A methodology for manufacturing system development

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ABSTRACT

In a model driven development scenario, the models of parts, processes and resources themselves are the carriers of information which is used and refined throughout the work processes. In this article, some basic concepts concerning model driven development are put forward, and a generic model driven work process is described, which covers the manufacturing development activities on a comprehensive level. Further, a case study of the development of a new motor line at the truck company Scania is presented to exemplify the concepts. The model driven approach is described on a more detailed level in the context of process planning.

Keywords: Manufacturing system design, development process, model-based

1. INTRODUCTION

This paper intends to describe and clarify the main ideas and concepts underlying a methodology for model driven manufacturing system development. General ideas of model and information based development processes are presented and exemplified in a manufacturing system development scenario.

An underlying hypothesis of the work is that an information driven work process model facilitates iterative and parallel work since it clearly describes activities in terms of required and resulting information.

- Interdependencies are easier to discover, understand and manage
- Activities can start and be performed in parallel as long as there is enough information

This hypothesis is neither verified nor refuted, but the paper puts some evidence forward to indicate its validity.

The proposed method is a result of research work in the ModArt project [0] within the Swedish MERA program (Manufacturing Engineering Research Area). ModArt (Modelldriven Artikel¬tillverkning) is an acronym in Swedish for Model Driven Component Manufacturing. Model driven development is the central theme of the project, with ideas developed in a close collaboration between industry and academy. ModArt is organized in four different main areas: Manufacturing Process Planning, Factory Planning, Equipment Investment and Information System Support.

2. DEVELOPMENT MODELS

2.1. Model driven manufacturing system development

The fundamental principle of this model driven approach is to clearly describe how the value of the manufacturing system is growing throughout the activities of the development process. Rather than describing a development process in stages with declared gates and results such as “project description” or “requirement document”, the purpose is to model each activity as a function with a description of which manufacturing system information it requires and generates. This way the generic development model can be adapted to different companies by selecting activities relevant to the needs. Moreover, since the model is independent of the business process, it can be adapted to any company’s selected business process model.

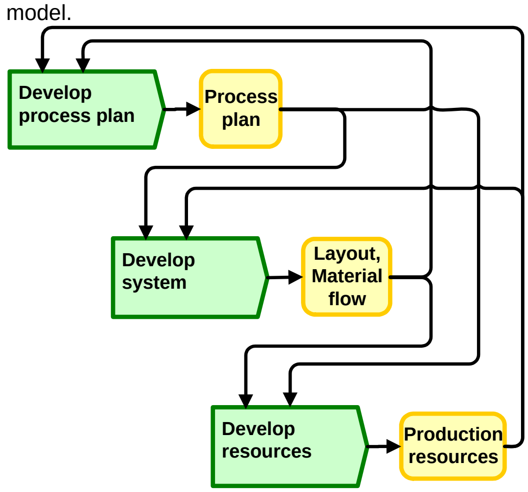

Fig. 1: The basic activities in manufacturing system development using the Astrakhan modeling annotation [1]

2.2. Different types of model driven

Activities can utilize separate parameters or full models with a certain purpose, viewpoint and detailing level, useable for answering questions [2][3]. The type of model driven development depends on whether the information and activities can be interpreted and performed by humans or by computer programs.

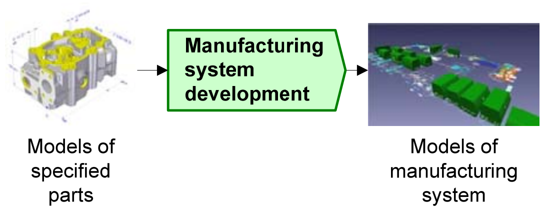

Fig. 2: Model driven manufacturing system development

In a digital model driven development, computer readable, digital, models are used as input (input, control and support) to an activity which delivers digital models as a result. In this paper, even a process where information is described in plain text, interpreted and used by humans, is considered information driven if the activities performed are clearly driven by the information they use and create.
An example of a fully digital model driven development is when models of parts and resources, such as 3D-models of parts with features and tolerances, are used in process planning programs to automatically create a sequence of machining operations.

2.3. Manufacturing system development process and information

In a model driven manufacturing system development, with its sub processes of process planning, factory design, production investment and operations, the models of parts, processes and resources themselves are the carriers of information which are used and refined throughout the work processes.

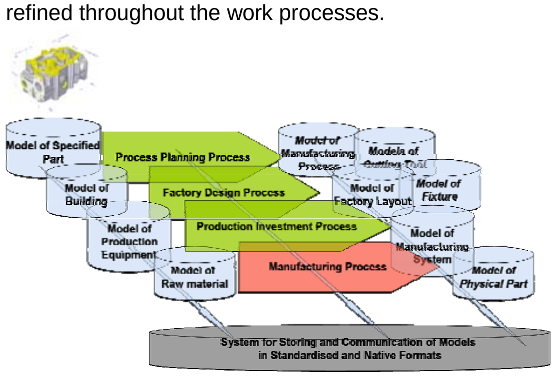

Fig.3 : Processes and models in manufacturing system development [0]

The manufacturing system is decomposed by production resources such as machine tools, tools, fixtures, material handling systems, resources which realize the processes. Apart from equipment, the building and media are also considered production resources. The processes are the sequences of operations on a micro, machine, level which contribute to the total flow of materials on a systems level. Figure 4 shows a crude concept model of some manufacturing concepts needed to describe the system. More comprehensive models can be found in [4] and [5][6].

The layout describes the geometrical interaction between resources, where the material flow describes their functional interactions.

The production resources are placed in relation to each other in a layout. The shape of the layout is determined by the dimensions of the resources, the material flow, buffers, truck corridors, control and maintenance platforms, media supply etc. Thus the principle is to describe three main activities – the one developing the processes, one developing the resources which realize the processes and the third one which integrates the processes and resources into a system.

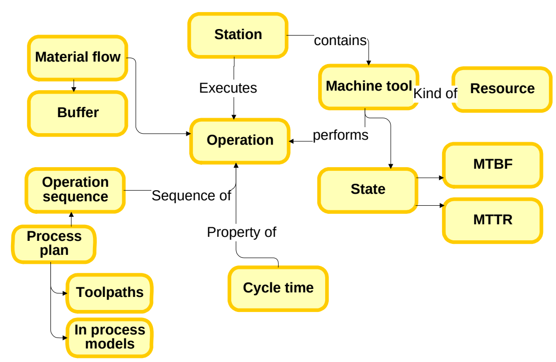

Fig.4 : Crude model of concepts in manufacturing

2.4. The development process in general

In theory, design should be performed as a top-down, zig-zag process where functional requirements are stated on a high level, met by a solution which poses new requirements on a more detailed level, which are met by solutions which pose new requirements and so on [7][8].
Apart from functional requirements, there are constraints which cannot be met by a specific design parameter, but which rather delimits the whole solution, such as weight limitations.

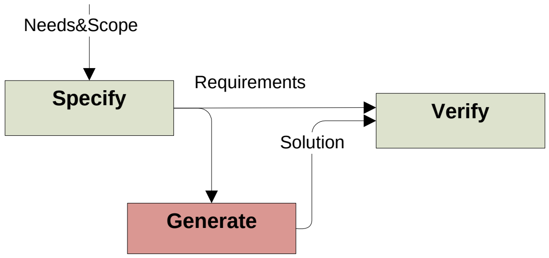

Fig.5: Simplified design activities

Even in a design process which is not performed in a pure top-down zigzag manner, most requirements are not fixed when design starts, but the design process is as much a process of defining the appropriate requirements as a process of finding an appropriate solution [9].

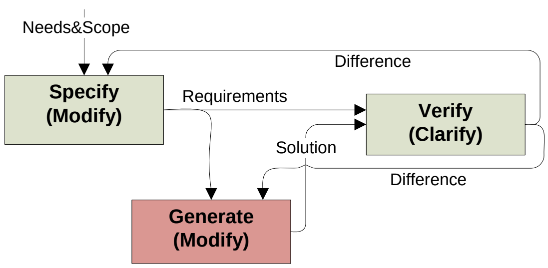

Fig.6: Design activities with feedback

This can also be seen as a negotiation of what requirements should be there, what values they should have, and how important they are on a scale from firm non-negotiable requirements to options and wishes.

In manufacturing system development, each activity contributes to defining various parts of the system: the process plan, the production resources and the system itself (layout and flow). Each part constrains each other: the process plan, layout and material flow descriptions serve as requirements and constraints on the production resources, and the properties of selected resources constrains the properties when designing the processes and layouts.

Thus depending on what the incentive is – where the change starts – a parameter is either a driving input or resulting output: the spindle max speed of a machine may be either input data to process planning or requirements on a new machine resulting from process planning.

3. USE CASE: Development of a new motor line at Scania

A new line for manufacturing cylinder heads is under development at Scania, a truck company in Sweden. The scenario describes how models of machines are used for preparing a process plan, which results in models of operation sequences, cycle times etc. Operation sequences are used as a basis for designing the manufacturing concept, for determining the total flow, and for dimensioning buffer capacities. Machine dimensions are used for designing the layout. Runtime data from operations of earlier machine lines is used to estimate probable stop-times for the new line.

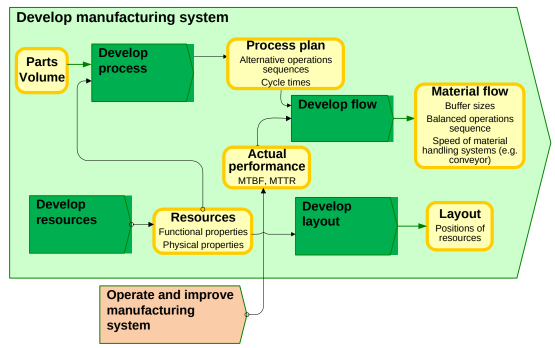

Fig.7: Design activities in a case scenario

Each design activity can be seen as either the activity of designing the output based on the inputs, or the other way around - of defining the requirements on the inputs based on a desired output. E.g. a process planning activity is either using the machines attribute spindle speed as an input to determine the cycle time of an operation, or use the desired cycle time to specify the required spindle speed.

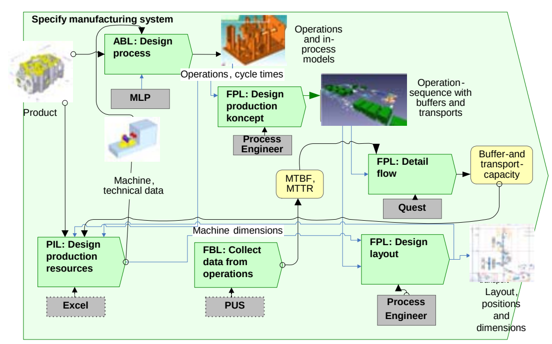

Fig. 8: Model driven manufacturing system development

Each of the activities may use a software tool to support the activity, and in this use case, Machining Line Planner (UGS/Siemens) was used for process planning, Process Engineer (Dassault) for factory design and Quest (Dassault) for flow simulation.

3.1. Process planning (Machining Preparation Process)

Rather than top-down design, in process planning you often have to state many design attributes early on, making educated guesses, and then modifying these values after testing the results and acquiring more information. Thus the design process is the process of elimination of doubt, iteratively narrowing down the uncertainty of the parameters, rather than detailing an abstract system down to a detailed description of the parts.

1) Process planning is conceptual as long as there is unambiguous or contradictory information about what to do, how and with what. Such "conflicts" are temporary solved by improvising by making assumptions.

2) Depending on the actual situation there can be more or less unambiguous/contradictory information, e.g. we can assume that when process planning is interacting with the product development process there will be a lot of unclear, unambiguous and contradictory information which must be considered. On the other hand developing a new manufacturing system for an existing product (such as in the case) is probably characterized by more concise information as there is experience, the product specification is quite fixed as are the corresponding manufacturing methods. So from a process planning perspective there is not so much unclear, unambiguous or contradictory information. But it's still a "conceptual process plan" when there are no formal decisions made.

The key interaction object between the process planning (ABL), system design (FPL) and resource investment (PIL) activities is the "Conceptual Process Plan" which perhaps from a PIL and FPL perspective can be viewed as a "negotiable should requirement" (if we refer to requirements in terms of MUST, SHOULD and CAN), i.e. the "Conceptual Process Plan" is not fixed, it can be revised on request from FPL or PIL because it might be desirable to change the plan due to restrictions caused, or opportunities offered, by real equipment.

To develop process plans for new products, process planners often follow more or less a consistent set of steps.[10]

- Study the overall shape of the part., identify the basic structure of the pan and potential difficulties in its production.
- Determine the best raw material shape to use if raw stock is not given.
- Identify datum surfaces and determine the minimum number and types of setups required to machine the datum surfaces. Then associate each setup with appropriate machining operations.
- Identify part features or geometric shapes, that are to be cut into the stock, from which the part is to be formed. Determine the shapes of the tools needed, the movements of the machines required, and the paths the tools must follow when cutting the stock.

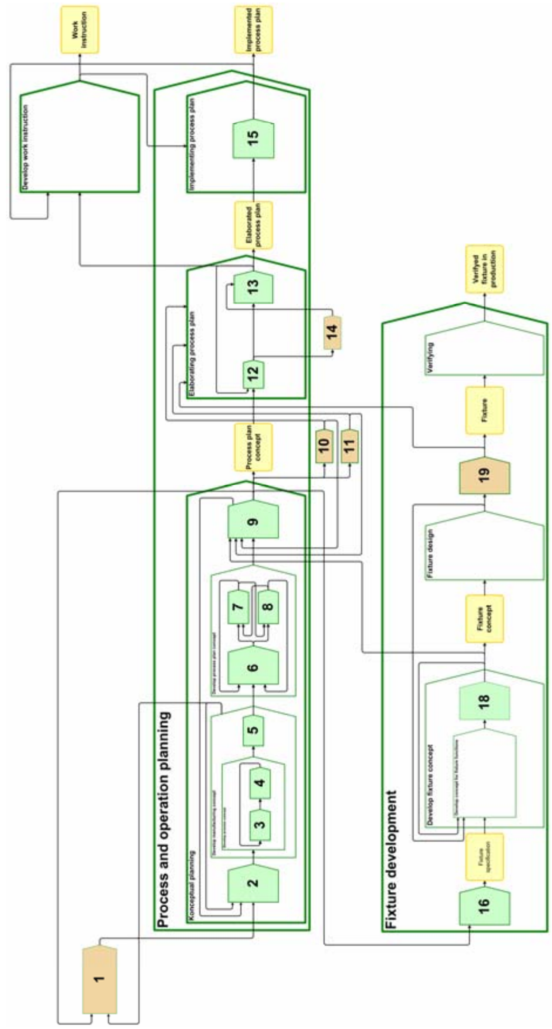

Fig. 9: Process planning as modelled in the ModArt project.

- Group the part features based on the required setups so that each group of features can be produced in the same setup. Then select machining operations for the collected part features for each setup.
- Order the sequence of the operations. For each setup determine the operation sequence required to produce the related datum surfaces and/or features, based on the interference and dependency between operations.
- Select tools for each operation attempting to use the same tool for several operations if possible. The tradeoff between tool-change time and machining time has to be considered.

- Select or design fixtures for each setup which depends heavily on the process planner's experience as a good selection of jig/fixtures is important for good product quality.
- Make a final check and verify the plan by checking the feasibility of the setups, verifying that clamps do not interfere with the tools, and so on.
- Elaborate the process plan. Generating more details for producing individual features, choosing feeds and speed, estimating costs and standard times, etc.
- Prepare the final process plan document and give it to the production manager.

4. DISCUSSION and CONCLUSION

In the domain of manufacturing system development, designing a line entails determining a process plan as well as a physical layout. The process plan and layout are two interdependent aspects of a line due to the fact that the machines, which are used to realize the operations, have geometric dimensions and interfaces to physical equipment in the layout. Thus determining exact process plan and layout is a negotiation between operation benefits and physical constraints. The information driven work process model described in the paper helps visualise the dependencies between development activities and various aspects of the line which is under development. This indicates that information driven work process models would facilitate iterative and parallel work since they clearly describes activities in terms of required and resulting information, elucidating interdependencies. Interdependencies are then easier to discover, understand and manage

The idea of describing a development process in terms of value adding activities goes in line with the Toyota principles of Lean Manufacturing: visualising added value in the manufacturing system development processes as well as in the manufacturing operations [12]. It is believed that this type of modelling could contribute to development in the same way as TPS has contributed to manufacturing.

5. ACKNOWLEDGEMENTS

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