooling and bladder presses for sheet metal. For NVPDO to build a unique supply base of low volume providers OEM-A purchasing would have to loosen their supplier quotas and requirements, making it feasible and affordable for low volume suppliers to join the pool and manufacturing would have to agree.

6.5 Manufacturing Actions

NVPDO niche vehicles are manufactured alongside their mainstream derivatives at OEM-A assembly plants. Since the assembly locations are shared upfront alignment between NVPDO, mainstream and manufacturing is critical. Currently manufacturing has a strong presence in the NVPDO development process after the niche vehicle program has been kicked-off. Manufacturing performs cost and feasibility studies as program assumptions solidify. With multiple vehicles being manufactured in each plant manufacturing's reluctance to study the program assumptions too early is understandable. Frequent assumption changes occur early in the product development processes and they drive too much rework for manufacturing. However, waiting too long for detailed manufacturing studies has driven excessive rework on the engineering side when assumptions come back non-feasible or too costly to implement. The frequent hard rock between NVPDO and manufacturing during the development process has historically been added complexity which places content limitations on the NVPDO programs.

It is important to note that the mainstream vehicle is already in production when the niche derivative is under development along with any other vehicles assembled at the manufacturing facility. When NVPDO defines a new niche vehicle manufacturing must determine what capacity it has available to build the vehicle. The following limitations are placed on NVPDO vehicle programs by mainstream manufacturing assembly plants:

- Floor space along the line available for stock: Parts take up space. Although NVPDO programs are low volume any part in the niche program must have space to sit on the line because the niche vehicles are not batch built. For example, if the NVPDO vehicle has a unique steering wheel there must be room on line to store the mainstream steering wheel and the NVPDO steering wheel. If the NVPDO wheel is offered in two or more colors this is additional space required on the line. Line space is always a premium commodity with programs wanting ever more content to make their vehicles sell. In some cases manufacturing cannot accommodate all of NVDPO's vehicle assumptions because there is simply not enough line space to assemble all of the components.
- Labor heads available: Some of NVPDO's components are pure trades for mainstream parts. Seats, for example, are unique on the niche vehicles however they replace the mainstream seats and are assembled in the same manner by the same labor workers when a niche vehicle is coming down the line. Other parts, such as intercooler radiators for supercharged engines, are purely incremental. The mainstream car does not have this part and therefore there is not a labor worker on the line to assemble it. If the job cannot be consumed by an underutilized worker and an additional worker must be added to the line, NVPDO is charged the overhead cost. NVPDO content is limited by how many additional heads the program can afford in manufacturing.
- Body-in-white limitations in the body shop: The body shop assembles the sheet metal shells, called bodies-in-white, of the vehicles and feeds them to the line for final assembly. Unique sheet metal components for niche vehicles such as hoods and rear decklids require a unique body-in-white to be tracked in the body shop. Body shops are not designed to handle a lot of complexity. Vehicles usually get personalized in final assembly with different levels of trim. NVPDO architecture changes which require a high level of differentiation in the body shop are difficult and costly to implement. Body shops are challenged to keep up with mainstream line speed and additional content slows output. NVPDO is charged for lost units as a result of additional time required to manufacture NVPDO vehicles. NVPDO is also

directly responsible for any tooling required in the body shop for assembling NVPDO unique vehicle content.

- Modification center availability: Mod centers are areas on site at the manufacturing facility where content which is uncontainable by the assembly line is delivered. Large decals on hoods or along the side of vehicles or any type of hand touches such as pin stripping are good examples. These are time and labor intensive touches which cannot be delivered with quality at line speed. In these cases the vehicle is brought off-line to a unique area. Some manufacturing sites have the room on-site to offer this but some do not. In cases where such content is desirable but unavailable NVPDO must choose between not offering the content to the customer and finding an alternative location to provide the content such as at the dealer, a very high cost alternative.
- Capacity of equipment: NVPDO is limited by the equipment capability at the mainstream assembly location. Assembly aids such as engine and suspension decking machines were specified long before the NVPDO programs existed. As mentioned NVPDO has larger powertrains and stiffer suspensions than mainstream. NVPDO is limited by the capacity of the engine decking and suspension compression machines. Late identification of such issues cost ProgramX a great amount of time. The springs selected through the tunable process were so stiff that the suspension decking machine was lifting the entire vehicle out of its cradle when trying to deck the suspension. Weeks were spent trying to find a suitable solution.

The costs of manufacturing NVPDO niche vehicles at the mainstream assembly plants have been steadily rising with growing program content and increased complexity. A lot of development time is spent resolving issues such as those mentioned above. It is becoming increasingly difficult to offer the NVPDO customer more content given the current manufacturing process. NVPDO finds itself looking at external locations to provide content that is not containable by the assembly plant. This is an expensive proposition since the vehicle would have to be shipped from the plant to some external mod center and then back to the plant to go though the distribution process.

NVPDO would benefit from a dedicated manufacturing facility for derivative vehicles. This is not a new concept as the need has been recognized many times throughout the life of NVPDO. The idea is for NVPDO to have its own facility dedicated to manufacturing niche derivative vehicles. Since NVPDO starts with a mainstream vehicle and makes modifications from there the sibling vehicles could be purchased from their manufacturing assembly plants and brought to the NVPDO dedicated facility for retrofits. This eliminates the constraints placed on niche vehicle content by the mainstream assembly plants. Implementation, however, is a big and costly job. OEM-A must be willing to make the high investment for a dedicated facility. A detailed cost trade-off study would need to be conducted to make sure that the large investment adds additional value to the enterprise. A distribution process would have to be worked out between the mainstream manufacturing plant and NVPDO that would allow NVPDO to buy reduced content vehicles. NVPDO would want to buy vehicles with no powertrains to avoid having to take the mainstream powertrain out and replace it with the new one. Or if NVPDO had to buy fully contented vehicles there would need to be a way for NVPDO to sell the take-out components back to the assembly plant. Shipping of vehicles from the mainstream assembly plant to the NVPDO modification facility would need to be arranged. OEM-A would need to recognize the facility as a manufacturing location to allow distribution of niche vehicles directly from the mod center. NVPDO would then become solely responsible for the quality of the outgoing niche vehicles. With volumes of no more than 10,000 units per year all of NVPDO's niche vehicle programs could be processed out of a single facility.

6.6 Management Considerations

NVPDO has historically benefited from minimal management. For the first seven years there was an NVPDO chief who reported directly to an OEM-A vice president. The individual program managers within NVPDO reported to the chief. There was overall three layers of management. This was very unique from the mainstream organization which contains many layers of middle management. The short direct line to an OEM-A decision maker saved a lot of time through elimination of multiple reviews which in turn streamlined the milestone gateway approval process.

In the last three years this organization has changed. As the number of NVPDO programs increased and as program complexity grew additional management came onboard. On ProgramX the program managers reported to an NVPDO chief engineer who reported to the NVPDO director. The NVPDO director reported to a higher organization director who reported to an OEM-A vice president. There were five layers of management during this time and ProgramX experienced a noticeable slowdown as a result. With so many managers in the mix management alignment becomes critical to the "go fast" nature of niche vehicle programs. NVPDO witnessed an increase in rework under this organization. Milestone review papers are generated and reviewed with one manager and reworked to their liking. The paper is then taken to the next layer of management and additionally reworked to their liking. This becomes a cyclic event when major differences of opinion exist. Fortunately OEM-A recognized the inefficiency of this organization and has once again reorganized NVPDO. The program managers continue to report to an NVPDO chief engineer who now reports to a new organization director who reports directly to an OEM-A executive vice president. Today there are four layers of management in effect. Frequent reorganizations however, generate new inefficiencies as people learn the business and become accustomed to their new roles. The NVPDO experience has proven that "Go fast" organizations such as niche vehicle development departments work best when management is stable and minimized with a short hierarchy to final decision makers.

The management program review process at NVPDO has also changed over the years with the organization. Historically milestone reviews have revolved around prototype demonstration vehicles accompanied by a short presentation of program metrics to a small group of decision makers. NVPDO always felt that the business was about products and that the product should prove itself ready to move to the next milestone. Overtime documentation requirements have grown as the NVPDO program approval process has changed. Today the approval process mirrors mainstream and documentation requirements are equivalent. So much time is spent in approval meetings reviewing program documentation that the demonstration vehicles no longer get driven by decision makers. The unique approval process for NVPDO was a major "go fast" enabler. The transition to the mainstream approval process has added time to the NVPDO process cycle time. The recommendation is for OEM-A to once again allow a modified program approval process for "go fast" programs which revolves around vehicle evaluations rather than document evaluations. Niche programs require that time be maximized on product development tasks and minimized on administrative tasks. Implementation of a unique approval process for NVPDO requires a cultural understanding. NVPDO programs are developed different and managed different than mainstream programs. They should therefore be approved differently. The department cannot find new ways to "think outside the box" and deliver programs quicker when they are being held to the strict requirements of the mainstream approval process.

6.7 Resource Considerations

As with any organization, NVPDO's most valuable resource is its people. In order to go as fast as possible NVPDO programs must have enough people with the right skills organized in an efficient structure. Figure 10 below gives a highly simplified approximation of how NVPDO is currently organized. There are a number of things to notice. Each program has a program supervisor who is the overall program manager. Each supervisor has their own program management and body engineering personnel reporting to them. Powertrain engineering is a separate group with its own supervisor who assigns a dedicated engineer to follow each program. These engineers are dotted line to the program supervisors. Chassis again is a separate group which distributes its resources across each NVPDO program; however, chassis organizes its engineers functionally and has each engineer performing a function on all programs. The chassis engineers are also dotted line to the program supervisors. It is easy to see that chassis and powertrain engineering experience greater cross program learning and information sharing than program management and body engineering. The chassis group has the most efficient structure having each engineer perform a function on every program, learning from past experience and continuously improving task execution. The program management and body engineering reporting structures do little for overall process improvement. For example, each program has its own engineer working on seats and the engineers do not report to a common supervisor. Lessons learned between programs are limited to the communication amongst these different program engineers. There is no formal process for information sharing between programs on these activities.

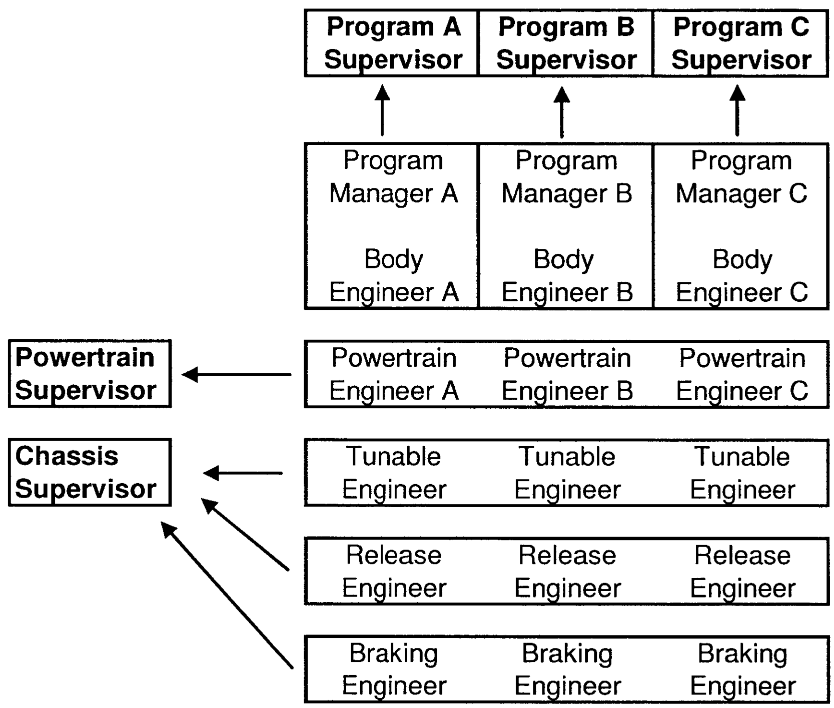

Figure 10: NVPDO Organization

There is also inefficiency generated by having so many different reporting structures in one organization. Tasks requiring approvals spend time trying to locate the appropriate authority. Chassis and powertrain engineers report experiences with receiving different directions from the two supervisors they report to, generating wait times or rework.

The NVPDO process would become more efficient overall if the department was organized as recommended below in Figure 11. The number of supervisors remains the same but they become functionally responsible. Body engineering, vehicle engineering and program management groups are formed that work across all vehicle programs like chassis and powertrain currently do. Body is best arranged like chassis with interior, exterior and structural engineers working across vehicle lines. Vehicle engineering is a group currently missing in the NVPDO organization; however the need for such a group has been identified. This group becomes responsible for the overall engineering deliverables which do not fall into the detailed categories of body, chassis, or powertrain. Each program has a program manager responsible for integration of all of the activities. These could become supervisor level positions if headcount allows.

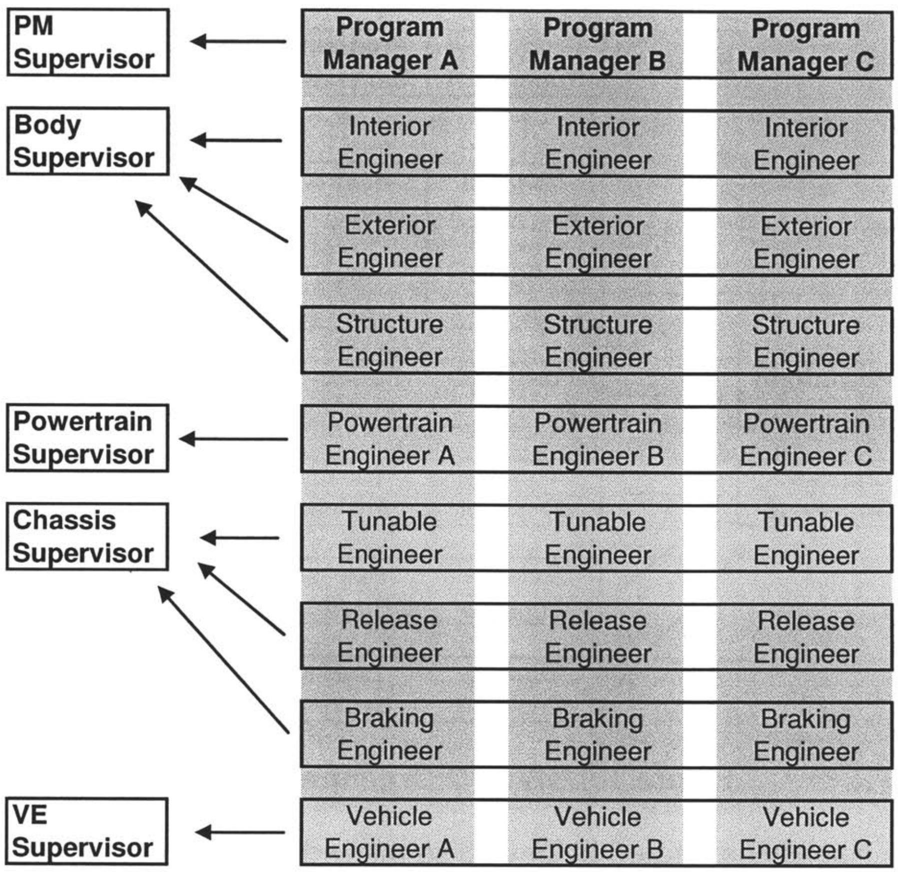

Figure 11: Recommended NVPDO Organization

This type of organizational structure affords the most efficiencies between programs and would help shorten the overall product development cycle time at NVPDO because repeat issues would be avoided. NVPDO is a limited resource department and therefore each position holds a lot of responsibility. This requires NVPDO to employ experienced engineers. "Go fast" programs do not have time for on-the-job learning. NVPDO must adopt a "best-of-the-best" mentality. In order for the organizational structure to be successful in finding efficiencies the personnel must be stable. A lot of movement and development of "jack-of-all-trades" engineers only slows the process as people learn new jobs over and over again. Implementation of this recommendation would require approval of the NVPDO director and acceptance of change by the

NVPDO engineering community. Physically performing the reorganization is simple since NVPDO is not a large department and the activities are collocated.

Another important resource consideration is quantity. As program content and complexity has grown over the years the size of the NVPDO organization has not due to head count restraints. Engineers have taken on increasingly more responsibility until the work load exceeds the manpower capacity and program timing is compromised. When this happened on ProgramX management turned to mainstream for help. Budget was transferred to mainstream for the work being shared by base program engineers. This was one way to relieve the workload on NVPDO but delivery and timing was difficult to control. The mainstream engineers still kept their mainstream responsibilities which caused delays on ProgramX and NVPDO could not be sure that they were getting what they paid for. Entire programs have been cancelled from the NVPDO cycle plan because management finally realized that the department was too small to deliver what had been promised however the want and need for the products exists in the marketplace. Public demand has indicated that there is growth potential for NVPDO. Rather than take the product away from the customer OEM-A should invest in growing the NVPDO organization by adding the resources required to deliver.

7.0 Conclusions and Recommendations

7.1 Conclusions for Lean Product Development of Niche Vehicles

Lean product development processes are required in the "go fast" world of niche vehicles. As the niche vehicle marketplace grows, so does competition and the need to get the product to market quicker. NVPDO is one organization which has developed a formula for survival, evidenced by over eleven successful years in the industry. Through interviews and case studies things gone right and things gone wrong over the years have been identified. This study showed the areas where NVPDO knows the way but it also revealed several opportunities for improvement.

Product development value stream mapping proved to be a useful tool for reviewing the high level body, chassis, and powertrain engineering processes at NVPDO. Major process issues were visible and non-value-added wait times were revealed. Working with the NVPDO teams to develop the desired future state maps provided the teams with focus and process improvement goals. The NVDPO product development enhancement strategy desired an 8 month process between milestones <4> and <9> of the niche vehicle PDP. The desired future state value stream mapping exercise determined that the process could likely be completed in 9 months based on a case study of ProgramX. Each value stream gave valuable insights to process improvements which would work toward achieving the desired future states. Beyond engineering the support activities were reviewed and this study identified several other process improvements that will also work toward the desired future state. In all, 22 process improvement recommendations were made with varying degrees of difficulty in implementation: easy, medium, and difficult. These recommendations are summarized below in Table 8. Implementation of each recommendation is assessed and comments are provided. The easy actions should be set in place immediately while NVPDO works on overcoming the barriers to the others. NVPDO is well on its way to another decade of successes. With a little bit of hard work there will be many more to come.

Action	Implementation Assesment	Comments
1 Collocation of suppliers	Difficult	Space limitations at NVPDO facility Supplier reps work on several programs
2 Eliminate late styling changes	Medium	Requires management alignment Enabled by frequent reviews
3 Improve internal communications	Easy	Enabled by weekly status reviews
4 Increase use of rapid prototyping	Easy	Replaces monument processes Requires change of thinking
5 Walk sign-offs through the system	Easy	Requires attention by the stakeholder
6 Set appropriate targets upfront	Medium	Requires that management listen to engineering
7 Test the right thing at the right time	Difficult	"Go fast" programs cannot wait Frequent assumption changes drive rework
8 Improve prototype availability	Medium	Requires early need recognition Requires available resources
9 Eliminate parallel paths	Difficult	Requires early agreement of program assumptions
10 Hold design freezes	Difficult	Requires early agreement of program assumptions Requires program to accept risk
11 Include NVPDO provision in base program targets	Medium	Requires partnership between NVPDO and Mainstream
12 Develop formal sharing process between NVPDO and mainstream	Easy	Requries devlopment of standard process Requires discipline by engineering
13 Employ dedicated work planners	Easy	Requires available headcount and budget
14 Improve evaluation of milestone readiness	Medium	Requires that management listen to engineering Requires internal communication
15 Maintain consistent process	Difficult	NVPDO must find the balance between "go fast" and delivering engineering disciplines
16 Develop dedicated low volume buyers	Difficult	NVPDO too small for dedicated purchasing Political and cultural barriers
17 Devleop a low volume supply base	Difficult	Requires OEM-A process change High cost to OEM-A and small businesses Requires manufacturing buy-in
18 Dedicated mod center for NVPDO assembly	Difficult	Logistical issues High investment Mainstream manufacturing reluctance
19 Minimize middle management	Medium	Requires OEM-A approval of a unique NVPDO reporting structure.
20 Unique NVPDO approval process	Difficult	Requires cultural understanding and OEM-A acceptance
21 Reorganize functionally	Medium	Requires movement of people and acceptance of change
22 Employ the right amount of resources for the job	Difficult	Requires OEM-A investment in NVPDO

Table 8: Recommendations for NVPDO

7.2 Recommendations for Further Study

The work presented in this thesis was completed at a high level. The value stream maps developed represent overviews of the complex engineering processes that take place between milestones <4> and <9>. Major process improvements were identified to improve the cycle time of the process. Each of the tasks in the high level value stream maps contains a process in and of itself with its own process improvement opportunities. Each of the engineering processes would benefit from a deeper value stream mapping exercise to identify further process improvements. Improving the cycle time of the individual tasks will greatly contribute to improving the overall process timing.

OEM-A would benefit from a detailed study of how the niche vehicle efficiencies could be applied to the greater OEM-A PDP. There are lessons learned from niche vehicle product development which would provide valuable insight to the mainstream organization. The small, lean niche organization should act as a proving ground for new streamlined processes within OEM-A.

Lastly, NVPDO is one of the many niche vehicle organizations operating in the automotive industry today. A study of other automotive niche vehicle product development processes in the industry and comparison with the NVPDO process would identify additional areas where improvement is possible. The best practices from each organization could be combined to develop the best overall PDP for lean product development in the automotive niche vehicle marketplace.

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Appendix

1.0 List of Interviewees

Vice President, OEM-A, Advanced Product Creation
Director, NVPDO
Executive Director, NVPDO
Chief Engineer, Mainstream ProgramX
Marketing Manager, NVPDO
Program Manager1, ProgramX, NVPDO
Program Manager2, NVPDO
Powertrain Program Manager, NVPDO Powertrain Supplier
Powertrain Engineer, NVPDO
Work Planner, NVPDO
NVPDO Chassis Development Engineer
NVPDO Chassis Design and Release Engineer
NVPDO Body Systems Engineer
NVPDO Surface Integration Supplier