A Cultural Analysis of Key Characteristic Selection and Team Problem Solving during an Automobile Launch

by

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B.S.E. Industrial and Operations Engineering, University of Michigan, 1989

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Abstract

This thesis analyzes an automobile launch at a US based automotive company. A number of issues are examined to gain insight into continuous improvement opportunities regarding robust design techniques and the use of teams. For robust design, the use of Key Characteristic methods and measurement plans is addressed while a cultural analysis examines the environment for cross-functional problem solving teams. The company's new lean production operating system is presented as a framework for understanding how robust design and team problem solving fit into the larger improvement efforts at this company.

Recommendations include suggestions for management to implement Key Characteristic methodologies and Control Plans during product development that include participation of production personnel. Additional recommendations are for management to develop a cultural environment that encourages team based problem solving both during product development and product launch.

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1.0 Introduction

Competitive pressures in the automobile industry have increased the need for manufacturers to offer products that attract and satisfy customers. The products must meet or exceed customer expectations for many definitions of quality from fit and finish to reliability, styling and performance and at a cost that provides good value. At the same time, customers are demanding a larger variety of product offerings that change more frequently. These two pressures have combined to place enormous pressures on the product development and production organizations of auto manufacturers to reduce the development time and improve product quality. Among many of the requirements to achieve these goals are good communication and quick problem solving. Better communication and team problem solving between traditional functional groups is a central issue in effective product development and can lead to the higher quality products that win in the marketplace.

1.1 Quality: Robust Design and Team Problem Solving

A significant portion of the efforts to improve quality can be traced to reducing variation. Variation reduction improves the fit and finish of the vehicle, increases its reliability and improves its performance. Reducing variation can be accomplished during production through equipment and operating procedure improvements and during development through robust design. Team problem solving is a critical component for discovering process improvements during production, while robust design is achieved by the the development teams ability to identify and resolve problems. Research in the automotive industry has shown that one of the most important aspects of a successful product development team is their ability to do team problem solving (Clark and Fujimoto, 1991). The following sections provide an introduction to robust design and team problem solving.

1.1.1 Robust Design

Robust design is one of the ways in which the design team can help create products that are insensitive to variation in the manufacturing process (Thornton, 1996). There are a number of tools that can be used to create robust designs such as Key Characteristic methods, Assembly Variation Analysis, and the use of slip planes and dimensional management techniques. Key Characteristic (KC) methods help to identify the features on those component parts that have a significant impact on the requirements of the finished product (Thornton, 1996). Assembly Variation Analysis simulates how variation in part features affects variation in the finished assembly. Another tool for robust design that engineers can use are slip planes to absorb variation from the mating of components. Figure 1 below illustrates what a slip plane is and how it can be used in design to reduce variation in finished assemblies. A robust design will use slip planes where possible along with datum coordination (see Chapter 3) and Key Characteristic flow down (see Chapter 4) to reduce the effect of component variation on the final assembly.

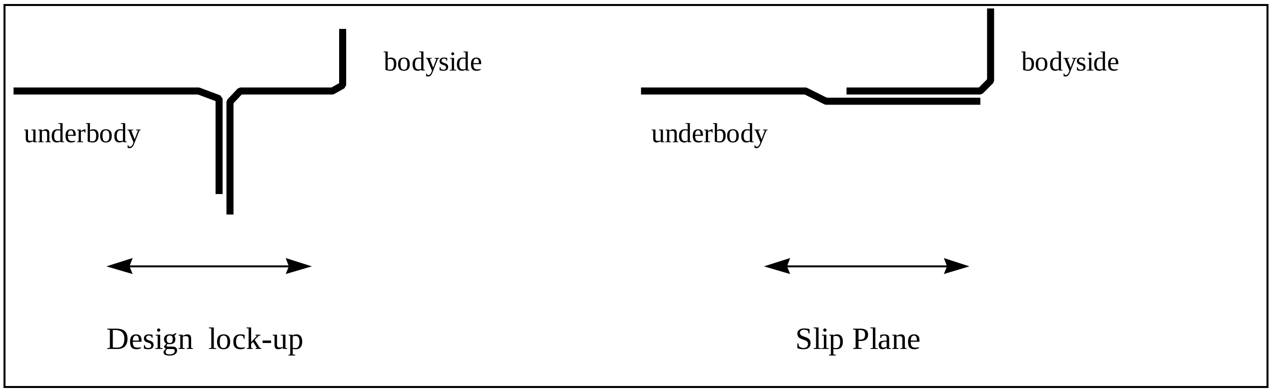

Figure 1: Slip Planes (Wolverine & Trikon, 1995).

1.1.2 Team Problem Solving

Numerous studies have been done of the Japanese automotive industry to determine the sources of their advantage in reduced lead time. Clark and Fujimoto from the Harvard Business School found that the following three structural characteristics provide the Japanese with their advantage, in order of importance (Clark & Fujimoto, 1989):

- Organizational capability for **quick problem solving cycles**…and rapid, **integrated problem solving**.
- quality of the supplier/producer relationship

- strategy that emphasizes incremental changes introduced more frequently.

In addition to quick problem solving cycles, manufacturing participation in those cycles is key. The integrated problem solving and quality of supplier/producer relationship listed above highlight that the participation of downstream groups in problem solving is a key component for reduced product development lead times (Clark, 1989).

1.2 Problem Statement

This thesis examines several problems that surfaced during the launch of a new vehicle at an American automotive manufacturer that will be referred to as the Wolverine company[1]. Problems that surface in production of a new product can generally be traced to either a non-robust design, errors in the design, a non-robust production process, or some combination of the three. Analyzing problems that surface during the launch of a new product can yield positive learning at both the technical level for how it might be prevented in future designs and at the organizational processes and design of teams level for how it could have surfaced and been resolved earlier. The problems presented in this thesis will be analyzed at both the technical and organizational levels. The technical level analysis will include a key characteristic study of the problem while the organizational analysis will examine the cultural context in which the different functional groups operate. Both analyses will show that strong cross-functional teams form the basis for both robust design and effective problem resolution.

The interaction of the product design and manufacturing groups will be investigated within the context of the Wolverine company's Corporate Operating System (COS). COS is the new lean production operating system for the Wolverine company. COS is a framework for a new extended enterprise approach to improving manufacturing operations within Wolverine. It comprises four sub-systems: Human Infrastructure, Leveled & Balanced Schedules, Value Added Activities, and Robust, Capable & In-control Processes. The last sub-system includes "robust product and process design" and "problem solving/root cause analysis" as two of its many tools

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[1] while the company name is disguised, the analysis is based on actual data.

and support processes.

These two tools within the Robust, Capable & In-Control Processes part of the COS framework will be analyzed by examining issues that occurred during a vehicle launch. The first issue was a process problem, the second issue a design problem, and the third issue was a combination of problems with the process and the design. All of the issues relate to doors: the first was an ergonomic issue with the height of a conveyor in a new “doors off” process; the second related to datum schemes for door build and assembly, and the third problem had roots in both the design of the product and the process of building up the doors and the body of the vehicle.

1.3 Hypothesis

This thesis will examine the following proposed hypothesis: when organizational structure, culture and development tools encourage all stakeholders to participate in the development process, the new product will launch with more robust, capable, and in-control processes. The communication of information among stakeholders is enabled by early involvement of manufacturing and team consensus on Key Characteristics. The use Key Characteristic flow down methodologies supported by measuring plans will reduce launch issues and aid in their resolution. This process requires management encouragement of the use of formalized team problem solving methods to assist in the effective knowledge transfer from the development team to the on-going production team. The transition of information about the design and process is critical to both the continuous improvement efforts for the current product, and the establishment of communication channels and methods between the groups for future products.

1.4 Structure of Thesis

Chapter 2 provides some background information on Wolverine and their new lean manufacturing operating system (COS). It provides a brief explanation of Wolverine’s organizational structure surrounding product development for trucks and includes a description of the manufacturing plants and the engineering staffs involved. An understanding of this structure will aid the reader in understanding the launch issues that the teams faced and the nature of the functional organizations to which the team members belonged.

Chapter 3 begins with a description of Wolverine’s approach to robust design through the use of dimensional management and platform teams. The chapter finishes with examples that show some of the issues with the execution of these goals in practice. Two examples of problems faced during a vehicle launch introduce some of the organizational culture issues that the platform teams face. The chapter closes with a case study of a third launch problem that highlights the importance of using Key Characteristic selection methodologies and team-based problem solving. All of these problems are presented to show that the higher level goals of communication through platform teams and dimensional management techniques require stronger and earlier participation by manufacturing stakeholders in order to reach their potential for preventing problems.

Chapter 4 is a technical analysis of the case study problem presented in Chapter 3. A Key Characteristics flow-down methodology is defined and presented through the example of the case study problem. The use of measurement plans is introduced to define how the necessary data should be collected and evaluated to verify that the Key Characteristics are maintained at their desired levels during production. Throughout the chapter, the importance of manufacturing’s participation in Key Characteristic selection and definition of measurement plans is evident.

Chapter 5 continues the analysis of the case study through a cultural analysis of the problem solving team and the overall environment in which they work. Ed Schein’s cultural analysis model is used to develop conclusions about how the manufacturing and engineering groups interact with each other and with their respective management organizations. These conclusions form the basis for understanding why some of the higher level COS goals of robust design and team problem solving were not always achieved in practice.

Chapter 6 concludes the thesis with an overview of the research findings. It begins with a summary of the conclusions and introduces an example of another product currently in development. This example is included to show some of the organizational changes with which the Wolverine company is experimenting to address some of the communication issues between the different engineering and manufacturing organizations. Chapter 6 concludes with some recommendations for actions by management.

2.0 Background

This section provides some general background information to help the reader understand the context of the launch problems that will be analyzed in Chapters 3-5. A short explanation of the Corporate Operating System (COS) is provided to show how Wolverine is changing the way they manufacture products. It is important to realize that Wolverine was in a transition phase in implementing COS at the time of this thesis. Because the development process for much of this product took place before COS was fully implemented, few of the COS principles were implemented for this vehicle launch. Future launches will benefit from Wolverine's progress in changing its operating system. This thesis will highlight those areas of COS that had the most impact on the examined problems, namely, robust design and team problem solving.

The remaining sections of this chapter provide a short introduction to the departments and plants involved in the various problems solving processes.

2.1 Corporate Operating System

The Corporate Operating System is the new operating system for the Wolverine company's manufacturing group. It is a framework that includes many of the tools of lean production within a structure that addresses the requirements of the extended enterprise. COS has as its core beliefs and values inspired people, a customer focus, and continuous improvement. The enablers of these core beliefs are their human resource systems, management behavior, communication, training, and a process focus. The various tools and support processes of COS are divided into four major sub-systems: Human Infrastructure, Leveled & Balanced Schedules, Value Added Activities, and Robust, Capable & In-control Processes.

Wolverine has developed a number of courses to teach the COS framework and the various supporting COS tools and processes. There is a central COS department which develops and executes training courses and provides both full-time on-site and support resources for the implementation of COS tools. Courses are often case based and use both external and internal case studies to show participants new approaches to manufacturing management. The COS group adopted a “cascade” method of teaching the COS courses by first teaching the executive vice-president of manufacturing. The executive vice-president then teaches the course to his vice-presidents, who then train their plant managers, and so on. For implementation in the manufacturing plants, each course includes hands-on projects on the plant’s “learning lab line” supported by the resident COS facilitator. Wolverine recognized that most of the changes called for in their new operating system require cultural change. To facilitate this change, they adopted the learning lab lines in order to give every plant the opportunity to learn and further develop the various techniques in a controllable environment before implementation in the entire plant.

The following is a brief explanation of the tools and processes found within each sub-system of the Corporate Operating System.

2.1.1 Human Infrastructure

The support processes for the human infrastructure sub-system include the following: recruiting and hiring, clarity of roles and responsibilities, performance feedback, policy focus and deployment and employee involvement and development. These support processes are taught and reinforced throughout the Corporate Operating System. Some processes such as policy focus and deployment have entire COS training courses devoted to them, while others such as role clarity are reinforced throughout many COS courses. The tools supporting the processes include: the hourly selection process, job descriptions, structure and recognition, appraisal system, Plan-Do-Check-Act, the suggestion program and cross functional training.

2.1.2 Leveled & Balanced Schedules

The importance of leveled schedules is addressed in the second COS sub-system. This section includes capacity and process planning, production planning and scheduling, and material flow planning. Wolverine teaches the following support processes and tools through COS training courses: market studies, forecasting, plant capacity studies, ABC, and the just-in-time (JIT) umbrella covering: kanban, containerization, quick setups, one piece flow, takt time and part plan.

2.1.3 Value Added Activities

Wolverine includes the following support processes in the sub-system of value-added activities: identifying and eliminating waste, best practice sharing and standardized work. Some tools that are taught to support this sub-system include: waste reduction, the Five S's (sift, sort, sweep, sanitize, sustain), visual management, and standard operating procedures.

2.1.4 Robust, Capable & In-control Processes

The final sub-system of robust, capable, and in-control processes contains the following support processes: robust product and process design, quick problem detection and correction and total productive maintenance. Tools that support this sub-section include: benchmarking, SPC (statistical process control), reflections, FMEA (failure modes and effects analysis), DOE (design of experiments), problem solving/root cause analysis, error proofing, and preventive maintenance.

2.2 Wolverine Truck Assembly Plant

Wolverine's Truck Assembly Plant (WTAP) is part of an industrial complex that includes a stamping plant and an engine plant. WTAP was built in 1938 and has always produced trucks. As it produces two different trucks, each with a number of engine, cab, and box-size options, it is known as one of Wolverine's most complex plants. This plant has a traditional automotive organizational structure with many different job classifications of assembly workers. Unlike many other Wolverine assembly plants, WTAP does not have a Modern Operating Agreement allowing for work teams and fewer job classifications. Most of the operators have close to 30 years of seniority and other than the plant manager, most of the management team has worked at Wolverine Truck for most of their careers at Wolverine. Due to this traditional structure, many of the plant's employees do not have a great deal of experience with participative management and team-based organizations.

Wolverine Truck has a number of full-time permanent engineers. These engineers belong to a unionized bargaining unit and are in functional areas such as process engineering, tooling, and resident engineering and cover all shifts of production. The process engineers are responsible for on-going process improvement efforts such as variability reduction and report to the Process Reliability Manager who reports to the Center Manager. On the production side, Wolverine Truck Assembly has operators who report to Supervisors who report to Area Managers. The Area Managers work in one of three centers in the plant: the metal body shop or Body-In-White (BIW) center, the assembly area or Trim/Chassis/Final (T/C/F) center, and the Paint center. The Area Managers report to one of the three Center managers, who report to the manufacturing managers, who report to the plant manager (see WTAP organization chart in the case study, Appendix).

2.3 Plant Vehicle Engineering

Wolverine's product design engineering group is called Vehicle Engineering. In early 1995, the Vehicle Engineering group started a new program to provide the plants with more technical resources while giving product engineers experience in a manufacturing environment that will be useful to them when they return to their product design jobs. The Vehicle Engineering group created a new department within the plant organizational structure called, "Plant Vehicle Engineering." This group reports to both the plant management and to the Program Management group within Vehicle Engineering. Product engineers typically rotate every 18-24 months and represent Vehicle Engineering in both the Body in White (BIW) and Trim/Chassis/Final (TCF) sections of the plant. These Plant Vehicle Engineers (PVEs) serve to increase the communication between the plant and the product engineers regarding design changes. Additionally, the PVE's goals include improving product quality by reducing process variation. At Wolverine Truck, these goals were similar to the goals of the plant process engineers and confusion often arose responsibilities. Since the plant engineers are unionized, they wrote grievances against the PVEs for not obeying contract rules such as overtime. These grievances aggravated the tensions between the manufacturing and engineering groups. Role clarity, an important part of the Corporate Operating System, needed better definition to ease these tensions.

The engineering group includes Vehicle Engineering, Program Management, and the Plant Vehicle Engineers. The manufacturing group includes the Advanced Manufacturing Engineering group and the Plant Managers of the assembly and stamping plants. They report to the same person at the President and Chief Operating Officer level.

2.4 Advanced Manufacturing Engineering

Wolverine's manufacturing group has technical resources of process engineers divided between staff level and plant level engineers. Both groups are bargaining unit employees. The staff level process engineers are part of a group called Advanced Manufacturing Engineering (AME) and are responsible for all of the advance work to design and install new processes. They are typically experienced process engineers from the plants who utilize their process knowledge to purchase equipment. They are responsible for sourcing the new process equipment and tools and for implementing the new processes in the plant.

In Wolverine's platform team organizational structure, AME is the voice of the manufacturing plant in platform team meetings with vehicle engineering. By participating early in the design process, they are often able to suggest design changes to create more robust manufacturing processes. During a product launch, the AME group has a number of their engineers and supervisors resident in the plant to ensure that new equipment and processes run smoothly. The AME engineers typically remain in the plant until it is determined that most of the major problems with equipment and new processes have been resolved. Once a process engineer moves into AME and gains expertise in particular processes, it is rare for him to move back to a plant process engineer role. After a new product is launched, the AME engineer will typically move on to another new program. The AME group has no program to parallel Vehicle Engineering's PVE rotation program.

2.5 Vehicle Engineering

During a product launch, there are also a number of product engineers from the Vehicle Engineering group that are in the plant to support specific design-related problems. These engineers support the PVEs and the AME engineers as needed to resolve specific part or build issues that required design engineering assistance. As they have usually worked previously with the PVEs that are doing their rotation in the plant, the Vehicle Engineers that spend time in a plant during launch tend to associate more with the PVEs than the other engineers in the plant (see Wolverine organization chart in the case study, Appendix).

2.6 Dimensional Management

Within the Vehicle Engineering group, there is a group responsible for dimensional control. As a number of automotive manufacturers have done in recent years, Wolverine has adopted a "Dimensional Management" approach to product development. Using this method, Wolverine trains all product engineers in dimensional management theory and techniques, such as Geometric Dimensioning and Tolerancing (GD&T). Additionally, they have designated a group of dimensional control engineers within every development group to serve as the group's technical resource on dimensional management. While every engineer attends at least two week-long courses on dimensional management, the engineering group dedicated to dimensional control specializes in it and both advises and drives dimensional management implementation for every Wolverine development project.

2.7 Wolverine Stamping Plant

Wolverine Stamping plant is located adjacent to Wolverine Truck plant and supplies many of the stampings for Wolverine's truck and sport utility vehicles. The plant is divided into two sections which produce stampings and many sub-assemblies such as door, tailgate, and hood assemblies. They have a similar structure to the assembly plants with permanent engineers, PVEs, and AME and PVE engineers for launch support.

3.0 Robust Design and Team Problem Solving

This chapter introduces robust design by first describing how Wolverine changed their development organization to support cross-functional platform teams. This change from functional chimneys to large teams of co-located engineers for a platform, or class of vehicle, greatly increased communication. This increased exchange of information earlier in the product development cycle is an important prerequisite for robust design. In addition to platform teams, Wolverine created "Dimensional Management" groups within the various product engineering organizations to drive the use of design methodologies that help create robust designs. The chapter concludes with two examples of problems experienced at the Wolverine Truck Assembly Plant during the launch of the 1997 Montana. A third example is presented in the Chapter 3 Appendix in the form of a case study. These examples highlight the potential opportunities for improvement through use of the Wolverine Operating System tools of robust design and team based problem solving.

3.1 Platform Teams

In the early 1990's Wolverine re-organized from a strictly functional organization to a new platform team-based structure. The platform team itself is composed of a cross-functional team of General Managers, Directors and Executives. They manage the entire platform and establish the organization, process, and platform level objectives to guide the lower level teams (PAP manual, 1995). From this high level platform team, there are a number of lower level teams created at the vehicle, system, and component level. A typical platform team would have a total of more than 700 members co-located in one building (Dimancescu & Dwenger, 1996).

One of the many benefits of the platform teams is that by having manufacturing representatives on the team, the design engineers get earlier feedback on production feasibility. The team works together to find solutions that will function well in manufacturing instead of the traditional, "throw it over the wall" approach. Typically, members of the Advanced Manufacturing Engineering (AME) group represent their understanding of the voice of manufacturing on the platform teams.

This earlier involvement of manufacturing in the platform teams has reduced the severity and frequency of process problems that surface during the launch of a new vehicle. In addition to AME's participation in the platform teams, representatives from the plants are formed into a "launch team" many months before the actual launch. These individuals are generally experienced managers within the plant and attend both review meetings and prototype build reviews to express potential process concerns.

While earlier manufacturing participation has had a very positive impact, problems still surface during the launch of a new vehicle. This remainder of this chapter describes three problems that the Wolverine Truck Assembly Plant experienced during the launch of the 1997 Montana pick-up truck. After the first problem is presented, there is a short section that defines dimensional management to better understand the technical aspects of the problem presented in the remaining sections of the chapter.

3.2 "Doors Off" Process

Among the new processes installed at Wolverine Truck Assembly Plant for the launch of the new Montana was a new "doors-off" process. The process consists of the following: doors are applied and fit in the body shop, the vehicle goes through paint, in the first station in the Trim/Chassis/Final (TCF) area of the plant (just after the vehicle is painted) the doors are removed and loaded onto conveyors. The vehicle without its doors and the separate doors ride through the Trim lines on their separate conveyors and get built up with all of their trim components. Near the end of the Final line, the doors are re-attached to the vehicle (see Figure 2). Many car makers have installed doors-off processes as they provide many benefits: easier access to the interior of the vehicle to install bulky items, easier access to the door to install panels and other components, improved ergonomics for the operators installing components, easier access to the door to install panels and other components, narrower process widths (as the vehicle without its doors open is not as wide) therefore using less plant space and requiring less walking by the operators, and finally, reduced surface damage to the exterior of the doors.

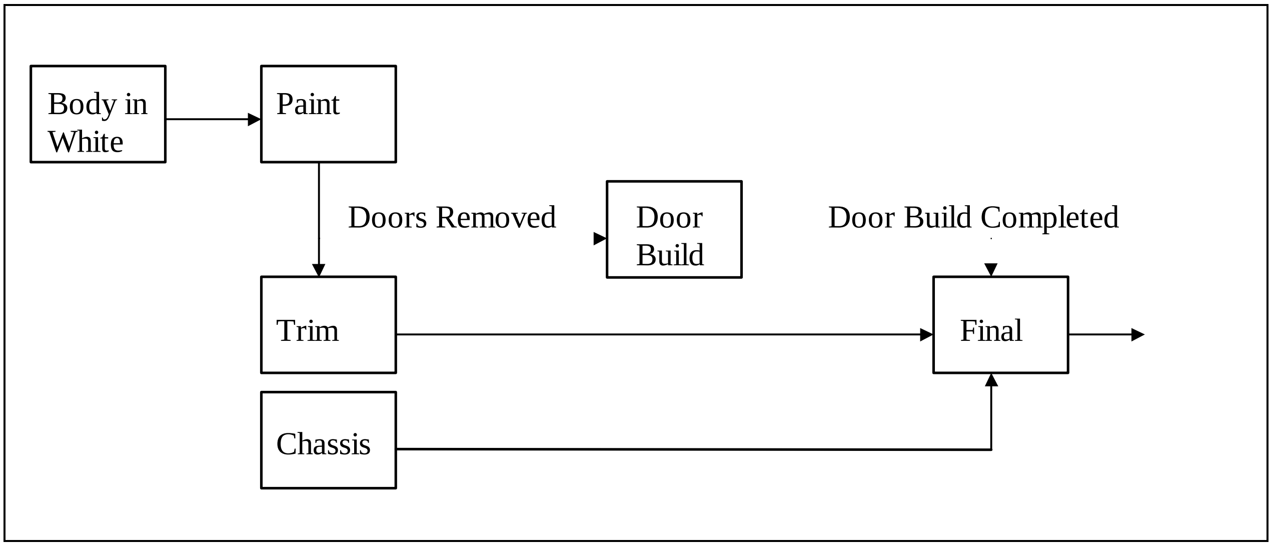

Figure 2: Doors Off Process.

In designing the new doors-off process for WTAP, one of the many decisions was to determine the optimum line height for the conveyor that carries the doors. As there are many stations in the door build up area, with differing requirements, this was a challenge. For instance, some stations include jobs such as installing screws on the bottom of the door panel, while others involve reaching through the window opening to install the side mirrors. In order to find the optimum conveyor height, the AME group hired ergonomic consultants to study each of the assembly jobs for the door build-up line. To simulate this door line height during prototype builds at the Wolverine technology center, the AME group built a stand-alone carrier. All of the door assembly operations during the prototype builds were performed on this carrier to show the height of the door for every operation. As the stand-alone carrier was stationary, the group did not simulate performing the operations while the assembly line was moving.

3.2.1 Problem at Launch

During the initial vehicle builds at Wolverine Truck at speeds approaching final production speeds, it was quickly apparent that the height of the conveyor line was too low for a number of operations. In particular, the application of two screws at the bottom of the door panels proved especially difficult while the line was moving. The line supervisor informed the Plant Vehicle

Engineers for the T/C/F process area and the Advanced Manufacturing Engineering group that ordered and specified the conveyors to investigate the problem. The PVEs quickly called meetings of all of the concerned parties: the line supervisor, the facility engineers, AME and the PVEs. The team met several times and within a few days had generated four possible solutions. Each solution was presented to plant management along with a recommendation by the team for the option that they as a group favored. The group recommendation to raise one half of the conveyor line and build platforms as required to accommodate operations that did not need the additional height was accepted by management. During the Labor Day holiday weekend in early September, the process change was implemented on the line.

3.2.2 Analysis of Problem Resolution

In this example, the necessary groups were able to get together and quickly form a team. Although many members had not previously worked together, and they did face some issues by not immediately including all stakeholders such as the facilities engineers, the team was able to find and implement a solution in a timely manner. The root cause of the problem was not very relevant, nor was assigning responsibility for creating the problem necessary. The problem received the attention of management only up to the plant manager level, and there was not pressure on any particular group to take blame for the problem and resolve it. This case is a good example of effective team problem solving.

The following example shows how team problem solving can be more difficult when the root cause is unclear, the solutions not obvious, data more difficult to obtain, and when management attention translates into pressure for resolution. A section on dimensional management and an example of a datum scheme problem introduce the main case example which can be found in the Appendix.

3.3 Dimensional Management

To give a short explanation of how dimensional management techniques are implemented during product development, it is useful to explain some generally accepted design best practices. They include beginning with a customer focus to develop a list of customer needs and potential latent requirements. That list is generally in subjective terms, such as “doors that are easy to close” and “a quiet ride.” Therefore, the next step is to translate that list into quantitative goals. A Quality Function Deployment (QFD) or “house of quality” process is often used to assist in this process (Clausing, 1993). The QFD process involves matching the qualitative goals to quantitative design features in a matrix format. Then, the quantitative goals are often compared to existing products both inside the company to determine feasibility and contrasted with products outside the company as part of competitive benchmarking. A senior management team representing various functional groups usually makes marketing positioning decisions as to the quantitative goals for that particular project. These quantitative goals for a new automobile are often described in terms such as the desired fit and finish tolerances (the gap and flush dimensions, see Figure 3), closing efforts of doors, and engine performance requirements.

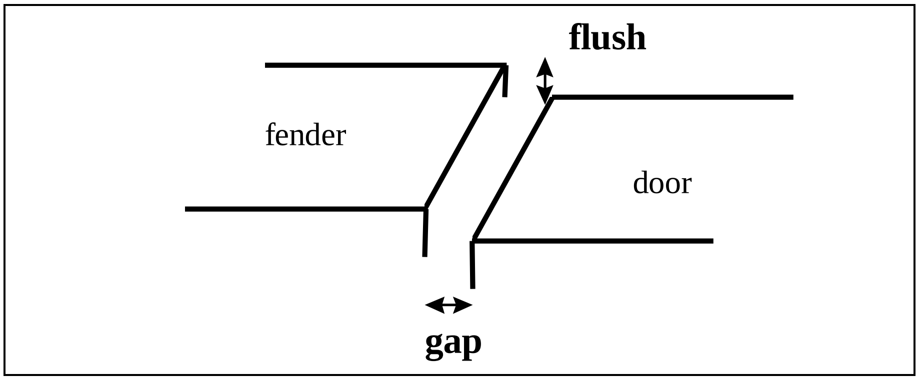

Figure 3: Gap and flush

Once the high level quantitative goals are set, the product development team designs a product to meet those goals. At this point, tolerancing and global datum schemes are created that will support meeting the high level goals. A datum is a theoretically exact point, axis, or plane derived from the true geometric counterpart of a specified datum feature. It is the origin from which the location or geometric characteristics of features of a part are established (ANSI Y14.5M 1982). Datums are reference points on a part that are usually easy to locate (such as an edge) and become the zero point from which to measure other dimensions and locate fixtures. By using datum points as fixture points, the fixture becomes the theoretically exact point in space and all of the attached components will use the same origin point. The ANSI GD&T standard referred to above and many internal Wolverine documents describe in detail the various principles to be followed in developing a datum scheme.

From these global schemes, datum and tolerancing schemes are created for the lower level sub-assemblies that support the global scheme. For instance, a finished vehicle might include a hinge point in its datum scheme. The sub-assembly datum scheme for the door assembly would then also use the hinge point as its sub-assembly datum. This process for creating datum schemes continues for every sub-assembly down to the detail component level. One goal of dimensional management is to ensure that the global datum schemes are transferred down to the sub-assembly level. By maintaining common datum schemes, it is easier to predict and manage variation in the higher level assembly from the variation in sub-assemblies.

Due to design appearance goals, however, it is often not possible to exactly transfer datum schemes down the entire chain of sub-assemblies. For instance, on a door it might be very useful to use a certain feature in the sub-assembly that becomes inaccessible once the finished door is assembled to the vehicle. Additionally, different design and manufacturing groups have different opinions about the best datum schemes to use to produce a low variation assembly. The following example illustrates what can happen when the engineering and manufacturing groups do not buy into the datum schemes suggested from dimensional management.

3.4 Door datum scheme problem

During the development of the Montana, the Dimensional Control group within the BIW Vehicle Engineering group suggested a new datum scheme for the doors. They recommended using a "big triangle" approach (see Figure 4). Traditionally, the datum scheme for doors included using the two hinge points and the latching point (a small triangle). Dimensional control guidelines suggest using the biggest possible "triangle" of three points on a particular surface to be measured. This is to spread the variation over the largest possible surface.

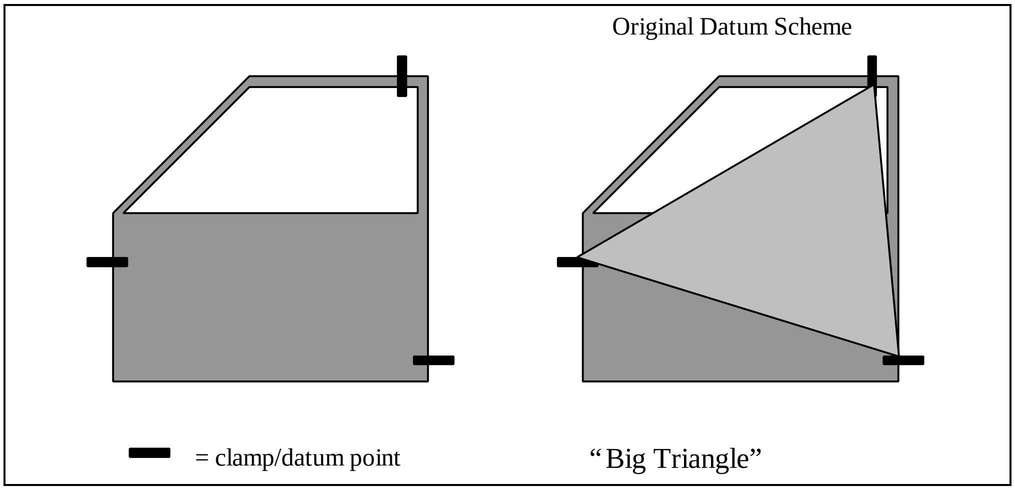

Figure 4: Original Datum Scheme

For the Montana, Dimensional Control suggested a datum scheme using a point near the upper hinge, a point on the lower rearward portion of the door, and one on rear part of the header, or top of the window frame of the door. This scheme would follow the dimensional control guidelines and provide the largest possible triangle within the door assembly. The launch team representative from Wolverine Truck’s body shop agreed with this scheme, as did a stamping plant representative.

3.4.1 Implementation in Stamping

While one stamping representative had approved the concept, the first time that the stamping plant’s internal dimensional control group saw the scheme was during the C1 prototype build, 16 weeks before volume production. The fixtures for measuring the assembled doors were received at Wolverine Stamping Plant (WSP) and the plant dimensional control group immediately took issue with their design. Part of the problem was that the upper fixture clamp caused the door to bend at the header (see Figure 5).

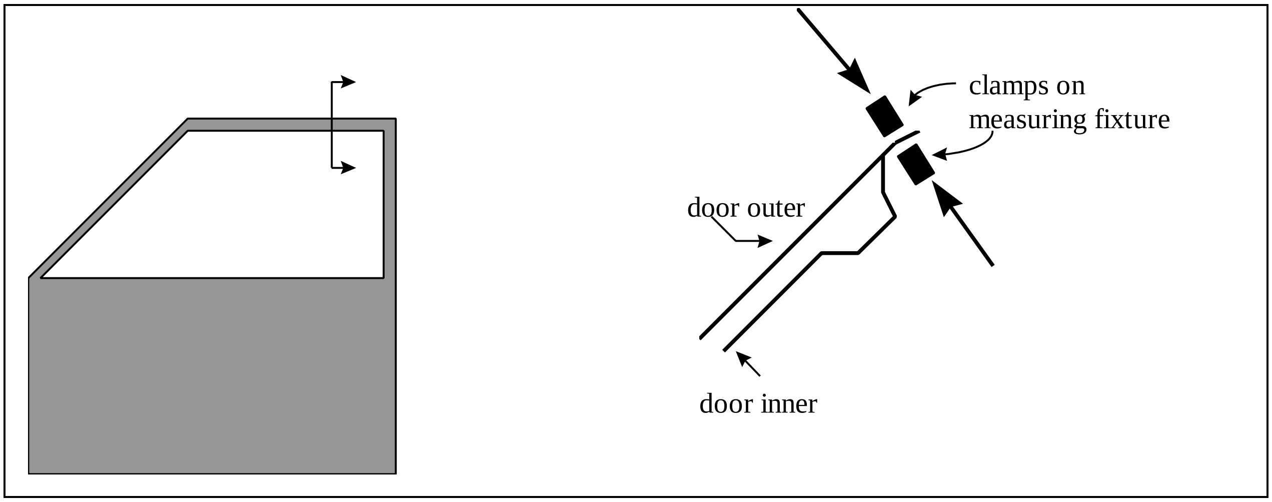

Figure 5: Fixture clamp on header

Although this particular issue was correctable, the WSP dimensional control team felt that the datum scheme was not robust since it required using the most flexible surface of the door (the top of the header) as a clamping and datum point. They therefore changed the fixtures by moving the upper datum point to the stiffer upper rear section of the header, along the B-post (see Figure 6).

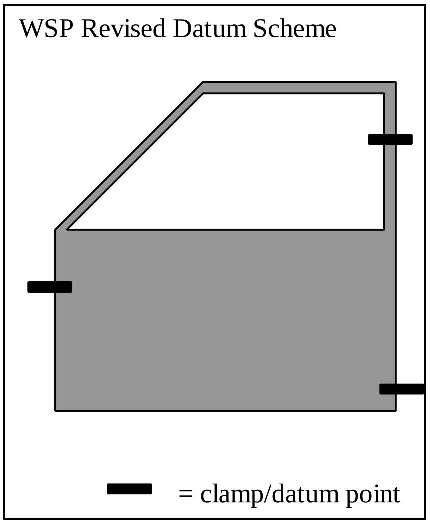

Figure 6: Stamping Revised Datums

3.4.2 Implementation in Assembly

When WTAP received the fixtures to attach the door assembly to the cab and started using them in volume production, they immediately noticed some problems. The door is manually loaded by two operators into the fixture before being located on the cab. As the operators load the door, they must be careful not to hit the door against any of the protruding clamps and locating pins on the assembly fixture. With the "big triangle" system, there are clamps from the bottom-most portion of the door to the upper-most portion. Therefore, the operators tend to look up at the upper clamp to make sure that they do not damage the header portion of the door and that it locates properly on the fixture. Meanwhile, the entire door is moving into position in the fixture. If the operators do not look at the locating pin that protrudes through the door handle opening, there is the possibility that they could hit the exterior door surface against the post. This caused a number of problems at WTAP during the early days of the launch.

The production supervisors at WTAP therefore decided to change the design of their door application fixture to the smaller triangle shown in Figure 7. This resulted in a costly re-design of their fixtures and in a different datum scheme from the stamping plant's. As the datums were no longer coordinated, sharing data between the plants for problem resolution was meaningless. When the assembly plant wanted to verify the dimensional results of the doors they received, they wrote their own coordinate measuring machine programs with datums that reflected how they assembled the doors.

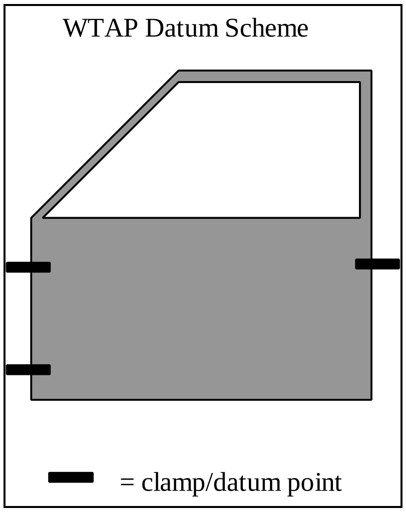

Figure 7: Assembly Datums

3.4.3 Analysis of Problem Resolution

Unlike the conveyor line height example in the previous section, this problem highlights the potential problems that can arise when design and production groups do not effectively communicate. While production buy-in was sought during development, not all of the stakeholders were able to participate early enough in the process. The result was that the datum schemes were not coordinated between the stamping and assembly plants, creating problems in sharing data. As the next example shows, the lack of ability to share data between plants can create problems in tracing problems seen in finished assemblies down to their component parts. This difficulty in traceability hinders problem solving efforts and increases friction between functional groups.

3.5 Door-Pop Case Study

The second example of a problem that happened during launch was termed “door-pop.” It was a complex problem that initially appeared during various prototype builds. The problem was described as a combination of movement and sound that the door made when it was opened from the outside of the vehicle. The root cause of the problem was not clear and data was often difficult to obtain for some of the reasons described above. As the cross-functional team worked to solve the problem during the vehicle launch, they were under time pressures to find resolution. The case study can be found in the appendix at the end of this chapter.

3.5.1 Root Cause: Variation and Design

As the case study shows, the door pop problem had root causes in both the design of the seal gap dimension and in the variability of the supplied components and resulting build at the assembly plant. Because of the problem was not clearly the responsibility of either group, neither took initial responsibility for resolution. When engineering took the lead in the team meetings, they perceived that production took less of an interest in resolving the variability problem. As one team member stated, "… there is a motivation problem because people perceive that is an engineering change issue and therefore there is no pressure to fix the process problems…."

The process variation problem was complex and subject to variation from a number of sources. Chapter 4 provides a detailed analysis of the problem and shows a method for understanding how the variability in the sub-assemblies affected the final key characteristic of seal gap and ultimately created the door-pop problem.

3.5.2 Timing of Addressing Problem

The engineering design problem is also of interest, however, due to the long period of time that elapsed between the identification of the problem and its resolution. When the product was engineering's responsibility, the problem was perceived to be a variation problem that could be resolved during production. When production began, the problem was perceived as an engineering problem that could only be fixed through a design change.

Engineering's initial reaction to the door-pop problem turned out to be indicative of the problems that would be seen in volume production. Their initial response of, "…it's a problem with the prototype parts, it will all be fixed when we get production tooling…" indicated that the design was sensitive to process variation. That the process variation was already seen in limited production runs of prototype parts was a warning of the potential problems to be seen from the production tooling and processes.

3.6 Summary

The above examples show that creating robust product and process designs and resolving launch problems requires effective teamwork between manufacturing and design groups. The first example with the door height conveyor showed how diverse groups can come together and quickly resolve a launch issue. The second example of the datum scheme problem and the third door pop example both show how robust design goals and resolving complex problems are hindered by poor communication between functional groups and difficulties in defining problems. Chapter 4 will examine the technical problem of door pop more thoroughly and suggest some alternative methods to study it to enable the groups to prevent a similar problem from happening again. Chapter 5 returns to the cultural environment in which the functional groups operate to explain some reasons for their difficulties in communicating.

Appendix to Chapter 3: Door-Pop Case Study

Scenario:

"To prevent this issue from reaching customers, we need to order a stop shipment."

It was July, 1996 and Ron Kaiser had a problem. While on his way to the press roll-out of the new 1997 Montana, he and Gary Grover - the vice-president of Large & Small Car, Jeep & Truck Assembly and Stamping Operations - checked a number of the trucks' doors. A problem that was first noticed during a pilot build had not yet been resolved: "door-pop." The launch had been going extremely well thus far and people were working together to resolve open issues. Ron - the Trim/Chassis/Final Center Manager - knew that solving this problem, however, was going to be more difficult. A number of people had been working on it for awhile now, and the concern still existed. Ron needed to take quick action to prevent vehicles from leaving the plant with this problem.

The door-pop problem was a combination of movement and sound that the door made when it was opened from the outside. As the latch was released, the door made a small "jump" motion away from the cab. This movement was often accompanied by a "ping" sound. Additionally, doors which exhibited this door-pop condition often had high closing efforts. Not all vehicles with high closing efforts, however, exhibited door-pop. Ron needed to quickly gather the appropriate people and develop an action plan.

Designing the 1997 Montana:

The 1997 Montana was designed to strongly echo the successful styling theme of the larger Toro truck. The design team had only 30 months to bring the vehicle into production. In that time, they successfully addressed the major issues from the previous model Montana, while taking into consideration many of the production issues that arose during the Toro launch experience. Manufacturing and engineering worked well together both during development and launch to raise and resolve potential problems. Many people from both engineering and the assembly plant thought that the launch was the smoothest they had ever seen.

The platform team succeeded in meeting their goals and launched the Montana to rave reviews from the press. It won the *Off-Road* magazine's Truck of the Year award, *Popular Science* magazine's "Best of What's New" award, "1997 Pickup of the Year" by Four *Wheeler* magazine, and is under consideration for many other awards. Additionally, it launched with drastically fewer problems than the Toro did when it launched. In fact, the Montana had fewer measured concerns per 100 than the current production Toro.

The design team looked at seven key areas: durability and reliability; roominess; performance; ride and handling; overall quietness; safety and security; and appearance. Balancing all of these goals took strong communication throughout the organization. As one manager said, "Take wind noise. It involves door fits, door seals, and the architecture of the cab itself. You can't segment the job, because when you have all the pieces together you won't have it."

While the door-pop problem did exist to some degree on the Toro - and a few other company vehicles - it was not identified as a high priority for the development team to resolve. Therefore the team focused their efforts on reducing wind noise and water leaks, which had been identified as an issue on the previous model Montana. One way to reduce wind noise and water leaks is to have a tighter sealing area between the door and the cab at the top, or header, of the door (see Figure 8). This can be accomplished by using bigger seals, designing a smaller space in which the seals are placed, and/or designing in some "static load compensation". Static load compensation uses the stiffness of the door to compress the seals against the cab. The new Montana was designed with a smaller "seal gap" between the door and the cab and with some static load compensation to compress those seals and provide a quiet cab environment. The combination of static load compensation and a smaller seal gap meant that the seals were under a load when the door was closed. It was generally thought that this load could be affecting the door-pop problem.

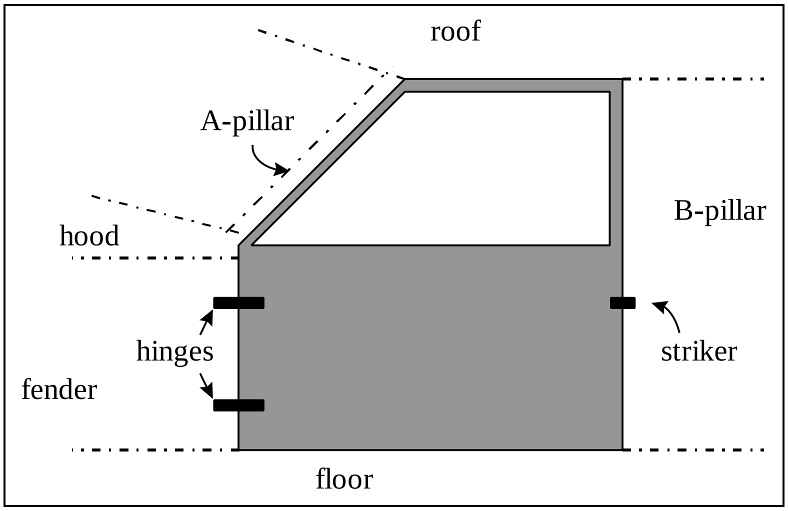

Figure 8: Door with mating assemblies

The design team was successful in their efforts to reduce wind noise and water leaks. From the first press test drives in Utah, the press raved about how quiet the cab environment was in the new Montana. *Car and Driver* said, "…this is arguably the best pickup on the market of any size," and called it, "… an effortless, quiet highway cruiser." There were no initial complaints from the press regarding door pop.

Wolverine Truck Assembly Plant Organization:

The Wolverine Truck Assembly Plant was built in 1938 and has always produced trucks. Today it produces both the full-size Toro and the mid-size Montana pick-up trucks. While it is one of several plants producing the Toro, at the time this case was written, it was the only plant producing the Montana. At the time of the Montana launch, it was planned that the mix would be approximately 75% Montana and 25% Toro.

Approximately 18 months before the launch of the new Montana, a new technical resource was added to all of the car company's manufacturing plants, including Wolverine Truck Assembly Plant (WTAP). Plant Vehicle Engineers (PVEs) were assigned from the product engineering group (Vehicle Engineering) to the plants (see Figure 11). This group of engineers had among their goals to reduce process variation and to provide a better link between product engineering and the plants for communication about product quality improvements. It was planned that each engineer would spend between 18 and 24 months in the plant. In addition to providing a technical resource for the operation, the individual PVEs would gain valuable manufacturing experience that would be useful to them when they returned to their product engineering group.

At WTAP, the PVE group was staffed to support both the Toro and the Montana. They were divided into a Body in White (BIW) group and a Trim/Chassis/Final (TCF) group. Each group was then sub-divided to cover different areas of the vehicle: for instance in BIW, there is a door engineer, a cab engineer, a box engineer, etc.

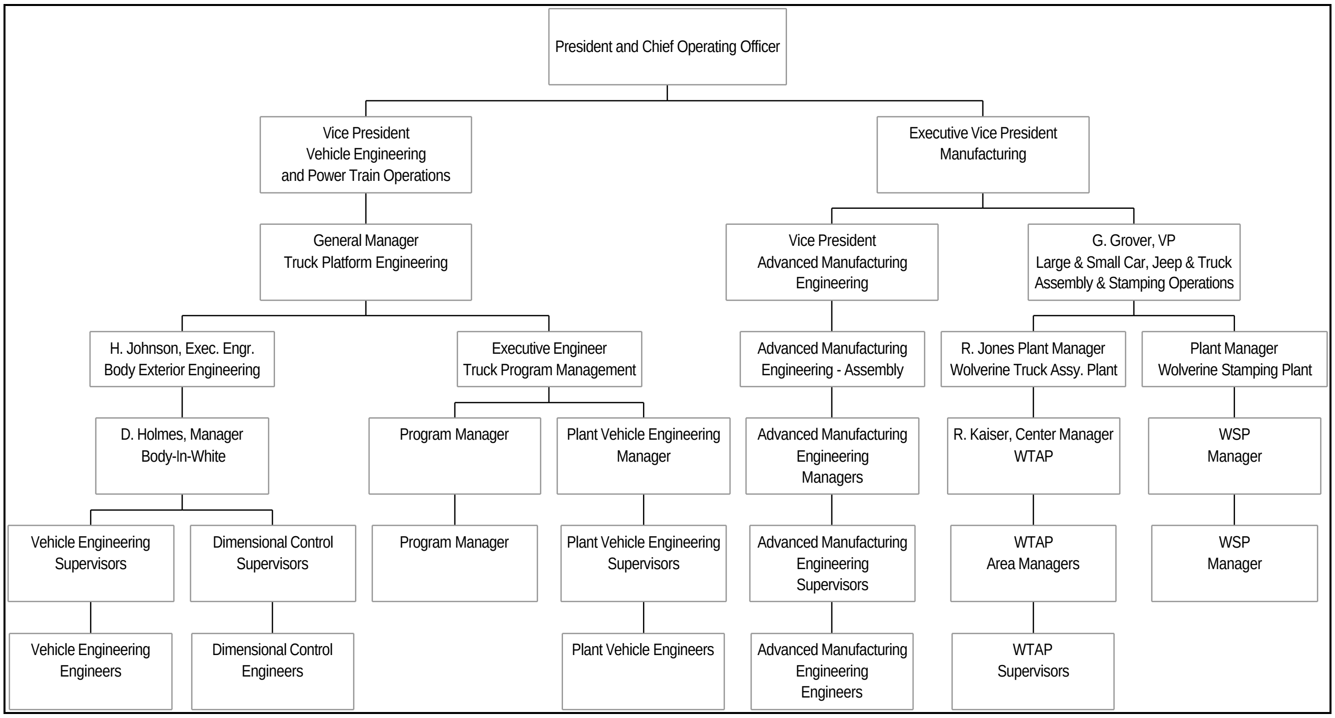

Figure 9: Partial Organization Chart

In addition to the PVE engineers, the plant has a number of permanent engineers. These engineers belong to a bargaining unit and are in functional areas such as process engineering, tooling and resident engineering. The process engineers report through the Process Reliability Manager who reports to the Center Manager. On the production side, Wolverine Truck Assembly has Supervisors who report to Area Managers, who report to Center Managers. The three Center Managers (BIW, TCF, Paint) report to the manufacturing manager, who in turn reports to the plant manager (see Figure 10).

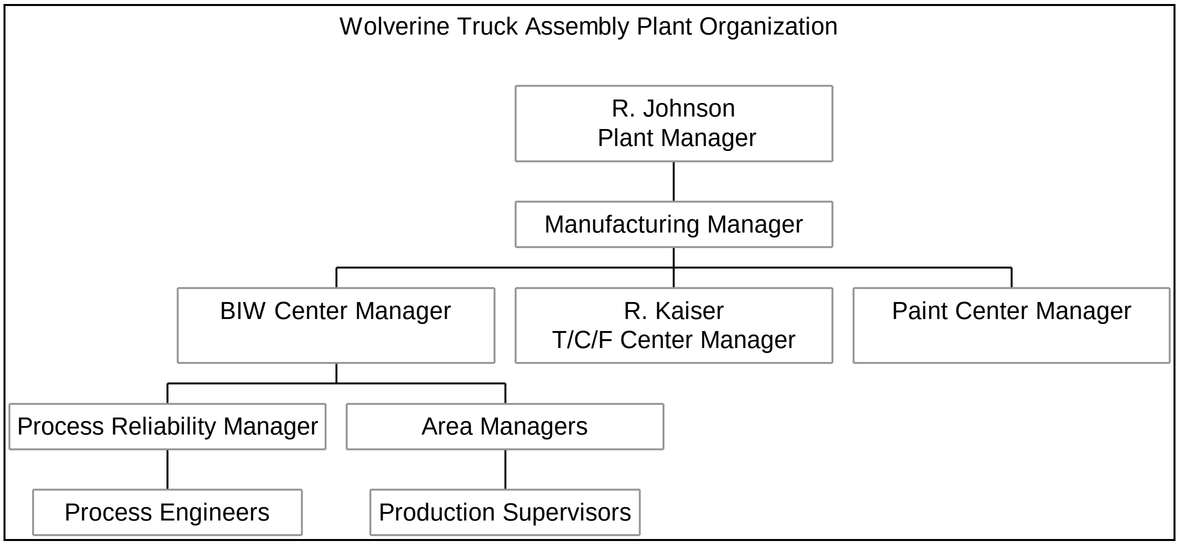

Figure 10: WTAP organization chart

During the launch, there were many additional technical resources in the plant. The Advanced Manufacturing Engineering (AME) group had a number of their engineers and supervisors resident in the plant to ensure that new equipment and processes ran smoothly. There were also a number of product engineers from the vehicle engineering group. These engineers supported the PVEs and the AME engineers as needed to resolve specific part or build issues that required design engineering assistance.

Pilot Builds:

During the F1 build (approximately 85 weeks before volume production), a manager in Program Management noticed the door-pop problem. At that time, product engineering told him that the problem would go away during the next build (35 weeks before production) when hard tools were to be used for the prototype build.

Throughout the subsequent prototype builds, the problem continued to be noticed by various groups. A BIW Area Manager identified the problem during the next build (16 weeks before production) and wrote a "BITS" (Build Issue Tracking System) concern[2]. The Area Manager also communicated the issue to Ron Kaiser, who brought it up along with other top issues in a major Body in White engineering and production review of the Montana. At the time, the explanation was that there was a 3 mm non-conformance issue with the body on this particular pilot build. Engineering felt that this non-conformance would not be seen on the bodies built on the new production tools at Wolverine Truck Assembly Plant. In the response to the BITS in the

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[2] BITS is a computerized concern tracking system whereby anyone can enter an issue that affects the vehicle build. Concerns are rated for severity and resolution timing is required. BITS are followed up by Program Management.

system, Program Management indicated that the problem was caused by various dimensional issues with the fender and the roof. Therefore the specific door-pop problem was not initially considered a high risk issue.

The Launch:

In the early phases of production ramp-up, Program Management continued to bring up the door-pop problem in regular weekly meetings with the PVEs, AME and production. The BITS on the door-pop issue remained open. The on-site Plant Vehicle Engineers, however, had many other higher priority issues that demanded immediate attention. For many of the engineers, door-pop was a sporadic problem that has always existed on the Toro truck, and one that tended to go away after the vehicles sit on the lot for a few weeks. It was theorized that the seals "take a set" during this period because of the compression they are under, causing the door-pop to diminish over time. Additionally, it was theorized that the door-pop was created from a wide variety of factors, making problem resolution difficult.

Technical Description of Problem:

In July, theories about door-pop and its root cause varied widely. Most people agreed, however, that the problem was a result of some combination of process variation in the cab build, striker location, and door build, and a variety of engineering issues such as the design of the "seal gap", the stiffness of the door and the latching mechanism.

In order to reduce the incidence of wind noise and water leaks, the design team had decided to design in some "static load compensation" to the header. The door would be designed to build slightly under flush at the header in the body shop. The door would then be "pushed" to a flush condition by the seals, which are installed near the end of the trim process. This pushing would result from the seals being compressed such that they deflect the door outward. For the Montana, this was accomplished by designing a smaller "seal gap" between the door and the cab in which the seals are placed.

While the styling and thus the form of the door remained similar to the existing Toro, the Montana's smaller size meant that its door would deflect -- or bend -- differently that the Toro's. Additionally, the Montana door would be built differently, using a laser-welded sheet metal blank to provide stiffness instead of a bracket in the door assembly. These changes combined such that it was not known precisely how much the door would move outboard when under a force from the seals. Therefore, the design of the "seal gap" dimension between the door and the cab became a difficult challenge.

It was understood that process variation did play a role in the door-pop problem, but it was not clear how much of a role. The response on the initial BITS written during the early prototype builds indicated that some people attributed door-pop to build variation. Others theorized that the problem was inherent in the design of the seal gap dimension and the static load compensation.

July, 1996:

By the time of the press roll-out in late July, the problem was still not resolved. In order to prevent the issue from reaching customers, Ron Kaiser, Roy Jones (the plant manager), and Gary Grover decided to stop shipment of all vehicles. This immediately elevated the door-pop issue across all functional groups. Engineering and production resources were focused on developing containment actions and a plan to study the root cause and appropriate corrective actions. Both the plant and the product and advanced manufacturing engineering groups mobilized to try to resolve the problem. The plant developed a list of containment actions such as measuring door closing velocities and deploying extra door fitters in two different locations on the final assembly line to re-fit problem vehicles. Vehicle engineering started a flurry of testing activities to try to better understand the phenomenon.

Both the plant and engineering did a number of yard audits for door-pop. Vehicles were 100% sorted subjectively for door-pop -- often over weekends -- and measured for closing efforts. Unacceptable trucks were re-fit by door fitters by either bending the door, moving the striker (the mating loop on the cab for the door latch), or by moving the door slightly up or down as needed. As these yard audits were done by both engineering and the plant staffs, conflict sometimes arose. In one incident, the plant spent an entire weekend certifying every vehicle in the yard. The next Monday, a truck platform Executive Engineer, Hank Johnson, found some vehicles in the lot that he found unacceptable. This created a stir and a number of teams were sent out to re-measure vehicles according to the agreed upon closing efforts criteria.

Situation Appraisal:

Plan Involvement:

As the underlying cause of the problem was not clear, determining the composition of the team and naming the team leader became difficult. As one member put it, “If a problem is clearly the responsibility of one particular group, it is amazing how the resources will come out of the woodwork to resolve that issue.” Since the door-pop problem was not clearly an engineering or a production issue, the definition of the team and its leader became less clear-cut.

After the stop shipment on July 31, product engineering took the lead and appointed a team leader to resolve this issue. While it was not obvious which group was responsible for the problem, engineering knew that they had some launch issues yet to be resolved and were the logical choice to lead the problem resolution. Therefore, Randy Muro, a BIW Dimensional Control supervisor, took the lead role in the door-pop problem solving process. The team included representatives from Vehicle Engineering (product engineers, PVEs resident at Wolverine Truck and Dimensional Control engineers), Advanced Manufacturing Engineering, Program Management, Wolverine Truck and Wolverine Stamping.

The following table shows the attendance record for the team members in the various door-pop meetings.

Dept.	Position	08/05	08/15	08/22	09/06	09/09	09/16	09/17	09/20	09/23	09/24	09/25	09/30	10/04	10/09	10/16	10/23	10/30	10/31
Engr.	Supv.	X	X	X		X	X	X	X	X	X	X	X						
Engr.	Engr.	X	X			X	X		X			X	X		X		X	X	
Engr.	Mgr.	X	X					X											X
Engr.	Supv.		X	X		X	X		X	X	X			X	X	X	X	X	X
Engr.	Engr.	X							X	X	X	X		X	X		X	X	
Engr.	Engr.		X																
Engr.	Engr.											X							
Engr.	Engr.													X		X			
Engr.	Engr.														X	X	X		
Engr.	Engr.											X		X		X	X		
Engr.	Engr.			X		X													
Engr.	Supv.			X		X													
PVE	Mgr.	X																	
PVE	Engr.				X	X	X	X	X								X		X
PVE	Engr.														X	X			
PVE	Engr.										X	X	X						
PVE	Engr.														X				
PVE	Engr.														X	X			X
PVE	Engr.												X	X		X	X		
PVE	Engr.												X			X			
PVE	Supv.		X		X	X	X	X		X	X	X						X	X
PVE	Engr.		X	X		X	X												
Stamping	Mgr.													X					
Stamping	Mgr.				X									X					
Stamping	Mgr.										X								
Stamping	Engr.						X		X		X		X		X	X			
Stamping	Mgr.			X			X		X	X	X		X	X					
Assembly	Mgr.	X	X		X	X	X	X		X	X								X
Assembly	Mgr.			X	X	X													
Assembly	Mgr.				X														
AME	Supv.		X	X															
AME	Supv.	X	X	X		X	X	X	X			X		X		X			X
Prog. Mgmt							X								X	X	X		

Engr. = Vehicle Engineering group (includes Dimensional Control)
PVE = Plant Vehicle Engineering (engineers from Vehicle Engineering resident in plant)
Stamping = Wolverine Stamping Plant
Assembly = Wolverine Truck Assembly Plant
AME = Advanced Manufacturing Engineering

Figure 11: Chart of Meeting Attendance

Since there were daily launch meetings at 2:00, the door-pop meetings were scheduled every day at 3:00 pm. The frequency soon was reduced to Monday - Wednesday - Friday at 3:00. By October, only weekly meetings were deemed necessary. Randy Muro generally led the meetings by going over the list of open issues and asking for a status update. As most of the items involved engineering studies, typically an engineer would respond with the status of the study.

Some of the reasons for sporadic attendance records and the disproportionate number of engineering to production people include the following: most meetings lasted between 1½ -2 hours and took place in a conference room in the front offices of Wolverine Truck and the meetings were held late in the day.

One of the reasons that the PVE group had such a large and varied representation on the team was that they re-organized after the launch ramp-up period in mid-September. Several engineers had completed their assignments in the plant, and the total number of PVEs needed to be reduced, since the Toro volumes produced at WTAP would now be lower. One change was that there would no longer be a "BIW door engineer" for the Montana. The responsibilities of that position were added to another engineer’s responsibilities. Participation on the door-pop team was thus split among several engineers who had interfacing parts and the lead PVE for Montana BIW.

The plant process engineers were represented by the BIW Process Reliability Manager.

<u>Contain Problem:</u>
In a memo to Ron Kaiser in early August, the team detailed the “opening effort issues under investigation”, the facts learned thus far, and a list of short term and long term repairs. The team decided to have production evaluate door opening efforts 100% and repair vehicles as needed. Additionally, the team decided to measure 30 vehicles per day for the seal gap dimension. As it takes some time to measure this dimension in 10 locations around the door opening, the team decided that engineering would be responsible for taking the measurements. The seal gap dimension had not been identified as a “critical characteristic” during the design phase, and thus was not usually measured. It should be noted that the seal gap dimension needed to be measured before the seals were on the vehicle, and was therefore done at the end of the BIW line, before the vehicle went into the paint department. Measurements of door closing efforts, on the other hand,

were done at the final line. Since the seals contain a black, runny adhesive, removing them at the final line to measure the seal gap and the closing effort on the same vehicle proved too messy to do on a regular basis. Therefore, data was gathered daily on both seal gaps and closing efforts, but it was not practical to take this data on the same vehicles every day. Special seals without the adhesive were used in order to measure the seal gap and the closing efforts on the same vehicles for engineering studies.

After these implementing these initial containment actions in early August, the team also decided to measure door closing velocities to determine problem vehicles that needed to be re-fit. Additionally, both engineering and the plant did a number of yard checks throughout August and September. In one engineering check, two supervisors opened and closed every door in the yard. Vehicles that failed this subjective test (for either door-pop or high closing efforts) received a purple sticker. Then, the trucks with the stickers were measured for closing velocities. A crew of body shop door fitters accompanied the engineers who measured the closing velocities and re-fit doors with high closing efforts. Doors were re-fit and measured until they passed the closing velocity specification.

Implementing the door closing velocity measuring in daily production proved to be a difficult task. Ron needed to find a space for the testing, to train the operators and to provide them with reliable measuring equipment. Initially the operators wrote the closing velocity on a separate measurement report. As that was too time consuming, eventually the operators were instructed to write the closing velocity on a sticker on the truck's windows. Due to time constraints, the operators used different measuring equipment from the engineers. The operators equipment measured magnetically, while the engineers' used optics. As the optic sensor system required mounting a separate piece on the door of the truck, it required too much time to be used on every vehicle as it passed by on the bias line. Additionally, as the operators only had a short amount of time to measure and record each truck, they would close the door about three times and record the lowest velocity that resulted in a fully closed door. As long as that number was below specification, the vehicle did not need to be re-fit. The actual minimum closing velocity could actually be lower.

Find Root Cause:

Problem Definition:

In the Kepner-Tregoe problem solving methodology used by Wolverine, the first step to finding the root cause is stating the problem. They recommend using a "what, where, when, extent" method to define the problem and the use of "is/is not" to clearly specify the problem to be solved. The door-pop problem did not lend itself to easy definition. The phenomenon was often described as the "pop" the door makes when you open it from the outside. As this noise and movement existed on other vehicles, individuals would often question if this was a real problem. Some even joked that it was a "door opening assist" and could be marketed as a customer feature.

However, when questioned whether door-pop was a problem or not, the answer was usually, "... well, doors which pop often also have high closing efforts."

In addition to high closing efforts, vehicles with door-pop often had over-flush doors at the top of the B-pillar (the door surface was above the mating cab surface at the top, rear portion of the door, see Figure 12). This was caused in part due to the outward forces from the seals that were in the tight seal gap.

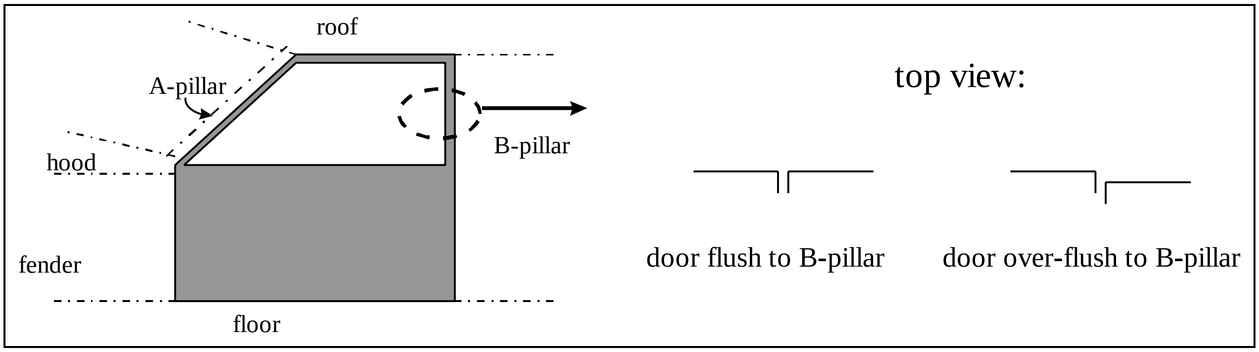

Figure 12: Flush vs. Over-flush

Throughout the problem solving process a number of studies were done to better define door-pop, including measuring the opening acceleration of the door. This particular test was difficult, as the vehicle needed to be opened from the inside to reduce the impact of the person pulling the door open from the outside. There were also more informal measurements, such as how many vehicles were on hold in the yard for door-pop and how much the fitters were complaining of back-aches from re-fitting doors at the end of the assembly line. Customer feedback was sought, and there were no initial complaints for door-pop recorded in the system.

Measuring closing velocity became the most used method for measuring door-pop.

Develop Possible Causes:

In early August at the beginning of the problem solving effort, Randy, the team leader, assembled a list of about 25 contributing factors to the problem and put the list and other information such as corrective action, owner and timing into an Issues/Summary document. This document became the driver for most investigative actions and the main vehicle for discussion of the door-pop problem during meetings.

In one early meeting, a member called a "time-out" to question whether or not the team really had a good grasp of the problem to be solved. The individual questioned whether the problem was door-pop, closing velocities, or a flushness problem. The group reacted with silence, then proceeded to explain to the individual that it was not any one of those items, but that all are related. The team felt that the Issues/Summary list covered all of the tasks necessary to study and resolve this complex issue. Most meetings were then devoted to status updates of the various items.

In all, there were over 20 studies done by the team. They ranged from studies of process variation to evaluations of potential engineering design changes. Studies were conducted at both the stamping plant (where the doors are stamped and assembled) and the truck assembly plant on variation of components, assemblies, and fixtures. Engineering evaluated softer seals, seals with differing diameters, means of deadening the "ping" sound, new fixtures for striker application, new ratchet designs for the latch mechanism, and various means of making the door stiffer at the B-post (to reduce the amount it would deflect under seal load).

After much evaluation, it was understood that the door-pop problem was a combination of a too-small clearance for the primary and secondary seals and a variation problem with the doors received from the stamping plant, the build up of the cab, and the striker application processes.

Data availability and credibility often hindered the analysis process. The CMM measuring points (or "m-points") between the stamping and assembly plants were often not the same. In fact, the datum scheme between the two production locations was also different. Although it was planned that both locations would have coordinated datum schemes, both the stamping and assembly plant deviated (in different directions) from the original plan in the months just before launch. These differences combined to make tracing the process variation component of the problem very difficult. Because the m-points weren't always coordinated, it became difficult to trace problems from the final assembly down to the sub-assembly and detail component level. Additionally, the two plants often did not trust the other's data, since it was measured differently. Many additional measuring points were added and entire new CMM programs were created to investigate this issue.

Confirm True Cause:

Early in the root cause analysis phase (mid-August), engineering determined that door-pop could be reduced by hanging the door with a wider seal gap. They acknowledged that the designed seal gap dimensions were too tight and set about determining what the design change should be to correct the situation. The ideal solution involved changes to all of the stamping dies and the header equipment. Not only would this solution be very expensive and time consuming to implement, it would be impossible to schedule given the Torop-up in production volumes. Therefore, the engineering team developed a "next best" solution that involved moving the door primary and secondary sealing surfaces outboard along the header.

This change was not possible to completely prototype, especially to evaluate the potential effects on wind noise and water leaks. Therefore, the team simulated the change using smaller diameter seals and found no increase in wind noise or water leaks.

Select & Implement Corrective Action:

From the beginning of August when the team first formed, it was under great pressure by management for resolution. Gary Grover (the vice-president) attended the daily Montana launch meetings about once per week and would often ask questions about the progress of the door-pop problem resolution. While a few team members attended the launch meetings, the main link between these launch meetings and the door-pop team was Doug Holmes, the BIW Engineering Manager. Doug was the manager of most of the team members from engineering and was the main source of information about management expectations to the door-pop team. He made it clear in early August that the team needed to decide whether or not to do an engineering change to the door dies by August 18.

By August 18th, engineering decided to submit an engineering change to the stamping group to evaluate the change for feasibility and timing. At this time, production was still ramping up and it was estimated that the change to the stamping dies should only take about 3 weeks. For the next several weeks, the door-pop meetings continued to provide updates on the on-going studies. By September 17th, another meeting with Doug Holmes was held. In that meeting, the team decided that while they wanted to go ahead with the engineering change, stamping needed to resolve their dimensional issues first.

Raising the dimensional non-conformities of stamping's supplied parts put some focus back on the process variation component of the door-pop problem. Initially, however, most of the focus was on stamping's and other supplied components variation, and not on the variation in the resulting build at Wolverine Truck. By mid-October, the new PVEs at Wolverine Truck really began to be involved in the door-pop problem. Unlike most of the PVEs who came to the plant for their first experience in a production environment, one of the new PVEs had extensive experience in both assembly and stamping plants. He brought a new focus to the assembly process and used daily process variation data to determine where Wolverine Truck Assembly could improve regarding the door-pop problem. This PVE stated that he did not feel right asking for a design change from engineering when the plant did not have capable processes.

Throughout the month of October, the PVE group made a number of changes to tooling to reduce the variation and move the Wolverine Truck processes toward their nominal specifications. Initially, these efforts were undertaken to potentially eliminate the need for the engineering change. In fact, by the beginning of November, the door-pop problem was significantly reduced, if one used as a measure the number of vehicles on hold for that problem. Since the closing efforts remained high, however, the PVE group agreed that the engineering change to the stamping dies was still desirable. Since production was by then at full volumes, however, the change could not be done immediately. The only windows of opportunity to make the changes without affecting production were the upcoming Thanksgiving and Christmas holidays.

The left hand doors were successfully changed over the Thanksgiving holiday and the right hand doors were changed over the Christmas holiday break. The results of the engineering change were positive: the over-flush condition on the left hand doors was eliminated. By having a wider seal gap, the seals were compressed less. This reduced compressive force resulted in the door header being pushed to its proper flush position, instead of its previous over-flush condition. As the doors were no longer over-flush, the bending operation on the final line was eliminated. Door closing velocities also decreased somewhat.

Prevent Recurrence:

The "Prevent Recurrence" section is the last section of Wolverine's problem solving methodology. Regarding the specific engineering design problem, a change was made for a future program that uses a very similar design to the Montana door design.

4.0 Technical Analysis of Door-pop

The Montana door-pop problem that was introduced in Chapter 3 provides a good example to analyze Wolverine's use of Key Characteristics. This chapter will begin by defining Wolverine's Key Characteristics procedures and implementation in platform teams. Next measurement plans called Control Plans will be introduced to show how the control of Key Characteristics can be defined. The door-pop issue will then be analyzed using the Key Characteristics flow-down techniques showing how the observed problem was created through the build-up of the various components and their variation. The chapter will conclude with a discussion of the data availability issues that the Montana team faced in resolving the door pop problem.

4.1 Key Characteristic (KC) definition

Key Characteristics (KCs) are product features, manufacturing process parameters, and assembly process features that significantly affect a product's performance, function, and form (Lee and Thornton, 1996). Many manufacturing companies currently use KCs to define such important characteristics during the design phase of a new product or process. A number of recent academic papers about KCs illustrate various new quantitative methods to systematically prioritize and manage KCs (Lee and Thornton, 1996). These methods rely upon starting with quantitative definitions of initial quality goals and use a "flow down" procedure to move from the high level goals to the important feature level characteristics. Flow charts are often recommended to capture the relationships between various KCs and to visually represent the flowdown. One important aspect of KC identification is differentiating between those KCs that might be problematic to achieve and those that can be achieved using current production capability. Potentially problematic KCs can be addressed by either applying robust design techniques or implementing special controls in production to ensure quality products.

For the various systems and components, Wolverine defines two different types of KCs: Key Design Characteristics and Key Process Characteristics. Key Design Characteristics (KDC) are those parameters or features in a part or system that are important for customers, sensitive relative to design function or reliability, or critical or historically difficult to control during manufacture and assembly, thus requiring special attention (PAP manual, 1995). Key Process Characteristics (KPC) are the individual process characteristics, requirements, and specifications that are critical to contain process variation within specified limits.

4.2 Teams at Wolverine

Wolverine's platform teams were introduced in section 3.2. Wolverine uses teams as the organizational structure to support new product development. These teams are therefore responsible for the selection of appropriate KDCs and KPCs. The platform teams are broken down into various levels of product planning teams by breaking the vehicle down into its various assemblies, sub-assemblies, and component parts. Wolverine typically creates teams at each level, following their organizational hierarchy. For instance, the vehicle level teams are typically made up of general managers and executives, the system level teams consist of executives and managers, and the component level teams consist of managers and product and process personnel (PAP manual, 1995). A number of teams are usually created at each level, however, made up of either executives for strategic decisions or working level engineers for design of systems. The following figure shows this structure and some sample teams for each level.

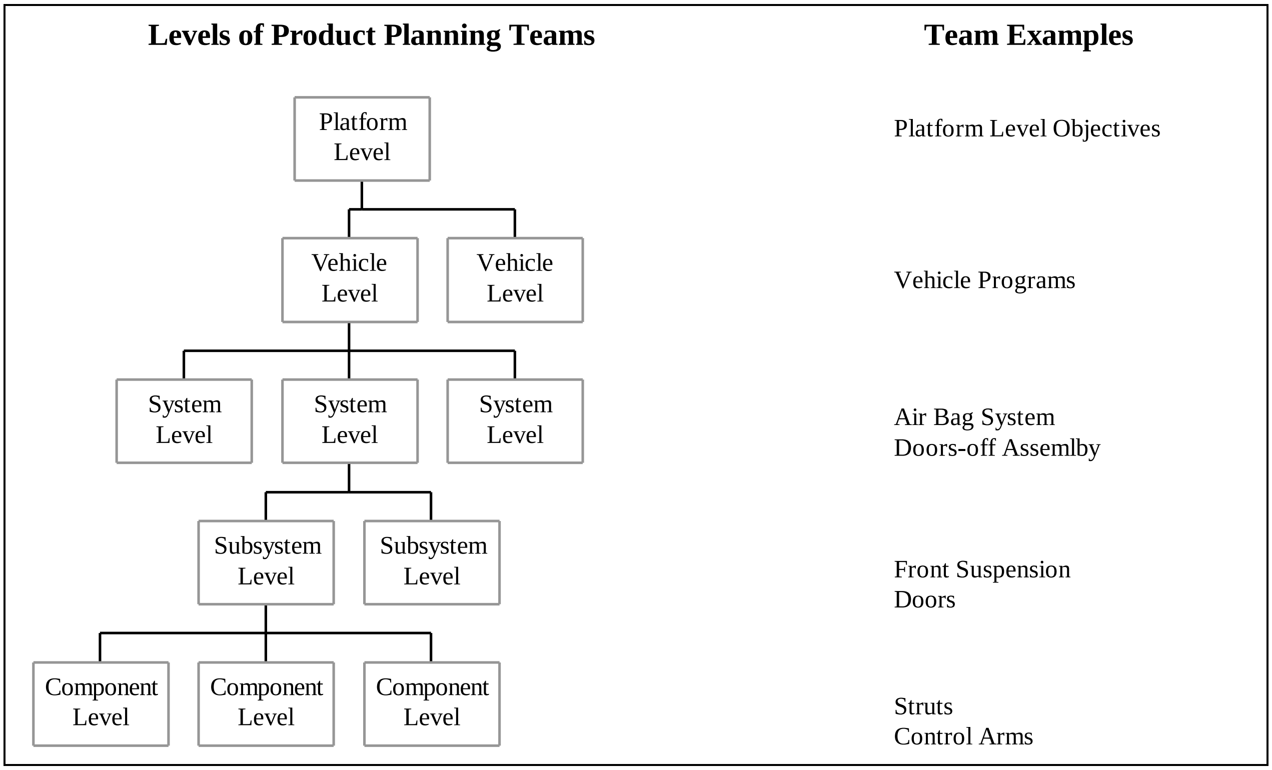

Figure 13: Team levels

Wolverine begins the KC selection process by defining functional and reliability targets during the approval phase for a new product. These targets are established by a team of engineers who represent the product or process system. Examples of teams are in the right hand column of Figure 13 such as Noise Vibration Harshness (NVH) teams, Air Bag System teams, Doors-off Assembly teams, etc. Teams include members from the various design and process engineering groups such as Body Engineering, Structures, Dimensional Control, Advanced Manufacturing Engineering, supplier representatives and other platform team members such as Purchasing and Finance as appropriate.

4.3 KC Methods at Wolverine

The various system level teams typically set performance and functional objectives that include customer desires, competitive benchmarks, and desired competitive position. These high-level objectives are then translated into subjective and quantitative goals, which then drive key characteristic selection. Tools such as Quality Function Deployment, Design Failure Modes and Effects Analysis (DFMEA), Fault Tree Analysis, Design for Manufacturing and Assembly (DFMA), Error/Mistake Proofing, Design of Experiments (DOE), Flow Charting, Finite Element Analysis, Geometric Dimensioning and Tolerancing (GD&T), Failure Mode Analysis (FMA) and Assembly Variation Analysis or Variation Simulation Analysis (VSA) are used to determine key design characteristics (PAP manual, 1995).

During the various phases of development, Wolverine defines objectives, deliverables, measurements, and methods to evaluate Key Design Characteristic selection. For instance, during the design approval phase, the deliverable is a preliminary list of design characteristics critical to meeting functional, reliability, and program objectives based on past experience or analytical studies (PAP manual, 1995). The measurements are the percentage of functional and reliability targets and the percentage of high risk failure modes that have identified KDCs at each design phase. The Key Process Characteristics (KPCs) selection undergoes a similar process to select characteristics that are critical to control the variation of the process. Deliverables for KPCs include lists of the process characteristics or production operations that are key to meeting the KDCs and lists of KPCs that are related to high-risk potential process failure modes based on past experience or analytical studies (PAP manual, 1995).

In practice, KDCs are designated as measurement points (m-points) or critical points. Critical points are a subset of measurement points and are chosen by the development team. They are typically points that are either more difficult to control or significant in determining finished product quality. During production, there are usually two types of programs written for the coordinate measuring machines (CMMs): short and long programs. The short program includes only critical points while the long Program includes all measurement points.

The dimensional control group within each vehicle engineering group is responsible to ensure that key characteristics are chosen. The documentation of the selected key characteristics is recorded directly in the CAD file in a table such as the following:

Table 1: CAD file showing KCs

Point	Measurement Point	Critical
ABC01	Y	N
ABC02	Y	Y
ABC03	N	N

4.3 Control Plans

In addition to (and sometimes instead of) charts listing measurement points in CAD files, many automotive companies use "Control Plans" to present detailed measurement plans (AIAG, 1994). Control Plans describe the steps required to ensure that key characteristics are maintained during production. They usually list the characteristic, the sample size and frequency, describe how it is measured, how the measurement is evaluated, and a reaction plan if the measurement is not as anticipated. A sample control plan is shown below:

Table 2: Sample Generic Control Plan

Dim.	Description	Sample size	Frequency	Measurement equipment	Method to evaluate	Reaction Plan
ABC01	door flushness	5	1/shift	CMM	X-bar/R charts	• Stop production. • 100% sort since last in-control point. • Correct process. • Produce and measure new parts.
ABC02	roof depth	5	2/shift	OCMM[3]	automatic	"

Control plans are useful because they describe in detail how KCs will be controlled during production. Their format on a document separate from the part drawing allows gauging,

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[3] OCMM stands for Optical Coordinate Measuring Machines which are used primarily to measure trends during production.

frequency, and reaction plans to be detailed in a clear manner for everyone from engineers to production operators. Control Plans are a convenient means of training new operators and engineers about what is important for a particular product and how those important characteristics are maintained. They are especially useful during problem solving activities as they clearly identify what dimensions are currently being measured, when and how. Control Plans that are living documents and updated after problem solving activities to reflect new procedures are also useful when developing new Programs as a means of documenting learning.

It is often beneficial to begin creating Control Plans during the development phase of a new product to ensure that the KCs chosen will be able to be controlled during production. They are often developed concurrently with the design and process FMEAs (Failure Modes and Effects Analysis, see Advanced Product Quality Planning and Control Plan, AIAG, 1994). Control Plans are especially useful as a tool during development because, unlike CAD files, they present key characteristics in a format that is more easily understood by all stakeholders. While the CAD files are accessible only to those that can read computerized drawings, a Control Plan format presents the KC data in a standard table.

The other major advantage of Control Plans is that a company can assure that feasible control methods for KCs are identified. While measurement plans are usually developed by the plant dimensional control groups when the vehicle launches, implementing a procedure to create Control Plans during the various development milestones ensures that the control methods are agreed to by all stakeholders. Discussion of control methods earlier in the development cycle can also lead to selecting different KCs based on feasibility of measurement and control. Additionally, by having cross-functional teams agree to the Control Plans, the company ensures that the various functional groups buy into the datum schemes, measurement points, and control and evaluation methods.

4.3.1 Measurement plans at Wolverine

In the truck platform examined for this thesis, Wolverine did not explicitly use Control Plan documents during development for KCs. Measurement plans do exist within the dimensional control groups of the production plants and lists of KCs exist on the CAD files. However, there is no one document that both production and engineering use that provides all of the information that would be contained in a typical Control Plan.

One of the reasons for this is that Control Plans are often viewed as bureaucratic, paper-creating procedures. When there are a large number of characteristics to be controlled and the control methods and frequencies change frequently, this is a valid criticism. The benefits to be realized in increased communication between production and design, however, are significant. Information technology can be used in a variety of creative ways to reduce the burdensome paperwork aspect of Control Plans.

4.3.2 Additional example

In addition to the door pop problem, the following example provides more anecdotal evidence of the potential usefulness of a Control Plan-type document in Wolverine. A different product was experiencing some issues in the final in-house quality assessments at the assembly plant. The measurement points chosen by engineering during development and listed on the CAD file were being tracked and measured as required. The PVE responsible for that sub-assembly began trying to trace the problem seen on the final product down to the component level by examining the collected data on the m-points. The m-points on the components, however, did not show a problem because the set selected were not predictive of the final quality. The PVE and the plant dimensional control group did a number of studies and discovered a different set of m-points on the components that better predicted the quality of the final characteristic. They changed the CMM program and the plant's internal measurement plans.

An updated Control Plan would provide a means of documenting that learning. While the PVE should try to ensure that the CAD file is updated, he is not the product engineer with control of that drawing. When a new product is developed by the same engineers that designed this product, the engineers would not necessarily know that their original assumptions were incorrect. A Control Plan would serve as a living document for both production and product engineering to record their learning about key characteristics.

4.4 KC History for Montana Doors

The 1997 Montana platform team had objectives to improve nearly every quality measurable for this mid-sized pick-up truck. In the "overall quietness" category were the objectives to have reduced wind noise and in the reliability section were goals to eliminate potential water leaks. In the appearance category, the new Montana was to have a similar "look" as the full-size Toro pick-up truck. This look included a door that was curved inward (inboard) to meet the roof. The performance category included objectives about the amount of force required to close the door fully.

4.4.1 Seal Gap Dimension

A balance clearly needs to be found when designing the vehicle to meet all of the above objectives, as there are interactions among them. For instance, in order to have doors which close with little effort, one could design a system with a small seal in a large space between the door and the cab. This would have a negative impact, however, on the overall quietness and would potentially allow for water leaks. As the Montana team had objectives for the closing efforts, water leaks, and wind noise, they performed a number of studies of various design solutions. For the seals they used curves provided by the seal supplier showing the amount of force provided by a particular level of compression. Given the geometry of the interface between the door and the cab, however, the design engineers could not perform traditional variation simulation analyses, as the exact spring back of the door was unknown. In the end, they decided to meet their objectives by designing small seal gaps between the door and the cab and using static load compensation.

Static load compensation uses the force of compressed seals to push the door to its proper location. When the finished door is assembled to the body in the body shop, the surface of the door to the roof is not flush. Two major changes happen in the trim section of the plant to change the flushness of this surface. The first change is that many pounds of trim components (windows and their regulators, trim panels, door locks, mirrors, etc.) are added to the vehicle. This added weight causes the door to deflect downward about the hinges which brings the door lower relative to the roof. The second change is the effect of the static load compensation of the seals. The seals are applied in the trim assembly part of the plant, and when the door is closed, they are under compression. This compression serves to push the door outboard and into a flush condition relative to the roof and to the "A" and "B" pillars (see Figure 14). The compressed seals provide a tightly sealed cab and help to muffle the wind noise and reduce potential water leaks.

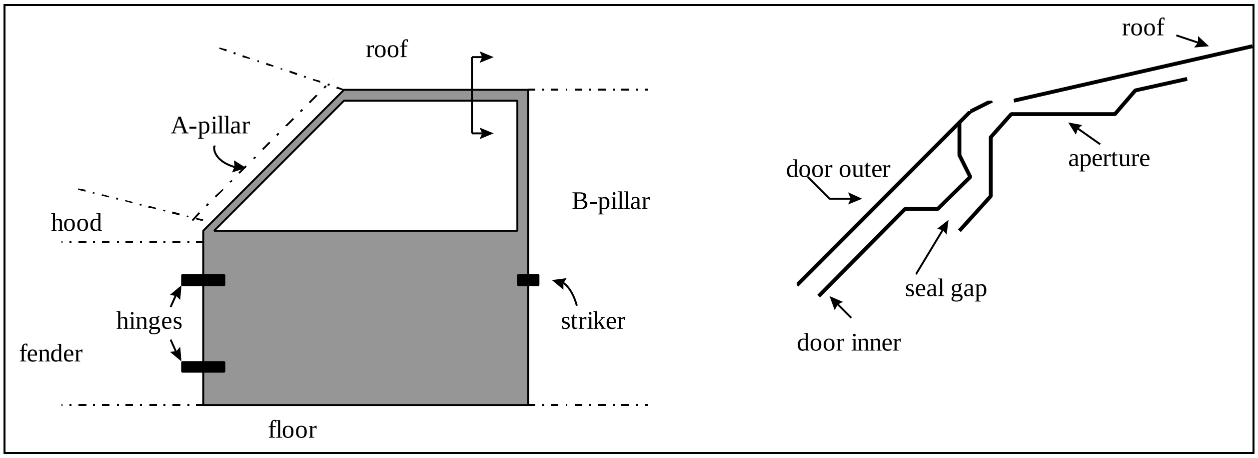

Figure 14: Seal Gap diagram

4.4.2 Definitions of terms

The figure above shows a side view of a door with the mating sheet metal components. The door is framed on either side by the "A-pillar" in the front and the "B-pillar" in the back. If there were a back door as in a four-door car, there would also be a "C-pillar" between the back door and the rear windshield. The B-pillar section of the vehicle is also called the quarter outer on the truck.

The roof, floor and A and B pillars are all attached to a component called an aperture that frames the opening and matches the door geometry.

A door is made of two main components, an outer skin and a stronger inner structure, and a number of smaller parts such as glass channels and reinforcements. The fender is the piece of sheet metal above the front wheels, just below the hood. The door is attached to the truck with two hinges that are located behind the fender. Latching of the door is accomplished with the "striker" that is a loop of metal attached to the rear portion of the aperture. The latch mechanism on the door has a ratchet arm that encloses the striker loop when the door is closed to keep it latched.

4.4.3 Designing the Door

While the existing Toro truck had a door design very similar to the proposed design of the Montana, there were important design, material, and process differences. First, the Montana is a smaller vehicle and therefore the door is also smaller. Secondly, the material used to build the Montana door also differed from the Toro in that it used a laser-welded blank for the door inner stamping. A blank is a piece of sheet metal used to stamp a component and is usually of a constant thickness. In order to have a door with the necessary stiffness, a blank would need to be very thick and therefore heavy and expensive in fuel economy terms. A typical solution was to use a bracket in the door assembly to provide support. The Montana development team, however, decided to use a new process that uses a blank made of two different thickness of steels laser-welded together (see below). A thicker steel was used for the forward portion of the door inner while the standard thinner steel was used for the middle and rear portion. The third difference was that the truck assembly process was planned to change to a "doors off" process for the 1997 model year (see section 3.3 for a description of the doors off process).

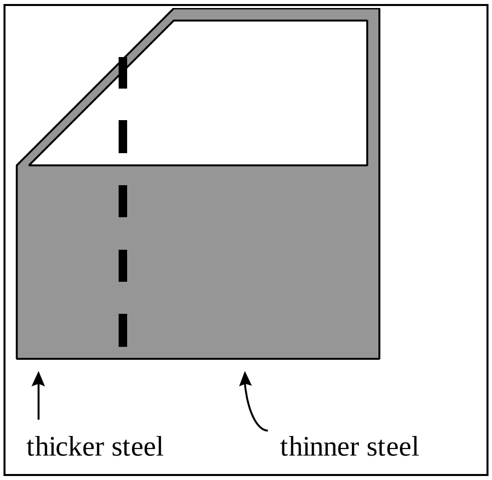

Figure 15: Laser-welded blank

These three changes combined to make the calculation of the seal gap dimension during the design phase difficult. With a smaller door, a different material, and a different process, it was not clear how much the door would flex when under pressure from the seals. The amount of flex was critical because it affected the final position of the door and therefore the flushness of the door to the roof and "A" and "B" pillars. The determination of the seal gap dimension was therefore both very difficult to determine and very significant to the overall quality of the finished vehicle.

4.4.4 Seal Gap KCs

Although it was clear that the seal gap was an important dimension, it was also very time consuming to measure and therefore was not listed directly as a KDC for the Montana. Instead, a number of dimensions on the door assembly, cab assembly, and finished vehicle were listed as KDCs. There were no KPCs defined regarding the seal gap dimension. All defined KDCs on the components, sub-assemblies and finished product were listed in the CAD file as "m-points". Because of the amount that the door would flex was unknown and the outward forces provided by the seals under compression was an estimate, it was not possible to accurately predict the seal gap by measuring the m-points on the various sub-assemblies.

4.4.5 Gauging Systems

Another issue that affected KC selection for the Montana was that Wolverine was in the process of switching from dedicated hard gages to flexible gaging systems in Wolverine Stamping Plant. These systems use a series of flexible posts to fixture the part and CMMs to measure it. The posts are free-standing and have adjustable heights to allow them to be placed in various positions to support the part to be measured. These flexible systems are significantly less expensive than hard gages as the posts can be used and re-used for a variety of parts. The flexible systems are also much easier to modify than the hard gages if one wants to change the measurement points at any time. The problem for the Montana team was that the stamping plant was in the process of switching, and it was not known if the transition to flexible gages would be complete in time for the Montana launch. Since the team had to build dedicated hard gages, they were constrained on the number of measurement points that they could choose. They needed to narrow down their list of the small number of points that they would like to measure in the long run by the beginning of pilot production. With a flexible gaging system, they could have chosen a large number of measurement points during the beginning of volume production and gradually reduced the list to the vital few key characteristics.

4.5 KC Flow Down Analysis for Door-pop

The following is a KC flow down analysis for the door-pop problem done by the author after the problem surfaced during the product launch. An approach similar to this can be useful during development to explicitly show how key characteristics are affected by the variations in the components and processes used to create them. In the early stages of product development, the tolerances can be used for the inputs to the flow down. As data becomes available from prototypes, however, it is often useful to use actual data to estimate the predicted variability for the flow down analyses.

4.5.1 Process Flow

In order to perform a KC flow down analysis for the door-pop problem, one needs to understand how the various components are assembled. The following process flow chart shows the general steps used to assemble the doors to the cab and the fixtures used.

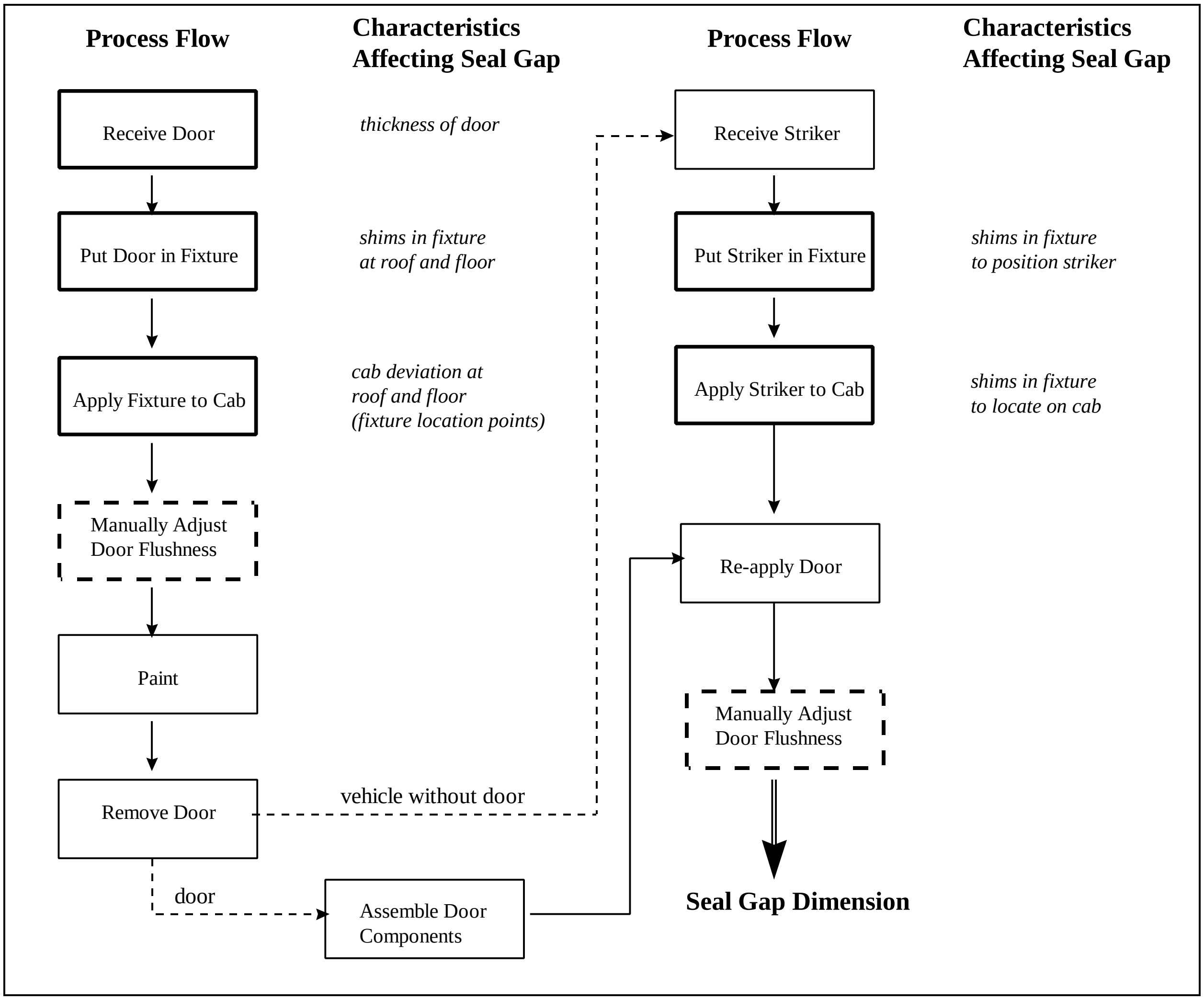

Figure 16: Process Flow Chart

Figure 17 below shows how the door is loaded into the door application fixture. The door is clamped as shown into the fixture. The fixture is then brought to the vehicle, where a second set of clamps attaches the fixture to the vehicle. The bolts are then driven to attach the door to the vehicle, and the fixture removed. A door fitter then attaches a weight to the inside of the door to simulate the weight of the door trim components to be added during the door build-up process on the door trim line. The weight moves the door to its theoretical final position and the door fitter makes any necessary adjustments to the hinges to move the door to its proper location for flushness with respect to the roof and B-pillar. Although the door will be removed after paint and then re-attached, it is worthwhile to adjust the flushness before paint as the door fitters have access to parts of the fender assembly that are inaccessible after the fender is applied. Additionally, by making the major adjustments before paint, the fitting operations done at the final line should be minor in comparison.

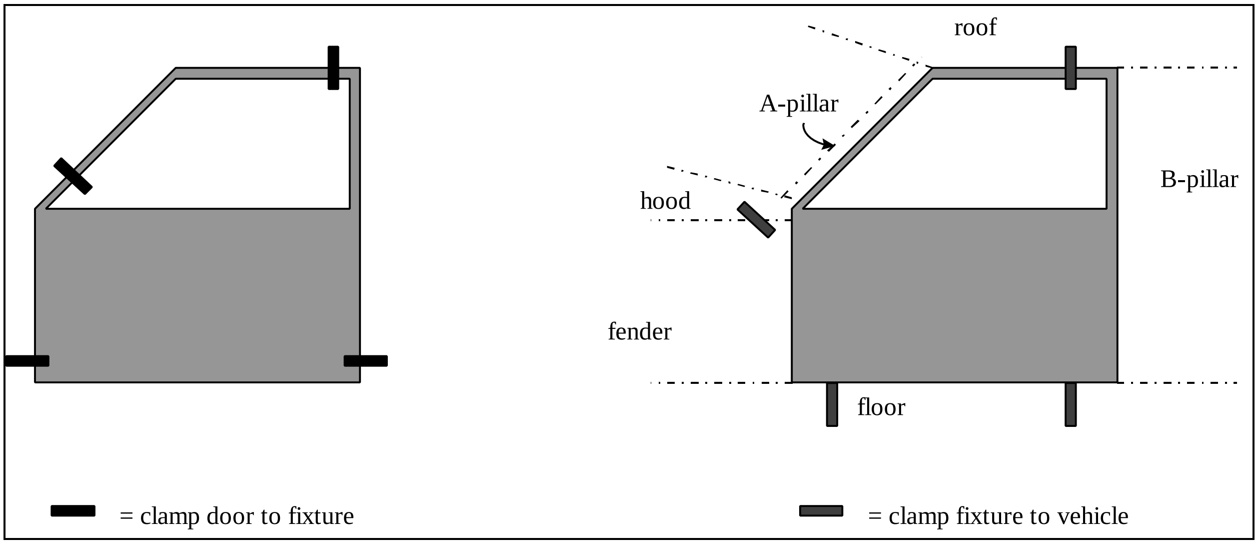

Figure 17: Door Assembly Fixtures

The vehicle gets painted and the doors removed to be built up separately from the rest of the vehicle. The striker is applied to the cab and the door re-attached near the end of the final line. Doors are then re-examined by door fitters for fit and adjusted as necessary.

4.5.2 Determining Seal Gap

Figure 18 shows where the seal gap dimension is relative to the door inner and the quarter panel. As shown in the figure on the right, the seal gap dimension is dependent on the thickness of the door and the location of the striker. The seal gap is also dependent on the flushness between the door outer surface and the quarter panel, as the door and/or striker will be adjusted to achieve the flushness requirement. Therefore, the flushness is determined first, based on the door outer location, the striker location, the location of the latch in the door, and the location of the quarter panel. The seal gap is then defined as the difference between the quarter panel flange location and the door inner location, corrected for the amount that the door outer surface is out of flushness.

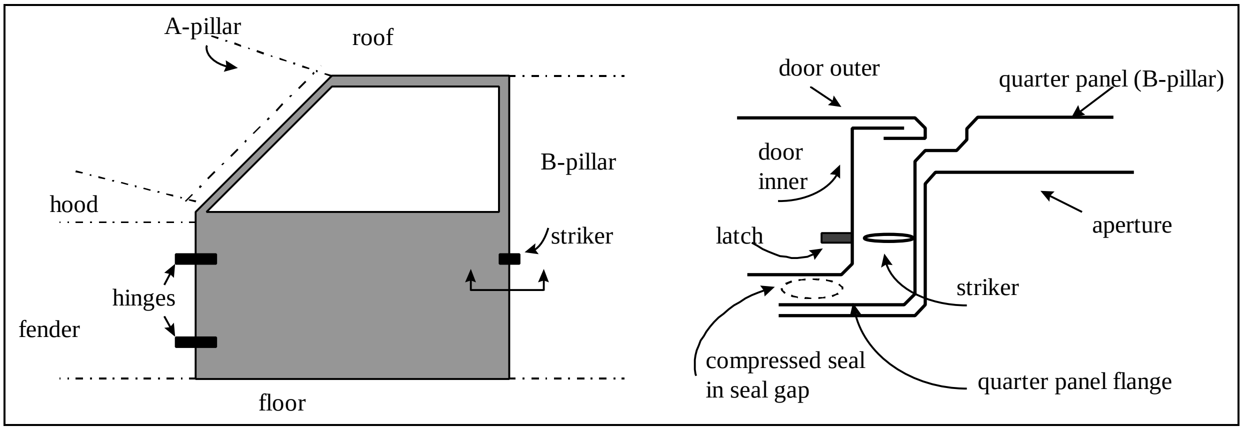

Figure 18: Seal Gap at Striker

The following equations explain how the variations in the above inputs combine to create the seal gap dimension and the flushness of the door to the quarter panel. All of the equations are showing the difference between the location of a measured point relative to its nominal location in the "y" or cross-car direction only. By summing the differences from nominal (or the errors "♑"), one can calculate the y-direction variations that the sub-assemblies will move in as they are attached to one another.

$$♑_{SG} = ♑_{q} - ♑_{i} - ♑_{F}$$

$$♑_{F} = ((♑_{s} - ♑_{l}) - ♑_{d}) + (♑_{f} - ♑_{Bp})$$

$♑_{SG}$ = seal gap

$♑_{F}$ = flushness of assembled door to quarter panel

$♑_{q}$ = quarter panel flange location

$♑_{Bp}$ = B pillar outer surface

$♑_{i}$ = location of door inner panel

$♑_{f}$ = flushness of door's outer surface

$♑_{d}$ = door apply fixture location

$♑_{s}$ = striker location

$♑_{l}$ = latch location

For instance, as explained above, the flushness ($♑_{F}$) of the door outer surface to the quarter panel is established first. The first step is that striker mates with the latch ($♑_{s} - ♑_{l}$). Then, the location of the door surface is determined by the following two components:

1. the difference between the location of the door from the mating of the striker and latch ($♑_{s} - ♑_{l}$) and the location that the door apply fixture placed the door ($♑_{d}$), relative to its nominal location. [$(♑_{s} - ♑_{l}) - ♑_{d}$]
2. combined with the flushness of the door's outer surface ($♑_{f}$) compared to the B-pillar or quarter panel location ($♑_{Bp}$). [$♑_{f} - ♑_{Bp}$]

The overall flushness of the door outer surface to the B-pillar or quarter panel is thus the combined deviation from nominal of the door location as applied and the geometry of the door outer surface and the B-pillar:

$$♑_F = ((♑_S - ♑_l) - ♑_d) + (♑_f - ♑_{Bp})$$

The amount by which the door is over- or under-flush ($♑_F$) is corrected manually by the door fitting operation. Therefore the seal gap ($♑_{SG}$) becomes a function of the difference between the location of the quarter panel flange ($♑_q$) and the location of the door inner ($♑_i$) corrected for the flushness discrepancy that was manually corrected ($♑_F$).

$$♑_{SG} = ♑_q - ♑_i - ♑_F$$

4.5.3 Seal Gap Causal Loops

The following causal loops are an additional visual aid to show how the seal gap dimension changes depending on the relative positions of the received components and how they are built to match each other in the process. For instance, if the door is received in an outboard condition, either the door must be bent inboard or the quarter panel brought outboard to match it in order to have the flushness between the door and the quarter panel in specification. There are two causal loops shown, one for the cross-car or “y” direction and one for the up/down or “z” direction. Both show similar results in that as the seal gap dimension becomes smaller the rate of door-pop increases. Additionally, as the door latch to striker location is mis-matched, the rate of door-pop also increases.

Both causal loops have reinforcing inner loops (shown by the ⊕ inside the loop) that say that if the quarter panel is received under-flush, then the door header will be over-flush to the quarter panel. This causes the door fitters to bend the door inboard to match the quarter panel. This in turn causes the seal gap dimension to become smaller, which increases the compressive forces on the door. As the compressive forces on the door increase, the door is pushed outboard. As the door is pushed outward, it becomes over-flush to the quarter panel. Since this loop is reinforcing (not compensating), it says that having an input of a quarter panel that is inboard throws the system into instability. The problem of door pop is created as a result of this instability.

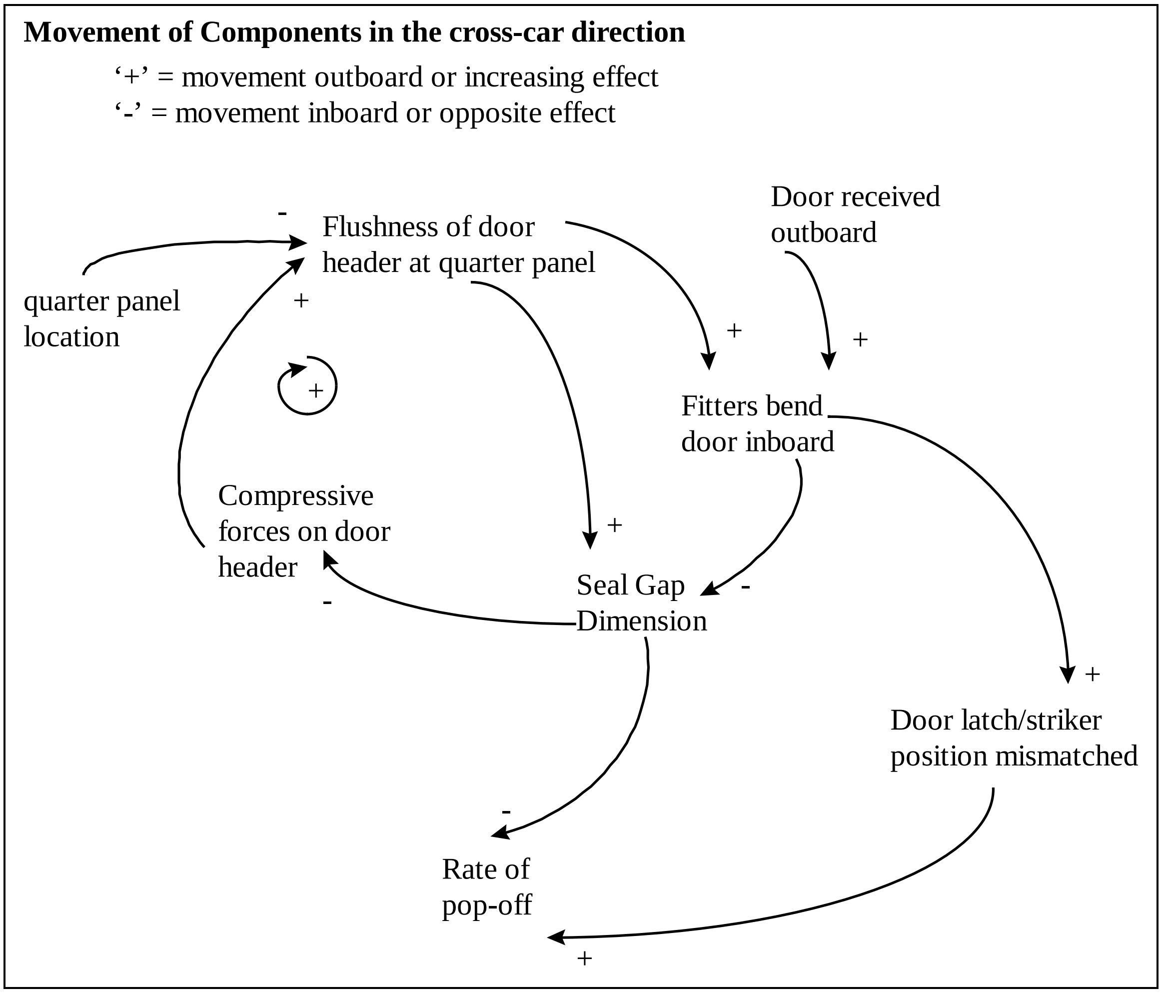

Figure 19: Causal loops for cross-car direction

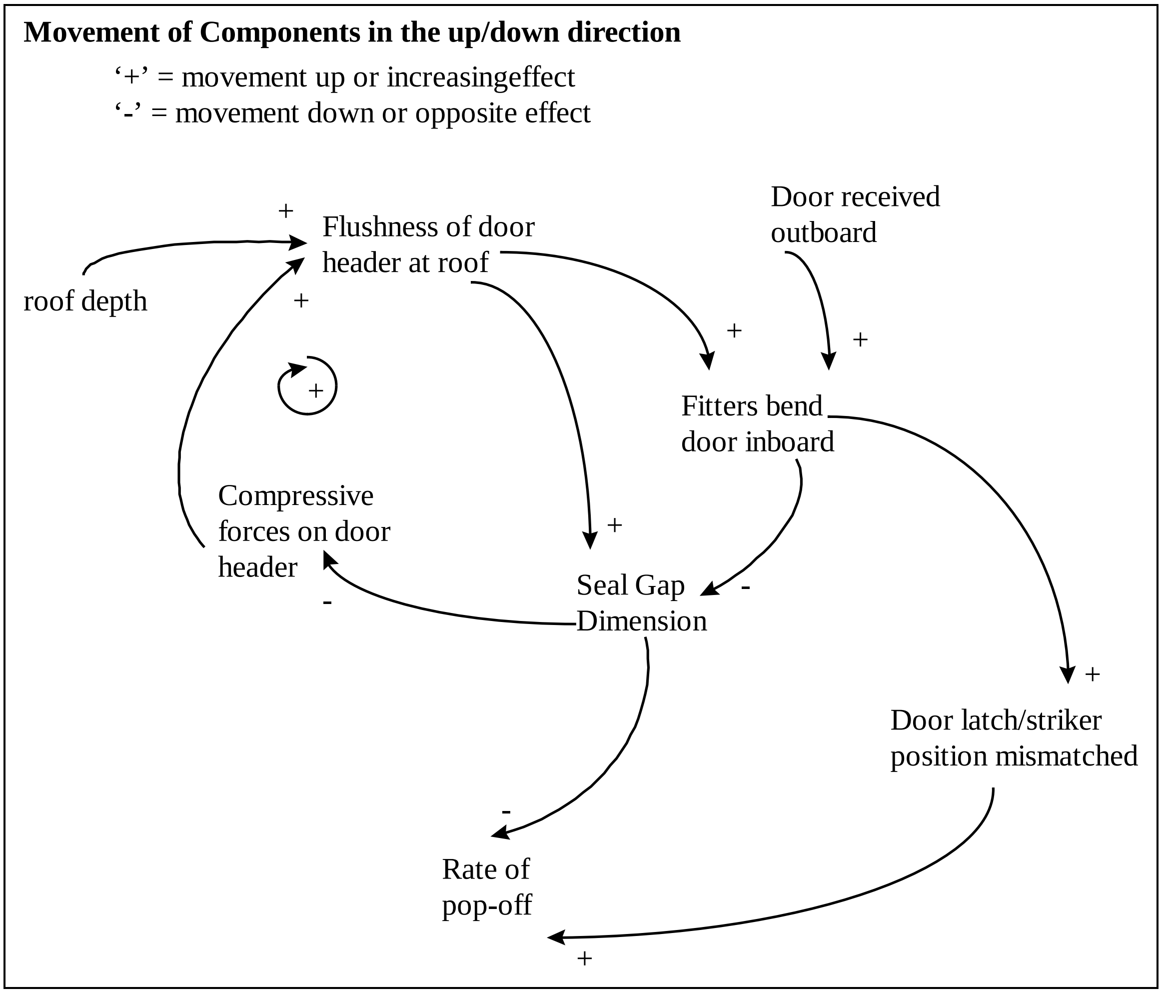

Figure 20: Causal loops in up/down direction

4.5.4 Seal Gap KC Flow Down

Figure 21 below represents the KC flow down for the seal gap dimension. It shows how the flushness of the door to the B-pillar affects the seal gap, and how that flushness is determined by the build-up of the various sub-assemblies. This flow-down is shown to give another visual representation of the same phenomenon shown in the equations of section 4.5.2 and the causal loops of section 4.5.3.

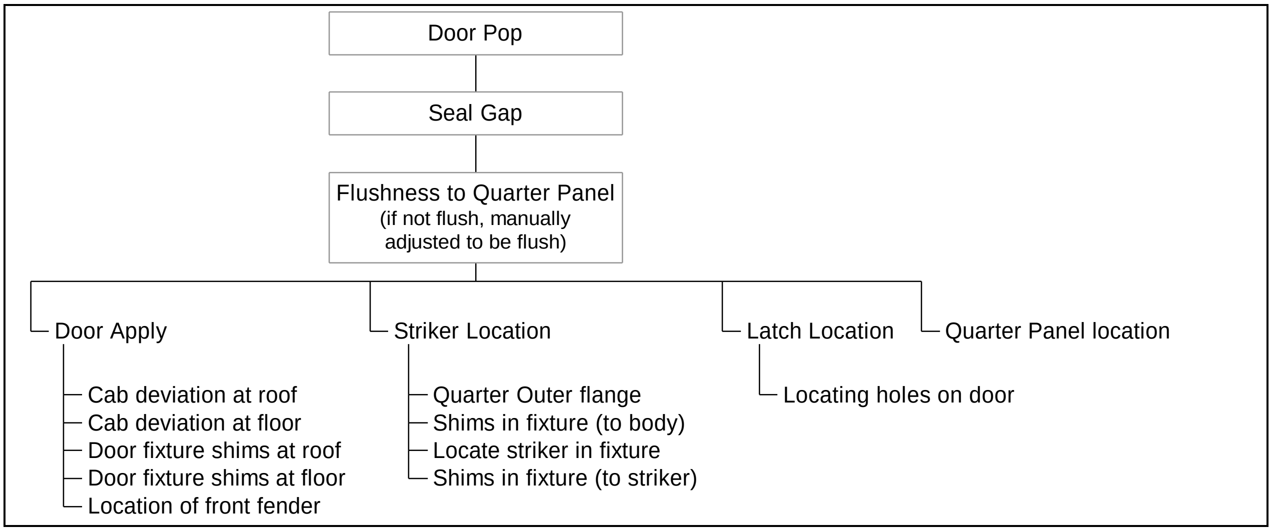

Figure 21: KC Flow Down

Figure 22 and Figure 23 on the following pages show how the above flow chart can be used to quantitatively predict how the seal gap dimension will vary based on variation in its component parts. The combination of the four branches represented above: door application, striker application, latch location, and location of the quarter panel can be shown in the following calculations, based on the equations in section 4.5.2.

There are two meaningful ways of analyzing this flow-down: the mean location component and the variation component. The mean location would use the nominal location to determine the nominal value of the KC (in this case, seal gap). The variation component is useful to determine the expected variation or tolerance band of the KC. There are also two types of data that can be used: tolerances or actual production data. During development, using the tolerances in this model provides a useful way to verify the design. Using process data can show how well the actual variation seen affects the characteristic of interest.

In the following examples, sample production numbers are used to show how the addition of shims in fixtures combined with the variation in incoming components combines to affect the key characteristic of seal gap. The first chart shows the predicted mean location of the flushness of the door to the quarter panel based on the mean differences from nominal of the component parts and fixtures. The numbers in every box are the difference from nominal of the measured dimension in millimeters. Positive numbers show that the dimension was measured outboard relative to nominal, while negative numbers show an inboard condition. These differences are combined according to the assembly sequence, which was explained in the equations of section 4.5.2.

FLUSHNESS			
Cross-Car direction	Note:		
	"+" = outboard		MEAN DIFFERENCE FROM NOMINAL
	"-" = inboard		
DOOR APPLY FIXTURE/CAB LOCATION:			
Top/bottom, near B-pillar			Net position
	At Roof	At Floor	at striker:
Cab	0.1	0	
Door Fixture(shims):	-2	5	
Total:	-1.9	5	2.07
STRIKER			
Quarter Outer flange (striker apply fixture locates here)			1.70
Shims in fixture (to body, inboard):			-3.00
Shims in fixture (to striker, outboard):			4.00
		net striker:	2.70
LATCH			
Locating holes rel. to Dr Outer datums (avg. 3 holes + slot):			-0.17
		Net mating:	2.87
FLUSHNESS			
Loc. of B-pillar surf., rel. to new datum line on cab fr. Fixture			0.10
Flushness of door at striker, rel. to door outer datums			-0.52
		Flushness:	0.70
Flushness = (Striker - Latch) - Door location + (Door flushness - location of B-pillar)			

Figure 22: Mean location of flushness

While the above gives us the position of the door in the cross-car (or “y”) direction, the following shows how to calculate the expected variation in that flushness location. Instead of adding the differences from nominal according to the assembly sequence, the variation component formula is simply the sum of the squared errors observed in each measured dimension.

FLUSHNESS			
Cross-Car direction			Variance = (Std. Deviation)^2
DOOR APPLY FIXTURE/CAB LOCATION:			
Top/bottom, near B-pillar	At Roof	At Floor	Net variation at striker:
Cab	0.01	0.02	
Door Fixture(GR):	0.02	0.01	
Door Fixture (block tol.):	0.01	0.01	
Total:			0.08
STRIKER			
Quarter Outer flange (striker locates here)			0.02
GR of fixture			0.01
Locate striker in fixture (design block tolerance):			0.01
LATCH			
Locating holes rel. to Dr Outer datums (avg.hole + slot):			0.01
FLUSHNESS			
Loc. of B-pillar surf., rel. to new datum line on cab fr. fixture			0.01
Flushness of door at striker, rel. to door outer datums			0.02
		TOTAL:	0.16
Total variation of flushness = Sum of squared errors			

Figure 23: Variation of flushness

4.5.5 Montana use of KC flow-down

The above analysis is a potentially useful method to determine how the build-up of the various components affects the final characteristic. If the final variation is unacceptable, this model allows one to see the effects of varying the deviations of individual components on the final assembly. In order to perform this analysis, however, one clearly needs data on the individual components. Therefore, these components need to be identified as key during the design phase so that measurement plans can be developed. Using a Key Characteristic flow down during the development phase is therefore critical to ensuring that the right characteristics are chosen.

While basic models similar to this were used for a number of characteristics for the Montana development, the team did not do a complete KC flow down for the seal gap dimension. Part of the reason for this is that the seal gap is of interest around the entire perimeter of the door, not just at the striker as analyzed above. Additionally, as one analyzes the seal gap in different locations around the perimeter of the door, the variation in the “x” and “z” (fore/aft and up/down) directions becomes important. For instance, at the interface of the door header and the roof, the door surface moves inboard and outboard at a 45° angle, not parallel to the ground. While both of these constraints could be handled in a computer-modeled version of a KC flow down such as a variation simulation analysis (VSA), these models are often very complex and time-consuming to construct but allow complex assemblies to be analyzed.

Regarding door pop, while an analysis such as the above would have shown the sensitivity of the seal gap dimension to variations in its sub-assemblies, that was not the entire problem. Another major important source of the door pop problem was that the designed seal gap was actually too small, given the deflecting characteristics of the door and the compressive forces of the seals.

4.5.6 Data Availability

As previously discussed, the development team was not able to define every KDC as an m-point due to the gauging method uncertainties and measurement costs. The seal gap was determined to be too difficult and time consuming to measure and therefore was not listed as a KDC. Additionally, the team was under pressure to keep the number of m-points low in order save money on specialized hard gages. Therefore, a number of the lower level points in the KC flow down were also not defined as m-points. This had a significant impact on the prediction of the door-pop problem and on the subsequent analysis to try to identify the areas causing the problem. When the door-pop problem began to be under serious study, a number of m-points had to be added to existing CMM programs. Entire new CMM programs needed to be written in some cases to gather the necessary exploratory data, resulting in increased costs and time delays.
In addition to a lack of data about the seal gap dimension, much of the data needed to complete a thorough KC flow-down using process data was not available or reliable. The records on shim

moves on fixtures, for instance, were not maintained by both shifts and thus were not useful. As the number of shims with which the fixture was certified was not recorded or marked, the only way to determine the net shim moves would have been to dismantle it and re-measure every clamping point on a CMM.

Another difficulty in data availability arose from the datum scheme differences discussed in Chapter 3. As the stamping and assembly plants used different datum schemes, data taken could not be compared between the two plants. The two plants also wrote unique CMM programs for measurement, further reducing the possibility of data sharing. The effect of these differences was that it was impossible to trace a high-level KC directly down to its component level as the m-points (and datums) often jumped between sub-assemblies.

4.6 Summary

Any development team that is deciding on Key Characteristics should consist of all of the stakeholders that influence the quality of the finished product. In this case, that team would include: Vehicle Engineers (design engineers), Advanced Manufacturing Engineers, plant Process Engineers, production representatives, and suppliers from both the stamping and assembly plant organization. This group should meet early in the development phase to begin selecting key characteristics. The team could begin with a "House of Quality" (Clausing, 1993) structure to begin defining high level Key Characteristics. After determination of those, product engineering would determine which design characteristics on the finished product define the high level (often qualitative) characteristics. The design engineer can do a flow down chart of all of the components that contribute to the KC. Input from other team members regarding probable variation on individual components helps complete the flow down analysis.

After determining which individual points will contribute the most to the variation and location of the Key Characteristic, the team can begin to develop measurement plans. Since it is possible that some of the important lower level characteristics might be difficult, expensive, or impossible to measure reliably, the team needs to consider potential substitutes. For instance, if a dimension on a sub-assembly is critical, but difficult to measure, one could continue the flow down analysis to find the lower level characteristics that affect that point and control those.

Key Characteristic flow downs are a useful tool to understand how critical characteristics in finished assemblies are affected by mean shifts and variation in the components and sub-assemblies that comprise it. As the way that the lower level characteristics combine to affect the higher level characteristics depends on assembly sequence, fixture points, and datum points, the coordination and calculations can be difficult. For that reason, methods such as KC flow down charts and causal loops can be useful ways of visualizing the stack-up of components for all team members. Finally, KC analyses can continue to be useful during production for problem solving. As long as data is available and coordinated, actual production means and variances can be used in the calculations to show the predicted response of the higher level KCs of interest. In addition to specifying how KCs will be controlled, Control Plans are a key tool to ensure that the data required for a KC analysis is part of regular measurement plans. By keeping this measurement plan information on a Control Plan, all team members from production to design engineering have access to the same information on measurement points and evaluation and control methods.

5.0 Cultural Analysis

5.1 Understanding a Technical Issue through Cultural Analysis

The noted MIT organizational development pioneer Edgar Schein describes that the concept of culture is, "…useful if it helps to explain some of the more seemingly incomprehensible and irrational aspects of groups and organizations" (Schein, 1992). A cultural analysis will be useful then, to help understand the Montana door pop problem and the issues that the cross-functional team faced in its resolution. This cultural analysis will help clarify some of the reasons that the problem took so long to be addressed, why the team had difficulty forming, and will help explain why they had problems working together to resolve the problem.

5.2 Schein's Model

Schein defines culture as, "A pattern of shared basic assumptions that the group learned as it solved its problems of external adaptation and internal integration, that has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems," (Schein, 1992). The definition of the group for this analysis is threefold: Wolverine as a whole, the engineering sub-culture, and the manufacturing sub-culture. Looking at some of the potential conflicts between these sub-cultures should provide some insight into the issues surrounding the door pop problem.

Schein advocates analyzing culture at three levels: artifacts, espoused values, and basic underlying assumptions. Artifacts are the visible organizational structures and processes, espoused values are the strategies, goals and philosophies of the organization, and basic underlying assumptions are the unconscious, taken-for-granted beliefs, perceptions, thoughts, and feelings. The following sections explain each of these levels in more detail.

5.2.1 Artifacts

Artifacts are all of the things that one sees, hears, and feels upon encountering a new group. These artifacts include the physical environment, the way people dress, the language they use, their products, and myths and stories told about the organization (Schein, 1992). One must be careful when interpreting such artifacts, because while they are physically easy to see, this does not mean that their meaning for the organization is as clear to the outsider. To understand this meaning, one must learn the underlying assumptions behind the artifacts.

5.2.2 Espoused Values

Espoused values are the norms, ideologies, chargers, and philosophies that individuals within an organization cite when explaining their own culture. These values predict what people will say in a variety of situations, although not necessarily what they will do. Espoused values often become clear when group members are asked to explain "why are you doing what you are doing?" (Schein, 1992).

5.2.3 Basic Underlying Assumptions

Basic underlying assumptions are the taken-for-granted and usually unconscious assumptions that determine perceptions, thought processes and behavior (Schein, 1990). These assumptions typically start out as values which undergo a validation process that judges how well they solve the group's problems. Values that become transformed into assumptions define a group's reality. Basic assumptions tend to be those assumptions that are neither confronted nor debated in an organization.

5.3 Wolverine Cultural Analysis

It is possible for a group to have inconsistent behavior supported by differing values, while at the same time having complete consensus on underlying assumptions (Schein, 1990). Many of the values espoused by an organization may be aspirations for the future, and not congruent with actual underlying assumptions. Looking at the cases where the espoused values do not match the underlying assumptions provides one way of studying a group's culture.

To help understand these differences between espoused values and underlying assumption, one can analyze those cases where the artifacts do not seem to be supported by the espoused values. These differences between what the organization *says* it values and the *visible artifacts* can often point to the true underlying assumptions. Using Schein's cultural analysis methodology, the following is an analysis of the cultural barriers to change between Wolverine's manufacturing and product engineering groups than hinder their ability to work together to solve mutual concerns.

5.3.1 Functional silos

Functional groups that act independently from other departmental groups and defer authority up the organizational ladder are often called "functional silos." While Wolverine has adopted platform teams to address this problem during product development, no such formalized matrix structure exists for the on-going production phase of the product. In contrast, many Japanese producers keep the development team together until well after a new program is launched (Womack, et.al, 1990). The following shows how the existence of the functional silos during launch and on-going production affect communication between functional groups.

Artifacts	Espoused Values	Underlying Assumptions
• Maintenance, engineering and production offices are physically separated. • "We don't need engineering in this meeting." • "Not my responsibility." • "That's a plant thing." • Not many cross-functional groups in plants (not like platform teams in design).	Cross-functional teams are important.	• Promotions, recognition and personal growth are easier to achieve within a functional silo. • If need assistance from a different functional group, use personal relationships in those groups, not organizationally defined cross-functional teams.

Conclusion:

Because there is not much required interactions between plant groups and product engineering, there are not many opportunities to develop relationships, which are necessary to get information and make progress solving issues. In addition, the internal plant groups do not often work on organizationally defined cross-functional teams. Therefore, people must rely on relationships with other functional groups, but do not necessarily have ways of creating those relationships with people outside their department.

5.3.2 Hierarchy (COS) (Positions of power/authority)

This section examines how the organizational hierarchy affects the implementation of the Corporate Operating System and communications between members of different functional groups.

Artifacts	**Espoused Values**	**Underlying Assumptions**
• Cubicles occupied by engineers and first line supervisors, and bigger ranks occupied private offices. • Managers have private parking. • “I disagreed, but I am only an engineer, and the argument was between two managers.” • Cascade COS teaching. COS roll down -- only move forward when boss says OK.	Management wants to go slowly and do it right the first time.	• Plant feels that management does not trust us. • Executive management does not trust plant to be able to evaluate themselves

Conclusion:

Hierarchy is very evident in Wolverine and is reinforced in the way that they are implementing COS. This creates a barrier in improving relationships between production and engineering in that they are used to deferring up the organizational ladder regarding problems. Therefore, problems tend to rise to a level when someone with the required power level in the hierarchy can pressure the other functional group into action. This creates delays in identifying and resolving problems at lower levels.

5.3.3 Hierarchy (Manufacturing status)

In addition to organizational hierarchy of executives who are above managers who are above engineers, there is also a perceived hierarchy based on function. Design engineering has traditionally been of higher status than production. The following shows how this difference in status affects relations between the functional groups.

Artifacts	**Espoused Values**	**Underlying Assumptions**
• PVEs (product engineers in plants) want to leave plant after 18 months. • Manufacturing is stuck with engineering problems • Big difference between staff and plant in quality of accommodations. • Plant process engineers and Advanced Mfg. Engineers are bargaining unit (most without engineering degrees). • Plant process engineers file grievances against PVEs for working overtime during contract negotiations.	• We are a manufacturing company. • "Volume Production" is as important as developing new products. • Manufacturing is important for competitiveness (COS).	• Manufacturing is a lower status. • People who aren't smart enough to contribute in development can do the less technical job in production. • In the past felt that there was no need to have degreed engineers doing process engineering work (changing now).

<u>Conclusion:</u>

Since manufacturing is perceived to be a lower status than product engineering, engineering groups discount the value that they can bring to cross-functional activities. This tends to delay when manufacturing opinions are sought during product development. With production input later in the development process, it is more difficult to make changes that could improve manufacturabilty. Manufacturing people also perceive that their judgment is less valued by others and often are less willing to provide input.

5.3.4 Emotional Displays

The following examines how the different norms for displaying emotion among various sub-cultures affect communications between functional groups.

Artifacts	Espoused Values	Underlying Assumptions
• Outbursts of profanity heard frequently among maintenance and production.	• This is a plant, one should expect rough language.	• To get attention, emotional displays are necessary. • People are not serious unless there is emotion.

<u>Conclusion:</u>
As there is no difference between espoused values and underlying assumptions for this category, one conclusion is that a barrier to communication between the plant and engineering centers around use of profanity. People in the plant generally use more profanity, and thus there is a "language" barrier between the two groups. Additionally, the people in a plant seem more prepared to react to emotional displays, therefore potentially allowing them to "turn off" what engineering says unless the engineers express it with either profanity or some other emotional display. Similarly, data does not carry very much weight in decision making unless it is accompanied by emotions.

5.3.5 Fear

Fear is a significant factor affecting communication both up the organizational hierarchy and between functional groups. The level of fear in the organization affects how the team members communicate with each other and with their management. This in turn affects how and when problems are addressed.

Artifacts	Espoused Values	Underlying Assumptions
• " Always have an answer even if you don't know, don't say 'I don't know.'" • Avoid being the one to bring bad news to the manager. • "I had my head chopped off before, and I don't want to do it again."	• Communicate freely about issues.	• Fear is a motivating force.

Conclusion:

Fear is a difficult one to analyze separately, as it is underlying in many of the categories analyzed. There is definitely fear present in both the manufacturing and engineering organizations. The level of fear appeared to be higher in manufacturing, which could be a barrier to their desire to work with engineering. If production people think that engineering individuals might pull them into longer term projects, production could be unwilling to work with them. Production might be convinced that it could be worthwhile to work with engineering on a particular long term project, but their fear of production management's reaction could potentially prevent them from doing so. Suggesting long term project work could bring wrath, as could ignoring short-term duties to participate in longer term activities.

The following is a causal loop diagram showing how the current workload of short-term crises coupled with production's fear of management if those crises are not resolved impacts production's willingness to work on longer-term issues. As the inner loop is negative, it shows that it is self-compensating. Therefore, as teams participate in more successful group efforts, their willingness to participate increases. This is balanced however, by a limited amount of time to dedicate to problem solving and a fear of management's reaction if short term crises are not addressed. Therefore, as the number of crises increases, the level of production's involvement in longer term cross-functional teams decreases. Additionally, as the perception of a negative reaction from management regarding those short term crises increases, the willingness of production to participate decreases.

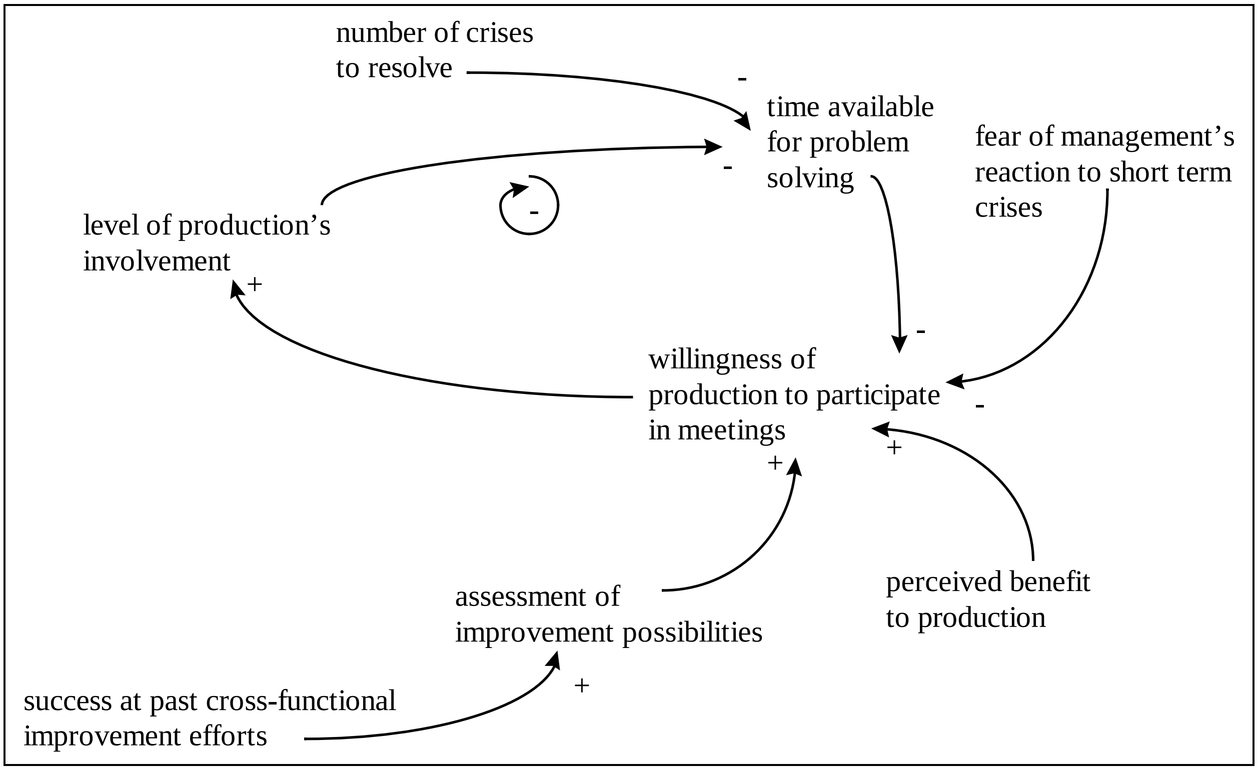

Figure 24: Fear causal loops

5.3.6 Ownership

This section examines the issue of problem ownership both at the individual and team level. Ownership is critical especially in teams, as the team leader should be the champion for implementation of the long-term corrective and preventive actions.

Artifacts	Espoused Values	Underlying Assumptions
• Bob's meeting" instead of "door pop off" meeting. • In meetings, people unwilling to put the real issues on the table. • "Be careful what you volunteer for." • If employee disagrees, then passive compliance followed by "I told you so." • "I knew that would happen." • In meetings, people want to know where the leader is headed before committing.	• Push ownership of problems down to the lowest level. • Assign names to activities for ease in follow-up.	• The person with seniority is the only one with authority to lead and make decisions. • Do what the boss tells you.

Conclusion:
The beliefs surrounding ownership hinder relations between the plant and engineering because people feel that putting your name next to an activity is an admission of responsibility. Often in cross-functional activities the actual responsibility is neither clear, nor relevant. Given the importance attached to assigning a name at Wolverine, however, people become very hesitant about volunteering to follow up on an issue. Sub-ordinates tend to wait until they know where the leader is headed, because there is no penalty for doing what the leaders wants, even if you might disagree with it. As there is little requirement or reward for taking individual initiative, the groups tend to give authority and responsibility to the leaders.

Additionally, Wolverine does not explicitly reward people for taking risks. By rewarding things done right and severely punishing things done wrong, there is a tendency for people to be risk averse.

5.3.7 Differences in perception of time

Schein tells us that, "…the perception and experience of time are among the most central aspects of how any group functions; when people differ in their experience of time, tremendous communication and relationship problems typically emerge." (Schein, 1992). The differences between perceptions of time between manufacturing and design groups are examined below.

Artifacts	**Espoused Values**	**Underlying Assumptions**
• Manufacturing people are on time for meetings on important issues and when they know upper management is going to be there. • Manufacturing people are late or leave and come back during meeting when they think the meeting is not important. • Meeting attendance is optional. Don't know who's going to show up until the meeting starts. • Its OK for engineering staff people to be 5 minutes late. • Manufacturing plant tries to schedule meetings at 6 AM and engineering at 3 PM. • Engineering meetings occur in conference room with start time and no end time. • Manufacturing meetings are on the floor and have no start or end time.	• Speed of decision making is key. • Take the time to analyze the situation before making costly and important decisions.	• Production: time is precious, we are making thousands of dollars of profits every minute. Make decisions quickly and take immediate action. • Engineering: meetings are a time to go over data with all interested parties, to analyze results and brainstorm how to resolve the issue.

Conclusion:
The plant is present oriented and measures time in minutes and hours. Engineering is long term oriented and measures time in weeks and months. The barrier to communication in this case is that the two groups do not respect or understand each other's differences in time perceptions. This clearly makes the communication process difficult and hinders their ability to work together and solve problems.

5.3.8 Use of data

Differences in the perception of data validity had a significant impact on the door pop resolution team. As data was often not trusted, its significance was not valued. These observations about use of data were across all functional groups, and therefore can be seen as indicative of the overall Wolverine culture. Differences between functional groups, however, serve to create this lack of trust in other's data.

Artifacts	Espoused Values	Underlying Assumptions
• "My opinion is…" is often heard in lieu of data and analysis. • "Sometimes you just have to go by gut feel." • Anyone can move a shim, records of shim moves are poorly kept. • "You don't need data!" • Opinions can be widely expressed without presenting supporting data	• "In-control processes and robust and capable systems are important"	• Existing data is not reliable enough to make decisions. • The right data is not available to support decisions. • Experience is a valid basis to make decisions.

Conclusions:
Data is not often a key decision driver. Some explain Wolverine's lack of data focus on the tough times that they suffered during the 1980's. Wolverine was so busy trying to stay out of bankruptcy that they missed some "growing up" with the total quality and lean manufacturing movements. Due to the perceived lack of quality data, data tends to be evaluated and associated

with the person who provides it. Often times it might not be questioned (when it should) if people feel the person is reliable or experienced. Likewise, there is often little trust in other’s data, especially if one does not have a history of working with that person. This is a barrier to work between production and product engineering, as it adds another layer of distrust between the two groups. Since these personal relationships are so important to trusting data, organized teams to encourage more personal relationships across functions could also improve the trust of data.

5.3.9 Communication with leader (catchball)

Catchball is a term from the Corporate Operating System that describes the act of a sub-ordinate hearing what a manager says (catching the ball), evaluating the information (processing), and then responding with feedback (throwing the ball back), for example as to feasibility. The concept of catchball is important to the analysis of the door pop problem because the interpretation of management's wishes had a significant impact on the speed and quality of the problem resolution process.

Artifacts	Espoused Values	Underlying Assumptions
• Limited interaction with the boss. • No set intervals to meet with the boss. No preventive maintenance in relationships. • Little catchball/ feedback between supervisor and subordinate. • Most recently chewed out issue gets priority. • "If we build to design, the top guy doesn't like the way it looks." • Do what the boss tells you. • "The leader doesn't know what he is doing." • "The team doesn't get what I am saying." • Leader gives long term goals but pounds on everyday issues. • Every once in a while leader blows up about lack of progress on long term goals.	• "Open door" policy. • Work to your objectives: long and short term, you will be held accountable for the long term ones during performance reviews.	• Mission on paper is not as important as the agenda of the leader. • There are negative consequences for contradicting management.

Conclusions:

Result of the poor “catchball” is that every individual has her own interpretation of what the leader wants. Additionally, there is a tendency for people to go to the boss only when there is a crisis or when there is good news. Therefore, people tend to wait until the problem becomes huge and hard to handle (a crisis) before informing the leader.

Since there is a lack of focus on the “vital few”, managers tend to be good at managing short term problems, but not longer term projects. This lack of reinforcement of long term priorities also drives people to work more on projects that they can complete on their own, as the individual will not have to rely on another person or functional group to resolve the problem. While not all problems that need cross-functional teams are long term, those that are provide opportunities to create personal relationships as well as work on system-wide issues.

Subordinates often hesitate to inform the supervisor about the implications about following their orders. There is a fear that the supervisor might think that the subordinate is questioning/disagreeing with orders. This is coupled with a desire to “protect the boss” from what they don’t want to hear in order to not distract the manager from ultimate goal, and potentially give you a new assignment.

5.4 Implications for problem solving team

The important themes from the previous section can be divided into the following broader areas:

1. Manufacturing vs. engineering (functional silos, production status, displays of emotion, perception of time)
2. Communication with management (fear, hierarchy, ownership, catchball)
3. Trust in data.

The following sections discuss how Wolverine’s manufacturing and engineering sub-cultural differences influenced some of the door-pop team dynamics.

5.4.1 Manufacturing vs. engineering

Many of the issues that the Montana problem solving team faced can be traced to the conclusions drawn above. For instance, the formation of the problem solving team was hampered by cultural differences among the various manufacturing and engineering groups. Since product engineering was not used to seeking input from production during development, they had few established relationships with production employees. Likewise, given production's status within Wolverine, they were not apt to seek out membership in cross-functional teams.

This lack of personal relationships between production and engineering people partly explains why the door-pop problem did not get addressed earlier in the launch process. Both groups were aware of the problem individually, and both knew that they could not fix it on their own. While both groups were used to delegating responsibility for problem resolution to the other, neither group had much experience spontaneously seeking help from the other to solve problems. For example, production raised the issue to engineering early in the launch cycle via the BITS concern. Engineering felt that the problem was a build variation issue that production would be able to fix once they built the vehicle to specification.

After the problem was elevated to a crisis level, the formation of the team itself was again influenced by the differences between engineering and manufacturing. Since engineering took the team leadership role, production felt that engineering claimed responsibility for resolving the problem and took on a secondary role. This secondary role included a lack of urgency to address production variation issues, since it was believed that the engineering design change would solve the problem.

Once the door-pop team was formed, problems based on differing norms for displays of emotions and perception of time surfaced. Initial meetings had a higher percentage of production employees present compared to meetings later in the problem solving process. As production realized that the meetings were long (often over 2 hours) and focused on data analysis instead of taking action, their attendance diminished. Production clearly placed higher value on meetings that felt like action, given their higher attendance at meetings that were held early in the morning on the plant floor. As the door-pop meetings came to be perceived as “engineering” meetings focused on studies, the production members who did come to the meetings participated less. They often waited until they were asked to provide input on recommendations from the group.

Differing norms for displaying emotions were tied into the ways in which production and engineering people interacted on a broad scale. In many instances, engineering personnel were intimidated when their first experience talking to production employees involved receiving a loud string of profanity. As the engineers were not used to communicating in this manner, their defenses rose and many of them put the production personnel into stereotypical categories. The result was to reinforce the underlying assumptions that the engineers had about the manufacturing people, namely that emotional displays are necessary to get attention. For the door-pop team, this meant that engineering people would tend give more weight to what production people said based on the volume and level of profanity used to express the idea. Additionally, many engineers would avoid discussing minor problems at all with certain production folks, to avoid dealing with the potential conflict. The engineers would wait until they felt that they had a solid, defendable case before discussing it with production. Production would then perceive that they were not important to resolve the problem. This diminished role in solving problems together often led production people into seeing their responsibility as judging whether an engineering proposal was feasible or not, and therefore how loud their reaction would need to be in order to be heard. This dynamic clearly reduced the opportunities for the two groups to find solutions together.

5.4.2 Communication with Management

This section of the cultural analysis is the most similar between the two sub-groups of manufacturing and engineering. Therefore, it will be analyzed at the overall Wolverine cultural level. The areas of fear, hierarchy, ownership, and catchball are tightly coupled with each other and had significant impacts on both the formation and dynamics of the door-pop team.

The underlying assumptions behind the fear and hierarchy within Wolverine drive many of the assumptions around ownership and catchball. Fear is used both within the manufacturing and, to a somewhat lesser degree, in the engineering organizations. The fear element is reinforced through the hierarchy within each group. While the manufacturing group tends to use fear as a motivating force even in the low levels of the organization between a supervisor and their subordinate, the engineers at all levels act in fear of the reactions of high level management.

This fear -- that is reinforced through hierarchy -- affects the willingness of individuals to take on ownership of problems. Taking ownership is seen as an admission of guilt and as an acceptance of responsibility for implementing resolution. Failure to satisfactorily resolve an issue for which one has taken ownership brings reprisal. The fear of this reprisal drives people to avoid taking ownership unless they absolutely must. The effect of this phenomena on the door pop team was two-fold:

1. No individual or group wanted to take initiative to set up a problem solving team because the problem was not clearly the responsibility of any one group, and,
2. Once the team was formed, people were hesitant to step forward as team leader since they would then become responsible for implementation of the solution.

Individuals at the lower levels in the organization also tended to hide behind the hierarchy walls to protect themselves from taking ownership. The hierarchical structure allowed the lower level individuals to defer responsibility for problem resolution to higher levels. This deferment lowered their level of buy-in and commitment to the resolution of the problem because in the end their analysis would be based on what they were told to do.

Similarly, the lack of catchball in both manufacturing and engineering organizations meant that the frustration felt by individual members was often not transmitted to the team leaders. Wolverine uses the catchball term to refer to a sub-ordinate receiving information from a manager, evaluating it, and communicating back (or catching the ball and throwing it back) to the manager their interpretation and assessment of the information. One instance in the door pop problem solving process demonstrates this lack of catchball. At one time in a review of the early Montana builds during ramp-up, a vice-president commented that the door seemed to be building low relative to the roof and fender. Given the variability in the build at that time, his valuation of the best way to correct the fit was to raise the door. That one statement about moving the door higher became translated into a more general edict that this vice-president wanted the doors to be mounted higher than the design called out. Since both the manufacturing and engineering cultures were not used to "catchball", neither group challenged whether the vice-president knew the long-term implications of his statement. Neither group went back to the vice-president later to see if this edict might change as improvements were made to the vehicle build. The impact on the door-pop problem was to induce a new variable into the problem because the doors could not be installed at the designed level.

5.4.3 Trust in data

Finally, the level of trust in data throughout Wolverine had a significant impact on the door pop team. The two manufacturing groups -- stamping and assembly -- did not trust each other's data. The engineering groups often did not trust data from manufacturing, and individuals within the engineering organization often questioned each other's results. This level of distrust was driven by varying opinions of motive. The fear and functional silos elements are the most likely causes of this distrust, as each group felt that the other was driven by fear of their management. For instance, assembly knew that stamping had an incentive to show that stamping's products were within specification. If they were not in specification, then the painful spotlight of management attention would be on the stamping organization to resolve their problems. Since each group understood the pressures upon the other groups, they tended to view other's self-supplied data with skepticism.

5.5 Summary

The above cultural analysis shows how the differences between the espoused values and the underlying assumptions between the manufacturing and design groups affected the resolution of the door pop problem. The differences between the two functional groups regarding displays of emotion, perception of time, and their common issues of communication with management and trust in data combined to create an environment that was not conducive to team problem solving. Differences between the groups hindered their interaction on a personal level, while both groups' relationship with management created a level of fear that in the end slowed the resolution of the problem and did not encourage addressing the root cause and preventing re-occurrence.

6.0 Conclusions and Recommendations

This chapter presents some general conclusions from the Key Characteristic and cultural analyses. A short example from a new development project is presented to show how the Wolverine company is currently addressing some of the communication issues between design and production. The chapter concludes with some recommendations for further management action to continue to improve the Wolverine company's product development and problem solving processes.

6.1 Conclusions

Management plays a key role in creating organizations that develop high quality products through robust design and effective team problem solving. Management's interaction with team members creates the environment that either encourages or discourages root cause analysis and implementation of preventive action. Management also determines the tools and procedures to be used in product development, such as Key Characteristic methods and measurement plans, and sets the tone for communication up and down the hierarchy and across functional groups.

These conclusions can be drawn based on the analysis in this thesis. Regarding the technical aspects covered in Chapter 4, the author draws the following conclusions:

- Key Characteristic identification and flow down from high level customer wants to lower level part characteristics can significantly reduce variation by creating robust designs.
- Participation of production personnel in KC meetings early in the product development phase will assist in identifying the correct characteristics.
- Control Plans are a useful methodology to drive identification of measurement and reaction plans. The easy to understand format of Control Plans encourages participation of all stakeholders in their development and makes them useful throughout the life of the product.

Additionally, the following organizational conclusions can be drawn:

- The questions management asks and they ways in which they interact with their sub-ordinates plays a strong part in determining how sub-ordinates behave.
- Striking differences exist between manufacturing and engineering surrounding displays of emotion, perception of time and status within the company. Management needs to recognize these differences and help the groups be aware of and respect how they differ, in addition to working on creating a more cohesive culture.

- Both production and design groups share issues of communication with and fear of management and trust in data. In addition to COS courses on “catchball”, management can take concrete steps in examining how they communicate up and down the hierarchy.
- Trust in data can be developed by a change in management’s questions about data. Questions about identifying key characteristics, seeing data, understanding how it was measured and whether the other stakeholders agree with the results can increase the perception of data’s importance throughout the organization.

In addition to the above conclusions, it is clear that management also has responsibility for organizational design. The following example from a new development project and the success of the platform teams at Wolverine shows that changing an organizational structure can have a significant impact on communication among groups. Additionally, the creation of rotational programs such as the Plant Vehicle Engineering rotations provides new opportunities for members of one functional group to interact with another. This example shows the impact of an organizational change on a new project at Wolverine.

6.2 Example of New Team Approaches

As the Montana truck was launching, another development team was preparing their early level prototypes for a new product launch in two years. Their management team recognized many of the communication hurdles that development teams traditionally faced and decided to try a new organizational structure to address them. The platform management decided to move the place in the organization chart where the process and product responsibilities came together down several levels. Instead of having process and product responsibility meet at senior management, they created an experimental group where the manager was responsible for both the product and process development. Additionally, they gave this manager a “geographic chuck” of the vehicle to design: the door.

This “door chunk” was a convenient example of one piece of the vehicle that was fairly easy to separate from the rest of the vehicle at the system level. The goal was to create a group that included all systems and sub-systems which interfaced with each other. For the door, this meant that the body-in-white sheet metal engineers would be in the same group as the glass and hardware engineers, the door trim engineers, the electrical systems engineers and the stamping and assembly process engineers (see Figure 25).

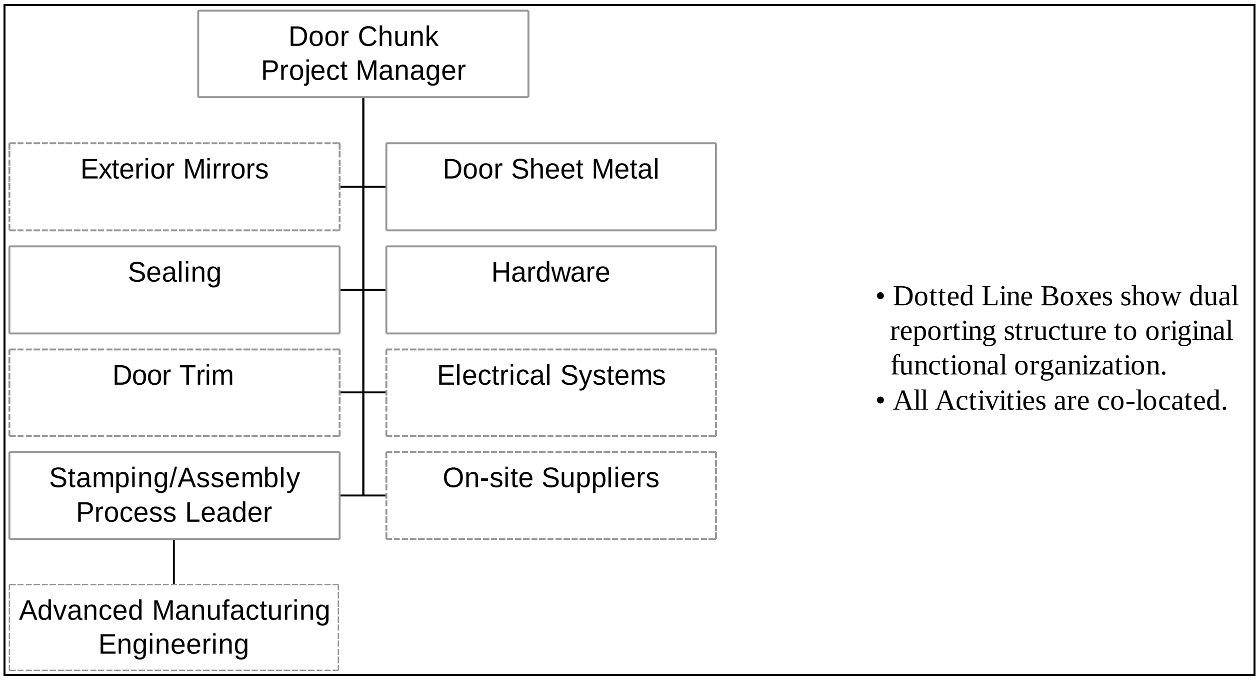

Figure 25: Door Chunk Team

In part because of this new organizational structure and co-located team, this door chunk team was able to address many of the launch problems that the Montana team faced earlier in their development process. For instance, the door chunk team had earlier direct participation from representatives of both the stamping and assembly plants. These representatives were able to address the datum scheme definition issue (see chapter 3) early in the development cycle. The stamping plant and assembly plant wanted to have the “small triangle” datum scheme using the hinges and the latch while the dimensional control people in engineering wanted to use the “big triangle” method (see section 3.4). By working out their differences early, the team was able to find a compromise between the two extremes. Neither group was completely pleased, but both could accept their agreement. In fact, they named this new compromise datum scheme the "mediocre triangle."

The door chunk team is trying another new approach by involving people from the assembly and stamping plants in the Process Failure Modes and Effects Analysis (PFMEA). A PFMEA is a methodology used in developing a new process that systematically looks at every potential opportunity for failure. The failures are analyzed for their probability of occurrence, their potential severity and probability of detection. Failures are then prioritized and action plans developed to minimize the occurrence and/or severity, or to increase the probability of detection. Involving people knowledgeable about production processes in PFMEA development is a key way to analyze potential problems and determine solutions. The door chunk team's process engineers moved their PFMEA team meetings to the respective production sites in order to involve the operators and other plant representatives in the bi-weekly PFMEA meetings.

Given the results of the cultural analysis presented in chapter 5, however, this new door chunk team is likely to still face some difficulties. They have already experienced concerns with continuity of production representation in PFMEA meetings. As the environment in the plants is often hectic, it can be difficult for the local management to spare someone to attend a meeting. While plant management recognizes the importance of future programs, the immediate time pressures from current problems often overwhelm the significance of a meeting to discuss a product that will arrive in two years. Oftentimes the people that management can spare to send to a meeting are those that are less knowledgeable about the plant and its problems. Therefore, the quality and continuity of the voice of manufacturing in the PFMEA meetings risks being variable.

Additionally, a number of observers of the door chunk team noticed that the manufacturing representatives seemed reluctant to voice potential concerns to their engineering counterparts. The process people are often more familiar working with physical parts and equipment and sometimes feel uncomfortable working with concepts and drawings on computer screens. This level of discomfort of the process people can lead to their silence, which is often mistaken for acceptance by the product engineers.

Finally, the new product development team will likely face similar issues that the Montana team faced surrounding the early detection and resolution of problems during prototype builds and the team problem solving during launch. The organizational structure change for the door chunk team took place in the vehicle engineering group and seems to have had success in the early development phases. As their is no equivalent lower level manager with responsibility for both the product and the process in the development stages closer to volume production, problems will most likely surface at that time. By the time the vehicle launches, the door chunk team will be much smaller and most of their work completed. The work to install new processes and ramp up to volume production will be performed by similar functional groups as those that launched the Montana. Unless organizational structure or incentives are changed for those groups, similar issues regarding cross-functional problem resolution are likely to arise.

6.3 Recommendations

Most of the recommendations for improvement possibilities center around management at all levels encouraging increased communication between the production and design organizations. For cross functional teams, management can do much to create an environment conducive to team problem solving by changing the types of questions that they ask their sub-ordinates. For instance, questions such as, "Is the root cause known? Which groups are on the team? What is the containment action? What is being done to investigate the root cause? and What preventive measures are planned?" are more conducive to effective team problem solving than, "What are you going to do about this problem?"

Similarly, management plays a key role in encouraging key characteristic selection using flow-down methodologies and cross-functional teams. By implementing Control Plans to document the teams decisions, management could provide both a vehicle to drive discussions of key characteristics by functional groups early and a record of the learning for future projects. Using Control Plans that are developed with manufacturing participation would also ensure that engineering and the necessary people in the plant agree on datum schemes, measurement points and reaction plans.

On the organizational level, Wolverine could consider expanding the scope of the platform teams to include volume production more explicitly. The full responsibility for the vehicle in production between the manufacturing and design organizations does not come to one person organizationally until the president level. Further use of the "chunk team" concept on other platforms and more participation of plant production people on development teams in addition to the Advanced Manufacturing Engineering representatives would also improve communication.

The Advanced Manufacturing Engineering organization could also encourage the informal communication ties between the volume production and development groups by adopting a rotational program similar to the Vehicle Engineering's Plant Vehicle Engineers program. By rotating their process engineers through the plants, the AME group could keep their process engineers up to date on the latest issues, while providing the plants with a broader technical resource for process improvement.

Finally, the PVEs that are located in the manufacturing plants could improve their production experience through some clearer role clarity. Their role is often confused with that of the permanent process engineers in the plant, as both have goals of improving quality through reduced process variation. Because of the tensions between these two groups in the plant and the difficult nature of working in a production facility in terms of hours and stress, a PVE assignment can often been seen as punishment within the Vehicle Engineering organization. They need to take steps to ensure that the PVEs are trained, understand their roles, and are integrated well into the production environment in order to ensure that the PVE experience is a positive one with learning.

Management’s role in continuously improving the quality of the products they produce is significant. Senior management affects which tools are used and the organizational processes through which functional teams interact to develop new products. The Wolverine company’s platform teams coupled with their implementation of the Corporate Operating System will provide many of the necessary tools and cultural changes required to supply products that delight their customers. A focus on Key Characteristic methods and cross-functional team problem solving processes will encourage the manufacturing participation in product development that is critical to the success of both the COS and the Wolverine company.

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