Workshop for Identifying Assembly Time Savings: An OEM Empirical Study

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***Abstract*—This paper presents the procedure and recommendations resulting from an original equipment manufacturer empirical study on an assembly time savings workshop. The focus of the workshop was to reduce the assembly time of an automotive vehicle by reverse engineering a vehicle currently in production and applying design for assembly guidelines. The workshop was conducted at the OEM's research and development laboratory in Germany and required a collaborative effort between the US manufacturing plant and the German design group. The organization, equipment needed, and method used to conduct the assembly workshop are discussed in detail. The outcomes of the empirical study include assembly time reductions as well as best practices for conducting a time savings workshop. Specific details about assembly time and time reduction are not included in this paper due to the proprietary nature of the project.**

Keywords— Manufacturing; Assembly; Reverse Engineering; Design for X; Case Study

I. Research Motivation

Companies are constantly trying to reduce product cost in order to increase profit. Many different approaches have been implemented to reduce product cost including lean manufacturing, design for six sigma, supply chain management, DfX, mass customization, reverse engineering, concurrent engineering, and product platform. These approaches to cost reduction are most often applied to a product that is already in the production phase although previous research has shown that a majority of product cost is determined in the conceptual phase of design. In order to reduce assembly time of a future vehicle, this research will apply cost reduction methods to a vehicle currently in the production phase and apply the knowledge gained to a successor model that is currently in the conceptual phase.

A. Design for X

Several methods and approaches are collectively referred to as "Design for X (DfX)." Generally DfX is a set of rules and guidelines whose focus addresses the improvement of a specific aspect of a product [1]. Within DfX several approaches which are applicable to automotive industry, specifically Design for Manufacturing (DfM) [2, 3], Design for Assembly (DfA), [4] , Design for Recyclability (DfR) [5]], and Design for Disassembly (DfD) [6]. While multiple methods may be used to improve the overall quality of the product, conflicts between methods often result in tradeoffs. For example, joining two parts together through welding processes rather than fastening will reduce the mass, make the joint stronger, and reduce assembly time; however, disassembly and serviceability will be significantly impacted. Research has shown that application of DfX methods helps to reduce the time required to bring products to the market, for example Ingersoll-Rand reported that use of the DfA and DfM software from Boothroyd Dewhurst, Inc. reduced product development time from two years to one. While this research is based on reducing the assembly time of a vehicle, the principles of DfA and DfM are of concern.

DfA is the design of components to ease the assembly of the product [3]. Assembly time estimation methods developed help designers during the early stages of the design process [7, 8]. DfA analysis uses the parts' symmetry, geometry, and size to estimate the two main parameters influencing assembly cost: handling and insertion times [1, 7, 9]. With an aim to reduce assembly time in the early design stages, DfA guidelines have been developed to create parts which assemble easier and quicker. One DfA guideline is the design for easy insertion which states: A part should be designed such that it is easy to align and insert. For example, if a part is difficult to align and insert, then chamfers could be added to help locate and insert the part (See Figure 1).

While application of DfA guidelines will design parts to be more easily assembled, this may have an impact on the cost of manufacturing the part and thus design for manufacturing should also be considered. DfM considers manufacturing input, throughout the design process, to design parts to be manufactured more easily and in turn more economically [2]. DfM includes a method for estimating the cost of manufacturing a part by various manufacturing processes including: stamping, injection molding, and casting. Examples of application of DfM method includes tooling costs, processing costs or controllability, and availability of materials or equipment [2]. DfM guidelines are used to assess the cost of manufacturing when comparing different processes. For example, when designing a part to be injection

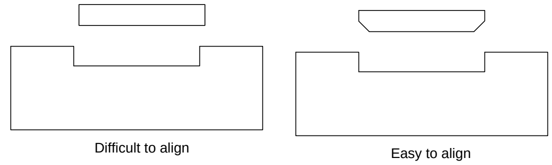

Figure 1. Figure 1: DfA Guideline: Design for Easy Insertion [2]

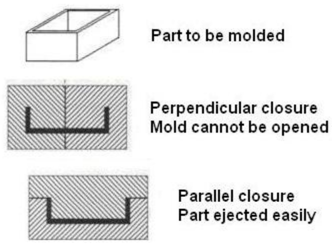

Figure 2: DfM Guideline: Mold Closure Direction [2]

molded, the designer should be aware of the mold closure direction (See Figure 2). Considering the direction of closure of the mold will help reduce the complexity of the mold and reduce the cost of the part.

Reducing the number of parts in a product by integration will reduce assembly cost, but may increase the cost of manufacturing by increasing the complexity of the manufacturing process. For example, to reduce the assembly time of the electric shaver (see Figure 3), the number of parts could be reduced by integrating the back cover, side plates and front cover into one piece.

For further assembly savings the number of screws may be reduced by replacing the screws with snap fits. While this solution reduces the assembly cost of the electric shaver, the cost to manufacture the redesigned covers will increase the complexity and cost of the manufacturing process. With the ultimate goal of increasing profit, the tradeoff between assembly time savings and manufacturing cost increase must be evaluated.

Examples of design for manufacturing and design for assembly rules are found throughout the literature and internal corporate documents. Often times, these are general principles that engineers eventually internalize. That said, there are some systematic methods [1, 2, 8] that have been used to formalize and focus the designers attention on specific aspects of a design that might have the greatest impact on cost savings from an assembly or manufacturing perspective.

B. *Reverse Engineering*

Reverse engineering existing products identifies current shortcomings, and presents an opportunity to improve upon the current design (through redesign) or evolve it into an entirely new product. Reverse engineering predicts what a product is expected to do through modeling, analysis, dissection, and experimentation and the redesign step follows to evolve a product to its next offering in the marketplace [10]. Otto and Wood present a method for product development (Figure 4) through reverse engineering and product redesign and provide several examples of application of the method [10].

The method developed by Otto and Wood consists of three stages: Reverse Engineering, Modeling and Analysis, and Redesign. The reverse engineering phase may be broken down into two separate steps. In the first step of the reverse engineering phase a product currently on the market is identified as the starting point in the product development process. It is useful to begin with a product currently on the market since if it currently exists in the market then it has already been engineered to certain level and therefore serves as a building block in the development process [10]. The selected product is evaluated across the following: operating parameters, customer needs, hypothesized functionality, product components, and physical principles [11]. The second step of the reverse engineering phase is to “experience the actual product in both function and form” [11]. This step of the reverse engineering stage includes: full disassembly of the product, functional analysis, and generation of design specifications. This step should determine what the intended function of each component is and how each component performs the perceived function. The results from the reverse engineering phase will help drive the direction of the remaining stages of redesign. A systematic process for product disassembly is summarized by the following steps [10]: (1) list the design issues, (2) prepare for teardowns, (3) examine the distribution and installation, (4) disassemble, measure, analyze by assemblies, and (5) form a bill of materials.

The disassembly process mentioned above would occur during the reverse engineering phase. Otto and Wood suggest the subtract and operate (SOP) method to support the disassembly process and provide examples of application of the SOP method to consumer products[10, 11]. In the first step of the SOP method, a component of the system is

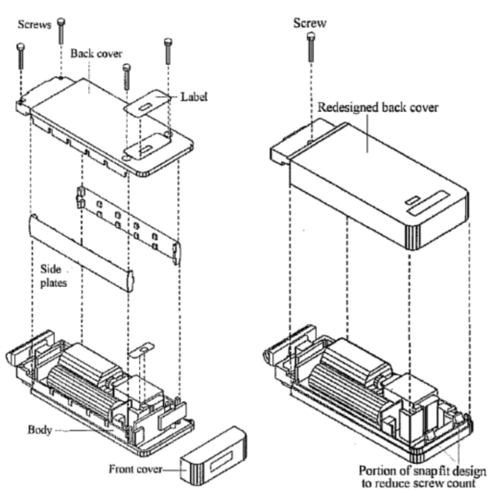

Figure 3: Tradeoff Between DfA and DfM (Image from [2])

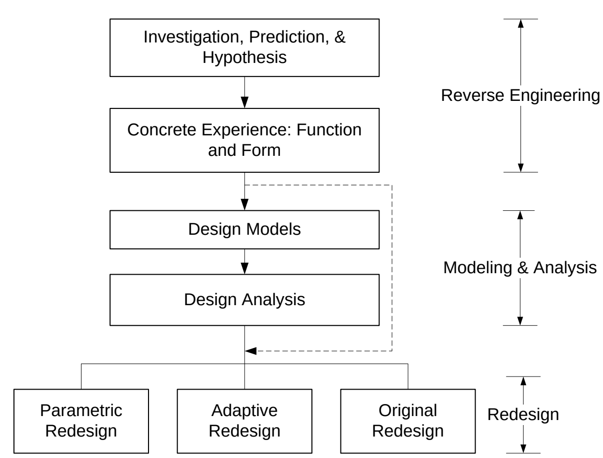

Figure 4: Reverse Engineering and Redesign Methodology [10]

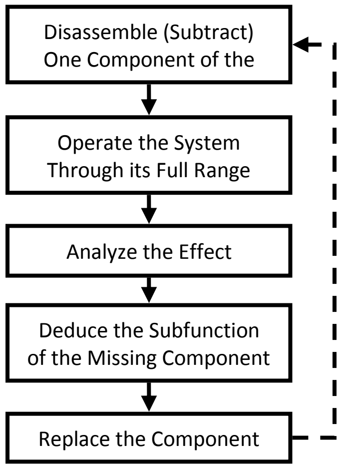

Figure 5: Subtract and Operate Flowchart (Adapted from [10])

disassembled (*subtract*) from the product assembly. The product is then run through its entire range of operations without the previously removed component. The effect that the removed component has on the product is observed and the function of the removed component is determined. The removed component is then reassembled and the procedure is repeated for each component. The SOP method is summarized in Figure 5.

Companies generally understand the way their product is built, its strengths and weaknesses, and the functionality of the components in their product [10]. This may be enhanced through reverse engineering their own products b the systematic approaches described above. Conversely, companies may, often times, seek to understand their competitors through their products. This is done, typically, through competitive benchmarking, which may also include reverse engineering. This comparison can also be done internally by comparing models or products within the company through internal benchmarking. The product must be benchmarked with other similar products in order to provide a point of comparison.

1) Competitive Benchmarking

To have a point of comparison for the assembly of the parts of the vehicle, a competitor's vehicle was chosen for benchmarking. For benchmarking purposes the OEM chose a competitor's vehicle that was similar to the vehicle to be disassembled. The vehicle was a slightly smaller than the vehicle, but it was the newest car on the market and therefore it was assumed by the OEM that it had the most recent technology advances and solutions implemented. A complete teardown of the benchmark vehicle was not conducted, but instead used to compare solutions and set targets between the OEM vehicle and the competitor vehicle [12, 13].

2) Internal Benchmarking

One source of benchmarking that is often overlooked is comparing a company's past products. Company's rarely use their own products as a source of comparison since the designers working on the new product are often the ones who designed the previous product[10]. Instead this should be a good starting point for a company working on a new product since if their previous product is on the market it must be of a minimum acceptable quality and thus gives the company a good base to begin new product development. This being said, the company must beware to avoid the trap of designing a product a certain way only because they designed it that way previously.[8, 10] It became evident in the workshop that there was a lack of communication between vehicle designers internal to the OEM. Often when a problem was identified in one model vehicle, a solution could be viewed on another vehicle model.

II. Empirical Study Research

Engineering design research has been supported through the use of several different types of research methods, such as protocol analysis, experimental designer studies, experiential reflections, ethnocentric studies, and case study [14-23]. Case study research is an approach often used to connect the theories studied in academia and the application of that practice in industry [18]. One of the best attributes of case study methodology is the ability to examine a case in the way it actually occurs [21]. Utilization of case study research a method has previously been doubted as a viable research method and has been considered invalid due to the lack of systematic rigor [22]. For a detailed defense of case study methods as a viable means of research as it relates to common misconceptions [20], the reader is referred to [22, 24]

Case studies are most appropriate when trying to determine what, how or why an event occurred [21]. One distinct characteristic of a case study over other research methods is it allows the user to analyze data as the data is being collected [21]. This allows for the person conducting the case study to adapt to the situation and environment as it occurs and collect any relevant data needed. One of the most difficult parts of using case study methods is drawing conclusions from the case study and presenting those results to the academic community [19]. The incorrect application of case study methods has produced a negative connotation towards the use of the case studies in research [21].

Researchers have not yet reached a consensus on what the specific differences between case study research and ethnographic or ethnocentric studies are. Ethnocentric, sometimes referred to as ethnographic, research is that in which the researcher-observer embeds themselves within the context and environment of that which is being studied. Examples of ethnocentric studies in engineering design [14-16]. Here, we make the demarcation between case study research and ethnocentric research not based on their implementations and methodological approaches, but based on their purpose and motivation. For the purposes of the research presented here, no pattern and hypothesis formation was done before the study was undertaken. These are critical elements for good case study research. Rather, we are interested in observing what occurred in this workshop, what lessons might be gleaned from it, and what patterns might emerge. In this manner, the ethnocentric study of the workshop might be considered as a preliminary exploratory empirical study that can lead to more well informed case study research based on the findings presented here. Specifically, in this research, the author is a participant in the workshop and can report on observations made throughout that may not be explicitly documented in archival form. This provides for flexibility in discovery and interpretation. That said, it also has the potential for researcher bias. To address this, we have attempted to keep the observations as objective as possible and have provided examples for each when available.

III. Actual Workshop Events

The focus of this workshop is to reduce the assembly time of a next generation automotive vehicle, currently in the development phase, by studying the assembly process of a model currently in the production phase of the product evolution process (PEP) (See Figure 6). In order to increase the profit of a company, the OEM focuses on reducing assembly time of a vehicle. The workshop was planned for the development phase of a future vehicle successor model before any firm design decisions had been made. In this case, it is held within the first two years of development of the new product.

The workshop was organized to be completed during a consecutive eight week period. The design of the new vehicle would begin with a set of selected “backbone” parts from the old vehicle. The “backbone” parts, also referred to as platform parts, - are the parts that would remain the same and be carried over from the current model to the future model. The remaining parts would be completely designed from scratch. This gave the workshop the opportunity to identify assembly time savings in the “backbone” parts, which could be immediately applied to the parts and assembly processes of the current vehicle, as well as design knowledge for the new parts of the successor vehicle. The parts that were not labeled as “backbone” parts would still be evaluated and used to form ideas and guidelines which would be given to designers to use while creating the parts for the new vehicle.

A. *Preparation*

To increase the efficiency and effectiveness of the workshop a number of preparation steps were undertaken. Since the OEM sent many employees from North America to Europe to participate in the workshop, the workshop needed to be organized and prepared to minimize the amount of time the employees would be away from the workplace. First, the workshop organizer determined an eight week time period for the workshop to take place and ensured attendance by any necessary personnel. The organizer was required to contact and arrange approval for transportation of any associates involved as well as retrieving security clearance to enter the research and development facility. The list of all members involved in the workshop may be viewed in detail in *Section D*. Since the associates attending the workshop varied from week to week, it was the organizers responsibility to reintroduce the workshop and to help focus the associates on the type of improvements that the team is looking for.

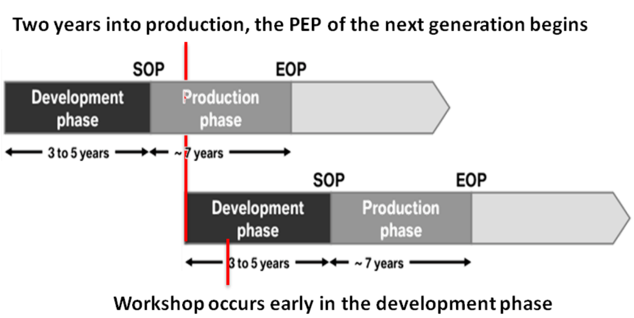

Figure 6: Vehicle Evolution Process (Adapted from [25])

B. *When*

The eight week workshop took place in the fall 2009. The implementation and usefulness of the workshop results for the next generation vehicle development requires the workshop to take place during the conceptual stage of the future vehicle design process. The timing of the workshop in the vehicle development process should come before any firm design decisions have been made on the vehicle. It is more costly to implement design changes as the product approaches full production (see Figure 7) and it is difficult to convince a designer to change a design or component that is currently fulfilling its intended function.

If this workshop is implemented in the beginning of the design process, during the conceptual phase, the information gained from the teardown can be used to help guide the designers to creating more assembly friendly components before the detail design or prototyping phases.

C. *Where*

The location of the workshop was crucial in order for the teardown to be successful. The workshop was located in main research and development (R&D) facility of the OEM. In the R&D facility, the team had access to all tools necessary for teardown and assembly of the vehicle. The team also had access to other vehicles which were in various phases of prototyping. The reason the R&D facility was chosen for the workshop was that it allowed for the group of designers, assembly planners, assembly associates, line supervisors, lean process experts, and time analysts to work concurrently on the goal of reducing assembly time.

The OEM wanted to ensure that the actual people assembling the vehicles at the plant (assembly associates) had a chance to share their points of view directly with the designers and planners responsible for the vehicle. This also

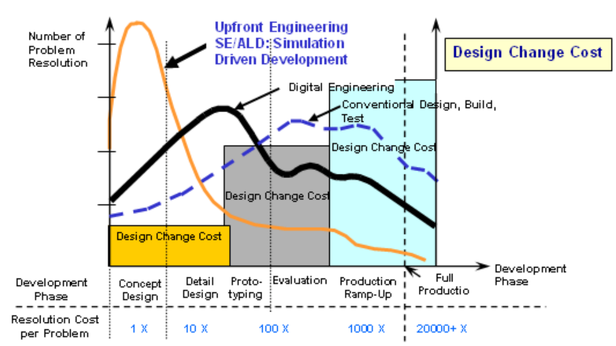

Figure 7: Cost of Engineering Changes at Different Stages of the Development Process (www.iti-global.com/education/articles/SimLedDev.htm)

allowed for the workshop to receive a quick turnaround on questions concerning part functionality or purpose. For example, if the team felt that a part was unnecessary and did not understand the reasoning for it, it could ask for advice from the designers or the assembly planner as to why it was made that way whether it fulfills a functional requirement or it is strictly for assembly purposes.

D. The Team

The workshop team consisted of associates from the U.S. manufacturing plant and associates from the German research and development facility. The team was broken up into two parts: the core team and the extended team. The core team was directly involved in the workshop while the extended team was called in as needed for further expertise. The organization of the team (Figure 8) includes both core team members directly connected to the inner circle and the extended team found at the outer circle.

The team members and their respective roles in the workshop are discussed below:

Time Analyst (TA) - This team member analyzed all of the parts and suggested solutions to determine estimated assembly time for the existing part and the estimated time savings if the redesign idea is implemented

Lean Process Expert (LPE) - This member of the team was asked to generate ideas and solutions for time savings with the focus on product redesign.

Line Associate (LA) - The line associate was the assembly expert in the sense that he/she was a trained assembly associate with years of experience in assembling parts on the vehicle. This line associate was important in the fact that he/she had knowledge of the assembly process of the vehicle, and the difficulties in the assembly process. The line associate participating changed depending on which part of the vehicle was being assembled; each line associate participated in the section of the workshop pertaining to their assembly area.

Line Supervisor (LS) - The line supervisor served as a leader for the team members from the manufacturing plant. The line supervisor was asked to support during the assembly process and often had a broader view of the entire assembly process than the line associate.

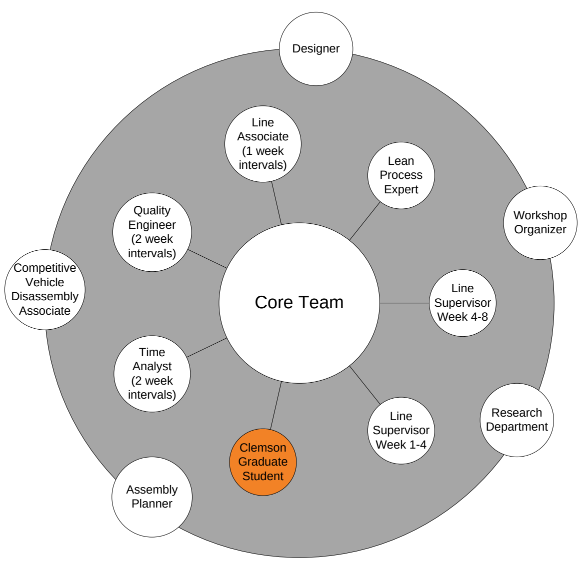

Figure 8: Team Organization

Clemson Graduate Student (CUGS) - The Clemson student was an active participant in the workshop and immersed himself in order to study the daily activities. The student was involved in another OEM project focused on mass reduction. This workshop presented the opportunity to apply the developed method. The student participated as a member of the core team and was present for the consecutive eight week workshop.

Quality Engineer (QE) - The quality engineer provided insight into current quality issues that the vehicle is facing, and possible quality issues that could arise with suggested redesign. The quality engineer was also knowledgeable in the safety regulations pertaining to the vehicle.

Assembly Planner (AP) - This member served as a reference for information regarding the specific assembly information of parts. This member would often be able to provide information on why a part or feature is needed for assembly purposes.

Workshop Organizer (WO) - This member kept the entire team focused and headed in the same direction. The workshop organizer was in charge of organizing meetings, planning the workshop, planning the time schedule for the workshop, and served as the overall spokesperson for the project. The workshop organizer was also required to gather any necessary equipment and tools that would be required for the vehicle build.

Designer (D) - This individual is specifically responsible for a set of components within the vehicle. It is his/her responsibility to understand all the function needs and requirement for a component and design a part which meets these needs.

Research and Development Department (R&D) - The research and development department helps to analyze the validity of suggested solutions and to test against other current products on the market. If the suggestion solutions to a problem are accepted as plausible, the research and development team will analyze the parts to determine if they meet all given specifications and pass information along to the designer for the redesign of the parts.

Competitive Vehicle Disassembly Associate (CDA) - This associate was assigned to help disassemble the competitive vehicle as the core team needed. The complete competitor vehicle was not disassembled, rather if the core wanted to compare a component or system they would ask this associate to disassemble the competitive vehicle to a state where the components could be viewed and analyzed.

The participation of the various associates from the core team in the workshop is summarized in Table 1. The assembly process is split up by bands which represent a section of the assembly process. Takts are the individual stations that comprise a band. A total of eight assembly associates were involved in the workshop, yet no more than two were present at any given time. It is important to note that there were only a

Figure 9: Numbered Sticker Label

few participants that were involved in the entire workshop. This often caused a lapse in understanding the focus of the workshop and thus extra time spent to clarify.

E. Equipment

In preparation for the start of the workshop a number of equipment and tools must be acquired. This list includes:

Computer with Projector/Large Monitor –The computer is used to record all information directly into an electronic spreadsheet. The projector/monitor would be used to display all information in the database during the workshop and during the actual assembly of the vehicle. The monitor is used to display real time part drawings, database results, and for presentations purposes. The monitor allows the entire group to view the same material at the same time allowing more opportunity for collaboration on the parts.

Numbered Sticker Labels - The numbered stickers are used to trace each part which is identified for improvement. The sticker is placed directly on the part and the pictures are taken while the part is on the vehicle or before it is assembled depending which provide a better visualization of the suggested improvement. The sticker number also serves as the primary key for the part in the database so that consistency is maintained between the pictures and the data (See Figure 9).

Camera – The camera is used to document visual evidence of the parts in question as well as parts from competitive vehicles for comparison.

Mechanical Tools-This includes all necessary for assembly including but not limited to screwdrivers, ratchets, power tools, or hammers.

F. Documentation

All of the results are recorded in a spreadsheet for documentation (Table 2). Each column of the spreadsheet represents a different suggested part and the rows represent information that is populated for each part. A number of different participants in the workshop were required to populate data to be entered into the spreadsheet.

G. The Process

The vehicle would be completely disassembled to the component or assembly level as it arrives to the manufacturing plant prior to the workshop starting. The vehicle would then be assembled in the same assembly sequence as conducted at the assembly plant, including any subassemblies required. The OEM sent the line associates and line supervisors responsible for each section of the assembly line for their respective portion of the workshop. For instance, during the engine assembly phase of the workshop, the engine assembly line section leader, and an engine assembly associate was selected to participate in this phase workshop. The associate would assemble the components they are responsible for, paying close attention to try to mimic the actual assembly process as closely as possible. There were some limitations in the fact that the research and development facility did not have all of the automation equipment and fixtures that the plant had and it would be far too costly to replicate these or shut down the line to use them for the workshop. As the line associate assembled one part at a time, the team would closely monitor and scrutinize the assembly process used to assemble the part onto the vehicle. The line associate would explain to the team what difficulties they may experience in assembling the part and the team relays information back to the associate on what they believe are possible problems. The team may ask the line

TABLE 1:
ASSOCIATE PARTICIPATION IN WORKSHOP

	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8
Band	STM	20-21	30	40-43	44	47-48	Motor	50-63
Number of Takts	31	26	21	52	39	57	N/A	52
Assembly Associate 1	■	■						
Assembly Associate 2		■						
Assembly Associated 3			■	■				
Assembly Associated 4			■	■				
Assembly Associated 5					■	■		
Assembly Associated 6					■	■		
Assembly Associated 7							■	■
Assembly Associated 8							■	■
Time Analyst 1	■		■		■		■	
Time Analyst 2	■	■		■		■		■
Quality Engineer 1	■	■			■	■		
Quality Engineer 2			■	■			■	■
CU Graduate Student	■	■	■	■	■	■	■	■
Line Supervisor 1	■	■			■	■		
Line Supervisor 2			■	■			■	■
Lean Process Expert	■	■	■	■	■	■	■	■
Assembly Planner	■							
Workshop Organizer	■	■					■	■

TABLE 2:
SPREADSHEET ENTRY (NOT ACTUAL)

Field	Data Type	Example	Owner
ID Number	Unique ID	1	Any
Process Number	Integer	123456	Any
Part Name	Text	Steering Wheel	Any
Classification	Text	Interior	Any
Vehicle Location	Text	Front Right	Any
Current Assembly Difficulties	Text	Aligning the steering wheel onto the steering column	Any
Improvement Ideas	Text	Add a locating feature for alignment	Any
Number of parts per vehicle	Integer	1	Any
Current Assembly Time	Integer (s)	33	TA
Redesigned Part Estimated Assembly Time	Integer (s)	20	TA
Time Savings	Integer (s)	13	TA
Designer Responsible	Text	J. Smith	D
Designer Feedback	Text		D

associate to remove and reassemble the part as many times as deemed necessary to gain a clear understanding of the assembly process. At this point, the entire team discusses the problem and possible solutions. If a simple prototype of the suggested solution is possible (such as removing a clip), the part would be altered or removed and the effect on the vehicle would be briefly tested, similar to the subtract and operate technique [10]. The plausible solutions would be documented and pictures of the part would be taken. Each part identified for potential assembly time savings was labeled with a number, and the documentation for that part was recorded in accordance to the numbering system. As soon as discussions for the part were completed, the time analyst team would conduct a DfA analysis for the part using the OEM in house computer assisted time studies tool. A time analysis for the current assembly process is then compared to the analysis of the suggested solution. For example, if the suggestion was to eliminate one of the five screws for a part, then an analysis for the part would be conducted for five screws and then conducted again for the same part with only four screws. The results of the time analysis are recorded and the difference between these numbers is populated, since this difference is the actual projected time savings for the part

At this point, meetings were set up for the designers responsible for the parts to view the results found by the team. During the workshop some designers attended during the week that the parts they were responsible for were being assembled and others came weeks later. This unstructured interaction with the designers forced the core team to deduce the intended function of a feature or component. Ideally the designer would be present at the workshop in order to provide immediate support to the core team about the functionality of the component or feature. This will be discussed in more detail in a later section.

When the parts are discussed with the designer, the designer is expected to either agree that further investigation and analysis of the part should be conducted or provides a reason as to why the part cannot be changed. This reason can vary from a variety of things including safety, functionality, and regulation (government, internal, country, etc). The rationale or comments that the designers give are also recorded in the database. The procedure that was followed along with the team member(s) responsible to complete each activity is summarized in Figure 10.

IV. RECOMMENDATION FOR FUTURE WORKSHOPS

An empirical ethnocentric study was conducted on an assembly time savings workshop in which an offline full vehicle build took place with a focus on reducing assembly time. The study provided useful information on suggested improvements to increase the efficiency and organization of the workshop.

One of the difficulties encountered at the workshop was the collaboration between associates in multiple countries and therefore there was often a language barrier between associates. When conducting a workshop in which multiple languages are used, there should be at least one person who is fluent in both or all of the languages to ease the transfer of ideas back and forth. The language barrier plays a large role in the documentation of the workshop. The language(s) in which the documentation will take place should be determined ahead of time. If it is necessary there may be multiple versions of the documentation in different languages, but this would be best to happen during the workshop as to prevent any data loss if it were translated at a later time.

The workshop would be more effective if the designers were required to participate fully in the workshop therefore any questions of functionality or purpose of part could be answered immediately. The core team would often develop questions of the functionality of a part, but without the direct involvement of the designer the team would have to proceed without answers to avoid falling behind schedule. Knowledge of the functionality of a component would allow the core team to develop solutions or ideas to improve the design of the part. For example, the core team identified the airbag module (Figure 11) as an assembly process for improvement.

The team suggested that the number of fasteners used to attach the airbag module to the vehicle be reduced. As a typical DfA guideline, this was an obvious opportunity for improvement and seemed simple enough to implement. Later in the week when the designer attended the workshop to learn of the improvements for the areas of the vehicle he was responsible for, including the airbag module, he informed the core team that the number of fasteners was required as a safety requirement to prevent the airbag from separating itself from the vehicle if the airbag were to be actuated in an emergency situation and thus the number of fasteners could not be reduced. If the designers are present at the workshop then suggested ideas can be immediately conveyed to them for feedback. If the designers come later in the week or later in the workshop then the parts discussed are often physically concealed due to the assembly of other parts near them and it is more difficult to relay to the designers the exact parts and demonstrate the ideas generated during the workshop.

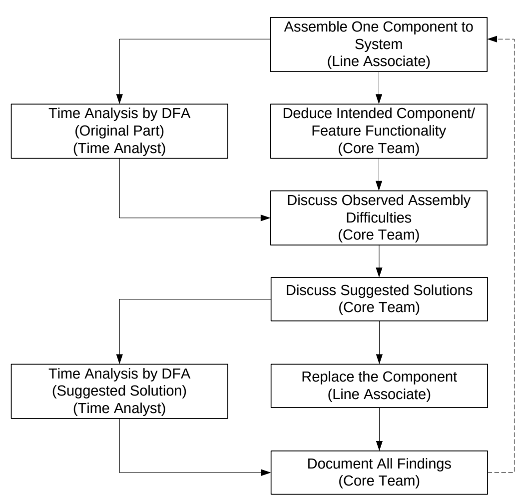

Figure 10: Actual Workshop Process Flowchart

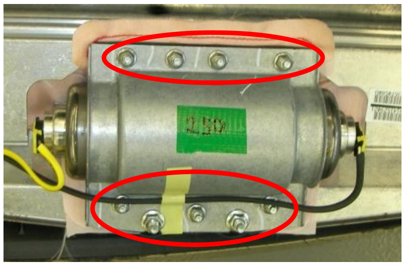

Figure 11: Current Airbag Module with Nine Fasteners (circled)

Another difficulty encountered during the workshop was the use of an older model of the vehicle to analyze the assembly, since many of the components have been redesigned or changed in order to help improve the design or ease the assembly process. The model used was one of the first "test cars" meaning they were one of the first fully assembled cars of the current vehicle model and according to the product development model (Figure 6) that approximates the age of the vehicle at approximately two year. To receive the most benefit out of conducting a similar workshop, the newest version of the vehicle model should be used with as many optional features included. This enables the workshop team to see the largest quantity of parts, and also to most closely resemble the current assembly process.

Another limitation is that this reverse engineering exercise supported assembly time analysis for manual assembly only. Automated assembly operations can be estimated, but the actual savings that could be achieved cannot be experienced in the hands-on exercise of reverse engineering and rebuild. This could be considered in future workshops.

Future work includes implementation of the suggested solutions for assembly time savings must to validate the actual time savings as opposed to the time savings predicted from a DfA time estimate. Due to proprietary information the actual data and results from the workshop are not included, but "best practices" on how to conduct a similar workshop are discussed.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding provided by Grant No. 2007532.

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