Standardized Assembly Process Planning based on the Toyota Production System

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ABSTRACT
Based on the principles of the renown Toyota Production System, a new planning approach has been applied to a product development project at Mercedes-Benz do Brasil, São Paulo. The key elements are Master Process Sheets, which document assembly operations as agreed standard operations and hence assure continuously high, repeatable quality. Master Process Sheets visualize the assembly operations using explosion drawings and provide a much higher degree of understanding and information accessibility to production workers compared to earlier main-frame based process planning systems.

INTRODUCTION OF MODERN PLANNING TOOLS AT MERCEDES-BENZ DO BRASIL S.A.
Along with the development process of a new vehicle project at Mercedes-Benz do Brasil, modern process planning tools have been introduced. Within an international project team of interdisciplinary functions, an important goal is the early acknowledgement of Design for Assembly (DFA) criteria in order to support the Concurrent Engineering philosophy.

The applied systems specifically allow for consistent process planning, bill of material verification for completeness and graphical representation of assembly processes via explosion drawings, which provide valuable support during all project phases starting from development phase to prototyping and finally supporting team members on the Assembly shop floor.

Key element are the Master Process Sheets, which are based initially on the so called Standard Operation Sheets out of the Toyota Production System philosophy. Currently at DaimlerChryslerAG this planning tool has been successfully applied at Daimler’s foreign assembly plants in Tuscaloosa, Alabama (M-Class) and in Juiz de Fora, Brazil (A-Class).

TOYOTA PRODUCTION SYSTEM ELEMENTS
The philosophy of manufacturing products with 100% quality (Zero Defects Quality) in parallel with minimal in-process-storage is based on the five main elements of the Toyota Production System (TPS), which represent in total an interdependent system.

The main pillars of the TPS are Just-in-Time, Jidoka (also known as Autonomation), and Total Quality Control (TQC) which in turn are based on the foundations of Flexible Production and Cost Minimization through Reduction of Waste.

The maintenance of the TPS is performed through Standard Methods and Processes and Continuous Improvement, also known as Kaizen supported by Training on the Job.

Toyota’s Corporate Objectives can be summarized in supplying society with the following:

- Vehicle of highest quality possible
- At the lowest costs possible
- With shortest delivery times

Derived from these corporate objectives, the direct goals of applying the TPS-philosophy are: (Taylor 1997)
1. Cost reduction through Elimination of all kinds of waste within the production processes
2. Installation of processes, which allow for the production of consistently high product quality
3. Creation of work environments, which can easily adjust to process, product and customer changes and still respect the individual needs of the employees.

In order to accomplish this seemingly conflict of goals, it becomes important to agree on standards, which guarantee work safety and simplicity of assembly processes.

STANDARDIZATION OF WORK PROCESSES
At Toyota, standardization along with Kaizen, the continuous improvement process, provide the basis for the Toyota Production System and its various elements. According to standardization, every individual operation along the sequence of processes in automobile manufacturing is described in detail. The operation steps during the assembly of a vehicle are defined at Toyota with a clear focus on improvements of human movements. After documenting a sequence of next-to-perfect operation steps on special operation sheets being openly displayed throughout the plant, work will be performed standardized in the same sequence and with minimal waste in terms of unnecessary movements. Also work safety and prevention of equipment damage due to incorrect operation are improved. Standardized work operations are the basis for continuous improvement and prerequisite for consistently high quality and traceability of assembly problems. In order to be able to standardize work operations, some requirements regarding processes, machines and quality have to be fulfilled:
**Process:** The work process has to consist of a series of repeatable steps. Human movements have to be describable in terms of movements of limbs, eyes, etc.

**Machinery / Equipment** has to allow for operation with minimal downtimes – machine shut-down and assembly line stops are counterproductive to standardization, since they prevent repeatability of operations.

**Quality** has to be consistently and repeatable in order to avoid tolerances, which lead to assembly problems on the shop floor.

At Toyota, standardization is required for the definition of guidelines regarding three major elements while describing manual work operations: Takt Time, Work Sequence and Standard-in-Process Stock.

**Takt time** describes the amount of time available for assembly per station and is calculated from annual production net-time and planned production volume. Cycle time represents the sum of all work operations assigned to a single station. The objective is the fill up most of the takt time with cycle time – the remainder is known as ‘Taktausgleich’ – mostly resulting from insufficient standardization leaving room for interpretation and from non-optimal model-mix production programs. ‘Taktausgleich’ is considered waste in the form of the waiting time and should be subject to elimination.

A standardized work sequence assures that no operations are forgotten, machines are operated correctly without damage and parts are manufactured / assembled with consistently high quality. A standardized work sequence is also prerequisite for constant cycle-times and low costs for ‘Taktausgleich’.

**Standard-in-Process-Stock** describes the minimal needed amount of parts between assembly processes allowing the machine operator to simultaneously supervise several machines in parallel. (Toyota 1985)

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**STANDARDIZED ASSEMBLY PROCESS PLANNING**

Standardized Assembly Process Planning consists of an interdependent system of individual tools, which allows for a parallel operation of **Macro-Planning** (sequence of work steps, assignment of operations to line stations, line layout) and **Micro-Planning** (detailed planning of operation steps including parts and tool lists, explosion drawing, quality requirements, and assembly times).

The Macro-Planning uses **Flow-Chart** and **Assembly Line Layout** to describe the sequence of required work operations and assembly line equipment. **Master Process Sheets** (MPS) are defined in parallel to allow for detailed analysis in a sense of Micro-Planning. During the development phase of product and production process, Macro and Micro-Planning are performed simultaneously. Depending on their qualification level, the production workers may be asked to re-write MPS’s into **Standard Methods & Procedure Sheets** (SMP) for additional training and assembly information.

**Macro-Planning with Flow-Chart and Assembly Layout**

The Flow Chart helps to divide the complex task of assembling a complete vehicle into simple and exclusive assembly operations – each being assigned initially an estimated time requirement based on previous experience. Total assembly time per vehicle, projected annual production volume and available annual net work time allows for the calculation of takt time and required number of line stations. The objective is to optimally assign operations to stations along the assembly line – always considering a meaningful sequence of steps.

Based on the sequence of work operations as depicted in the Flow-Chart, the Assembly Line Layout can be detailed using a scaled drawing of the future layout including building restrictions, station borders, and conveyors. Machinery can be placed according to assigned work in stations.

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**Picture 2:** The elements of Standardized Assembly Process Planning
### Micro-Planning with Master Process Sheets (MPS)

Parallel to the rough assignment of work operations in the Flow Chart, detailed description of operation steps is defined using Master Process Sheets. Parallel work is possible, because each MPS describes an independent work operation. Following the Toyota Production System elements **Standardization** and **Visualization**, work operations are depicted by explosion drawings providing information on assembly location, direction and required tools or assist devices. Based on the graphical product information on CATIA workstations as provided by development, Process Planning Engineers define fixing concepts, norm parts and tools.

### Table: Master Process Sheets (MPS)

<table>
<thead>
<tr>
<th>Stat.</th>
<th>MPS Number</th>
<th>Seq.</th>
<th>Operation (Master Process Sheet)</th>
<th>Operation (Portuguese)</th>
<th>Comment</th>
<th>Qty</th>
<th>MA</th>
<th>TG [min]</th>
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</thead>
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<tr>
<td>TBL</td>
<td>3 290 00 0</td>
<td>1</td>
<td>Bracket Steering Column</td>
<td>Suporte Coluna Direção</td>
<td></td>
<td>1</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>TBL</td>
<td>3 820 00 0</td>
<td>2</td>
<td>Pedal Box (Brake/Clutch)</td>
<td>Pedaleira</td>
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<td>3</td>
<td>Wiper System Mechanics &amp; Motor</td>
<td>Motor</td>
<td></td>
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<td></td>
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<tr>
<td>TBL</td>
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<td>Painel</td>
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<td>Climate Control Head</td>
<td>Controle Ar</td>
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<td>Motor</td>
<td></td>
<td>1</td>
<td>2.00</td>
<td></td>
</tr>
</tbody>
</table>

**Picture 3:** Extract from a Flow Chart

**Picture 4:** Extract from the Standard Times Table
Each work operation again is subdivided into several standardized steps. Using the *Standard Times Table*, early determination of assembly time and thus manpower requirements can be attained (see picture 4).

The main driver for the standardization of work operations is their ability to be described by sub-tasks; each sub-task again standardized and documented in the Standard Times Table. In general, only value-added tasks are described on the MPS’s - exceptions are non-value-added tasks, assuring work safety or process reliability. Check notes are assigned to MPS work steps regarding critical or safety relevant tasks, informing the assembly worker that special supervision or quality control is required.

Master Process Sheets are subject to constant changes and require update. Changes are based on product modifications, suggestions for improvement by production, and usage of new tools. Prior to official submittal, a new or modified MPS requires verification and approval by Development, Quality and Production. Picture 5 shows an example for a Master Process Sheet and below its’ main components are listed:

(1) **Explosion Drawing**: Visualization of assembly process, parts, positioning direction, torque information

(2) **Operation Name**: Denomination of Master Process Sheets as referenced in Flow Chart.

(3) **Control Items**: Reminder on safety or quality related critical processes.

(4) **Operation No.**: Each Master Process Sheet receives an identification number, which references production shop, construction group and allows for differentiation of vehicle type.

(5) **Symbol**: Listing of abbreviations of standardized work operations according to the Standard Times Table.

(6) **Operation Steps**: Precise description of operation steps assuring tasks to be easily understood and performed by team members as basis for repeatable quality work.

(7 & 8) **Work Time**: Individual planned times based on Standard Times Table and total time per work operation.

(9) **Parts Listing**: Assembly parts, part numbers, quantity and reference to balloon-code in explosion drawing.

(10) **Tools Listing**: Required tools to assure specific usage and allow for removal of all unnecessary tools from the line.

(11) **Approval Area**: Prior to official submittal to the shop floor, representatives from development, quality, process planning & production approve the MPS for correct content.

(12) **Change Area**: For quality and warranty reasons, secure tracking of each MPS change history is required. Each modified MPS shows updated release No., reason for change and responsible process engineer.

**Line Balancing by Flow Chart & Master Process Sheets**

During the preparation of Master Process Sheets for all work operations, the Flow Chart serves as an overall guide, showing which MPS have been already completed and assigned to assembly stations. The previously estimated times are constantly replaced by detailed values as calculated in the MPS.
As noted earlier, work operations are listed in the Flow Chart according to meaningful sequence of parts assembly and equal assignment of work content. With constant progress of process planning, the cycle time in each station will become more stable – in order to achieve equal values for cycle time in each station, some Master Process Sheets may have to be re-assigned to neighboring stations. Line Balancing is known as equally distributing work along the assembly line while keeping a minimal gap between cycle and takt time. Flow Chart and Master Process Sheets support the process planner in simultaneously planning the future vehicle assembly from the macroscopic and microscopic perspective.

**Standard-Methods and Procedures Sheets**
The Standard Methods and Procedure (SMP) Sheet is another tool, which could be described as a worker’s translation of a Master Process Sheet. Depending on the skill level of production team members, they may be asked to manually re-write the MPS content by hand in order to fully understand and memorize the assembly processes. This process leads to in-depth analysis and evaluation of the MPS contents and helps to further reduce non-value added waste from the assembly processes. It also delegates more responsibility to the shop floor team members taking advantage of their specific assembly know-how. Specifically during a new vehicle production ramp-up, this exercise proves very valuable in continuously improving processes hence reducing work time and labor.

In comparison with the Master Process Sheets, SMP-Sheets do provide an even higher information content regarding safety and assembly hints. While MPS are generated independently from the assembly line layout (assigned to stations only via Flow Chart), the SMP-Sheets are related to specific assembly stations showing the workers movements in top-view. Due to the high skill level of production workers at Mercedes-Benz do Brasil S.A., it was determined unnecessary to generate SMP’s. Along the assembly lines only DIN A3 copies of Master Process Sheets will be displayed.

**Systems Environment at Mercedes-Benz do Brasil S.A.**
The Master Process Sheet System (MPSS) has been initially set up in an Microsoft Access Database allowing access for several users from process planning within the project team. Information regarding assembly parts is transferred on a regular basis from the Metaphase Product Data Management System. All additional tools like Flow-Chart, Standard Times Table and Layout have been generated on standard Microsoft Office products.

In the future, the MPSS will be run from a professional server environment allowing other process planning departments to access the system. This will gradually shift process planning information and responsibility to the line functions at Mercedes-Benz do Brasil S.A.

**CONCLUSIONS**
The introduction of Standardized Assembly Process Planning as described above, provides to all phases of a new vehicle project a clearer understanding of involved parts and assembly operations supporting the main objective of Concurrent Engineering in providing early manufacturing feedback during the development phase. The simultaneous application of Flow-Chart and Master Process Sheets help to organize and structure the vast amount of detailed assembly operations. Following the Toyota Production System principles of Standardization and Visualization, this planning procedure provides a much clearer understanding of assembly processes and content of parts compared to earlier planning tools based on mainframe applications developed in the 70’ and 80’, which did lack the possibility of graphical information. Assembly operations back then were only described as code – therefore understanding and acceptance throughout the production environment was considerably low.

Specifically for the international vehicle project at Mercedes-Benz do Brasil S.A. with its’ focus on worldwide production locations, using Master Process Sheets will facilitate the planning information transfer and allow for easier training and shorter production ramp-up.

Additional future activities involve the integration of Standardized Assembly Process Planning tools into a Computer Aided Process Planning System (CAPP), in order to allow for higher integration of process data and additional use throughout the planning and production environment.

**BIOGRAFIES**

Dipl.-Wirt.-Ing. Master of Science Henning Oeltjenbruns has worked on the ‘M-Class-Project’ from 1995 till 1997 as a Facilities and Assembly Process Engineer. During his stay in Alabama, he learned first hand about the principles of the Toyota Production System and used the Master Process Sheet System as a tool for daily process planning work. Since 1997, Mr. Oeltjenbruns is responsible for Assembly Process Planning of a new vehicle project at Mercedes-Benz do Brazil in Sao Paulo, Brazil. Currently he is working on his Ph.D. doing research on influential factors of successfully implemented production systems.

Univ.-Prof. Dr.-Ing. Uwe Bracht is chairman of the ‘Institut für Maschinelle Anlagentechnik und Betriebsfestigkeit’ at the Technical University of Clausthal, Germany. His research involves new approaches in the Design of Production Facilities and Material Flow Logistics. Previously, Dr. Bracht has held for eleven years leadership positions within the Technical Planning Department at the DaimlerChrysler plant in Bremen.

Dipl.-Ing. Oliver Meyer, a former student from the University of Clausthal-Zellerfeld, wrote at Mercedes-Benz do Brazil in 1998 his thesis on Standardization in Process Planning. Mr. Meyer is currently employed by Volkswagen AG, Wolfsburg, Germany.

**REFERENCES**

