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How digital prototypes become hardware in high volume production

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ABSTRACT - The present paper is written to give especially the participants of the FISITA Student Congress a closer look at the work of a production planner regarding the transfer of a design model into hardware referring to the stages of the development process. Starting from a rough estimation of a price and the required budget, a planning process is described from rough-cut planning to the support of a running serial production line. An important part is the way of arranging project groups in order to assure delivery of parts in all stages under time, cost and quality aspects. Technical topics are manufacturing processes such as forming, welding, surface protection and automation. Economical topics are e.g. pricing, make-or-buy decisions, layout of the production line and the search for economic potential.

TECHICAL PAPER – In a development process of new car generations, various interests of different parties have to be combined in order to achieve an optimal solution. Customers of high-class cars have high demands on quality, comfort, safety and durability of automobiles. However, the automobile still has to be affordable - automobile manufacturers, of course, want to sell their cars and make profit. In times of increasing competition, it is getting harder to stand out from the crowd but not lower the margin. New features and technologies are applied to new car series, but acceptance of price increases is limited. Additionally, other aspects arising from environment and transportation laws have to be considered.
All this has to be brought in line with the goal to produce at convenient costs. In these times, the vertical range of manufacture is much lower than it was 30 years ago. Many suppliers have specialised in the production of parts such as interior, exterior parts, axle and transmission parts and electronics. Although many OEM´s have their own production plants for e.g. axle parts, it is not assured that an order is placed internally. This procedure is quite similar for all parts a manufacturer is not considering its core competence.

The development process is very complex. In this paper, it is described from a production planner's point of view whose focus needs to change during the development process. As the work is more focussed to technical feasibility and target cost achievement at the first stages, controlling of target dates and costs becomes more important towards the start of production. However, the description does not claim to be complete and is held as abstract as possible, in some terms referring to the production of a structural component such as an engine cradle. The process may vary from one OEM to another and/or from one supplier to another, this is just an example.

INITIAL COMPONENT DEVELOPMENT AND REQUEST FOR QUOTATION

The demands for vehicle properties are summarised in a performance specification by the product management containing an operating schedule. From this, development engineers and designers derive the design of every single part or module, creating a design model and a product specification sheet.

Contents of the specification sheet are for instance:

- functional description
- materials to be used
- number of units to be produced per day / per year
- tolerances
- surface requirements / coating
- target weight
- corrosion and temperature resistance requirements
- ergonomic requirements
- assembly requirements
- determination of responsibilities and contact persons
- schedule for development process and quality gates
- documentation and identification marking
- logistics concept for prototyping and serial production
- applicable standards
- test procedures

The component specification sheet is submitted to potential internal and external suppliers for a quotation. At this point, the work of the production planner at a production plant starts.

ROUGH ESTIMATION OF RESOURCES AND PRICE / DETERMINATION OF SUPPLIER

For an estimation of the price, the process has to be stripped down to single steps in order to determine the production method, order and processes. As on an engine cradle, there might be metal sheets to be formed, tubes to be bent and/or hydroformed, forged parts, welded or pressed-in bolts and nuts to be joined to a structural component. The part is not only joined; the whole process including cleaning, coating, palletising into specified load carriers and the delivery to the assembly plant have to be considered.

A very important fact is the strong dependence of the production planning on the location. Aspects like

- labour costs
- labour time and shift model
- available space for production and storage
- infrastructure
- energy costs
- material costs

have an enormous influence on the production layout. In areas with high labour costs, the automation degree needs to be high while in other areas / countries, a greater degree of manual operation can be utilized. In countries with high energy costs such as Japan, technologies with low power consumption are preferred. If the material costs are high, the cut of material has to be minimised which may result in a more complex forming process.

Considering the named constraints and the available budget, the process steps for manufacturing the part have to be predetermined. At this stage, it is important to integrate experts for production technologies, material flow and logistics. Several functional groups work on different topics. Forming specialists estimate material usage, size and costs of tools and suggest the press to use. Specialists for joining compare technologies to assemble the parts. Buyers estimate prices of assembly parts. When the joining process is divided into single steps, the steps have to be combined in order to estimate the number, size and automation degree of the machines used and the staff needed. In addition, costs for post treatment, such as surface blasting, washing, coating and sealing have to be estimated and a presumption of rejections has to be considered. Experience from similar projects is often used to estimate prices. At this stage, a good coordination of all activities and conversation with the development department are of high importance. The result of the functional groups´ work is a rough production concept.

When the rough concept is compiled, planners and controllers have to calculate a price for the part, which is communicated to the project management of the development department. After consideration of technical and economic aspects and presentations of concepts of the potential suppliers, an order has to be placed. The internal development schedules determine specific deadlines such as the predefinition of the supplier. When the order is placed, a target price is submitted to the supplier and the next stage begins. The decision for one supplier is then fixed, but can still be revised in a very early stage if profound problems occur. The closer that a change occurs towards the start of production, the more problems would arise by changing the decision.

Two methods of placing an order can be used. In the first method, the supplier gets CAD data and the component specification sheet and has to offer and deliver exactly what is specified. Using the second method, the potential supplier is considered a development partner and has to propose improvements that make the part easier to produce, lower weight and price and to make processes safer. Many changes to the structure component can be made in early stages.

PROTOTYPING

Prototyping is a very important and complex part of the development process and is running parallel to rough-cut planning and detailed planning periods. Prototyping ends with the commissioning process.

For component and vehicle tests, a number of prototypes are ordered by the development department. Normally, prototyping has several stages referring to the technical-release procedure of the OEM. Structural components such as engine cradles need to solve crash tests, fatigue tests, assembly tests, corrosion tests and many more. Some pre-tests may be made using mock-ups and partly assembled prototype cars, but the final testing is done with fully assembled prototype cars. The manufacturing of prototypes and the testing of cars are very sophisticated and expensive parts of the development process. Prototype parts and cars often cost up to the hundredfold price of the serial production price or even more. Testing facilities have detailed schedules. The main focuses at this stage are quality and target dates. Therefore, prototyping needs to be carefully planned, documented and organised. All cognitions from prototyping contribute to avoid problems in series production.

Usually, the time frame for setting up a prototype production is very tight. The basics for the transfer from design model to prototype come from the rough estimation stage. The predetermined process steps need to be transferred to prototype tools such as forming tools and welding fixtures, which should emulate the planned production steps as far as possible. Thereby, prototype tools need to be simple and easy to change when changes to the part are decided. Not all steps can be carried out at the OEM´s facilities. Often, specialists for prototyping are involved in that stage. The task of the planner is to search for potential suppliers of prototype tools and specialists to perform particular process steps. The planner discusses technical details, timetables and costs and arranges technical infrastructure, logistics, responsibilities and contact persons. The determined material needs to be procured in the required amount, dimension and quality in coordination with the purchasing department. The planner controls and reports the progress of the project permanently.

It is helpful, especially for prototyping, to build a task force consisting of experts for all concerns to be considered in manufacturing of the component. Production department shall also be integrated in that early stage and regularly informed about the progress of the project. In periodical task force meetings, all issues related to prototyping are discussed and recorded.

Changes to the part can be initiated by both sides, development and supplier. If stress analysis or testing do not show the expected results or space requirements change because of other components, the responsible engineer at the development department changes the design. In such a case, the suppliers of the parts have to implement the changes quickly and deliver new parts. Otherwise, suppliers often realise that certain details are a disadvantage for production. These topics are discussed during task force meetings and details are worked out. The planner has to discuss the proposals with the development engineers. The decision about the proposal is then checked back with responsible engineers of various development fields.

In early stages, the change rate is quite high descending towards the start of production. Furthermore, the adaptation of the single components and herewith the dimensional quality are permanently improved.

ROUGH-CUT PLANNING

At this stage, the rough concept has to be detailed and adapted to new conditions, demands and constraints arising during the development process (e.g. variants of the components, change of the estimated production volume). All activities in relation to the part, its properties and its manufacturing method have to be coordinated with the developer responsible for the component.

An important topic in this period is to approach the target price / costs. If the estimated price is higher than the target price, the supplier will recurrently be called on to present its target achievement path. Every single factor and every process step are surveyed on the search for cost potentials. The required budget needs to be approved or adapted.

In meetings with machine building companies, the general requirements are discussed and finally the potential suppliers are determined. Internally, the inspection planning has to be started. Make-or-buy-decisions for single parts (e.g. forming parts, hydroforming parts, sub-assemblies) are also made at the rough-cut planning stage comparing estimated internal costs with supplier quotes.
Several tools are applied in order to minimise risks and to optimise the rough concept:

- value stream analysis
- risk check
- FMEA (failure mode and effect analysis)
- SE projects (SE = simultaneous engineering)
- simulation of production processes, material flow and logistics

In a value stream analysis, the rough concept is examined by representatives of all concerned departments, such as production, quality management, maintenance, production planning, facility planning, material flow planning and logistics. The concept is compared to similar and former projects in order to avoid waste of any resources.

Depending on the considered part, a FMEA may be required for reasons of product liability. Engine cradles for instance, mostly being combined with suspension functions, are safety parts. Therefore the part itself and the production process need to have a risk check, normally followed by a FMEA. In the FMEA, all possible faults and malfunctions have to be considered, causes, consequences and arrangements for prevention are determined.

SE projects are often made in cases of complex production processes in order to consider different scenarios of the workflow. Usually, the SE partner is a highly experienced company in the sector of machine building or manufacturing systems engineering. The object of the SE project is to determine the best way to manufacture a part and to compile requirement specifications used to request for quotations of manufacturing systems.

In recent times, many OEM´s require digital process simulation; this tool is widely used in automotive and related industries helping to optimise space requirements, to select equipment in terms of accessibility (e.g. types of robots, welding torches or welding tongs for a welding production line) and to simulate the production flow. Thereby, malfunctions are simulated in order to realise what each malfunction of one machine means to the output of the system. Buffer sizes are also optimised this way. Many but not all tests and experiments can be replaced by simulation. If properly utilised, simulation can save costs and reduce the time to market. In many cases, simulation is part of an SE project.

All the concepts worked out at this stage need to be reconciled with departments related to the production process such as production management, maintenance department, logistics material flow planning, factory planning, logistics planning, quality management and last but not least the labour representatives.

At the end of the rough-cut planning period, the inquiry documents are sent out to potential suppliers for quotation. The component-specific requirement sheet contains for instance

- type and arrangement of the machines
- technology
- work contents of the machine / cycle times
- average availabilities
- number of operators
- activity times and work contents of operators
- operation concept
- inspection concept
- space requirements and placing (shop plan)
- way of picking (parts)
- clamping and fixation concepts for the parts
- traceability of parts
- degree of automation / buffers required
- material flow, handling and logistics concept
- production equipment
- technical infrastructure (energy, fluids, gases)

In addition, drawings and CAD data, standard requirement specification and supply specifications belong to the request documents.

DETAILED PLANNING

The detailed planning stage starts when the inquiry documents are sent out. Questions of the potential suppliers have to be clarified, usually in several meetings. Then the offers are presented by all the machine building companies. The production planner needs to discuss the content of the offers in order to make them technically comparable. The offers are then given to the purchasing department in combination with a recommendation based on technical facts. The decision whether a single machine, a package of machines or the whole production line will be negotiated, is defined in advance. Finally, the buyers lead the negotiation about the price and order the machines. Beside the production line itself, also inspection equipment and common production equipment needs to be procured. Specifications for service products, lubricants and hazardous materials need to be compiled. The information about the required material dimensions, quantity and form of delivery are given to material purchasing department in order to finish price negotiations.

In the delivery period, the production planner is in charge of surveillance of the supplier's progress. He has to provide machine testing parts to the system suppliers and needs to compile all required documents related to the production line. At this stage, coordination and monitoring of all dates is very important. Preparations at the factory, e.g. construction activities, provision of power and gas supply, installation of exhaustion can run parallel to the assembly of the machines and should be finished as far as possible by time of the factory acceptance test.

COMMISSIONING OF THE PRODUCTION LINE

Usually, complex machines and systems are first started up at the supplier's site. The commissioning stage officially starts with the factory acceptance test. Certain requirements have to be fulfilled in order to receive the factory acceptance test (pre-delivery buyoff). A team consisting of production planner, maintenance personnel, production personnel and process specialists check the system regarding functionality and compliance with the requirement specifications. Faults and required changes are recorded and have to be worked off till the next approval. In case of severe faults, the factory acceptance test is denied and has to be repeated.

If the factory acceptance test was successfully passed, the systems get demounted again, shipped to the production plant, re-assembled and started up. Payments to a supplier mostly depend on a successful factory acceptance test.

OPTIMISATION OF PRODUCTION TILL FULL VOLUME IS ACHIEVED

When the machines are set up at the production plant, the optimisation process continues. Sequences and cycle times are to be optimised; the material flow and daisy chain are started up; fixtures are optimised. This process needs to be well-coordinated; the communication between the single machines has to be focussed. Malfunctions need to be simulated in order to achieve an optimal error handling. Furthermore, the adaptation of the single parts needs to be refined at this stage in order to e.g. determine the final trimming of formed parts.

At full operation status, the machine or system is handed over to the customer. The production capability of the machine and the inspection equipment needs to be demonstrated.

In the period between the achieved full operation status and the start of production, the system has to show its capabilities in several production tests. A predefined number of parts have to be produced under serial conditions. All the time between the tests, optimisations to the system are made. When all tests are successfully passed, the approval for serial production is given.

After the start of production, the production volume is piecemeal increased till the peak line is achieved. If the required average availability is proofed, the final acceptance test is passed. The production planner's role changes at this point.

IN-SERIES SUPPORT

Even in serial production, the processes may not run stable; parts and production volume can be changed because of new requirements. Even after years of production, certain process steps may be in need of optimisation. The production planner supports alterations, continuous improvement processes and has to clarify guarantee issues with the supplier.

SUMMARY

Automotive technology as well as production method gets more sophisticated. The type of work of a production planner has changed with this progress. In former times, more special knowledge was needed. In these times, the planner needs to have more interdisciplinary skills in order to make a good job. A production planner must be able to communicate on all levels, whether he talks to the operator of a production line or to the CEO of an OEM. Beside a strong technical background, economic knowledge, the ability to work and build teams and good soft skills make a good engineer. Finally, the diversity makes this job so interesting.

REFERENCES

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