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Citation for published version (APA):

Florusse, L. B. (1992). Manufacturing processes from an industrial management viewpoint. *Computer-integrated manufacturing systems*, 5(4), 269-275.

Document status and date:

Published: 01/01/1992

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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- The final published version features the final layout of the paper including the volume, issue and page numbers.

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Manufacturing processes from an industrial management viewpoint

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Abstract: From an industrial management viewpoint, all the aspects of manufacturing processes that influence the organization of, the capacity for and the control of activities inside or outside a company are of interest. An industrial management description of manufacturing processes should enable a manager to define these influences for a specific process. This article focuses on the relation between manufacturing processes and process-planning. In order to study this relation in more detail, the concept of manufacturing routes is developed. This concept provides a basis for mutual comparison of manufacturing processes. The results of three case-studies indicate that the tooling characteristics of a manufacturing process dominate the influence on the capacity demanded for carrying out the process-planning activity. Specific values for this influence are given in an example.

Keywords: manufacturing processes, management

A host of recent publications has attributed the rehabilitation of manufacturing as the core activity of industrial companies. Important triggers for this attention were publications by Skinner¹, Kantrow² and Hayes and Wheelwright^{3,4}. Hayes and Wheelwright pointed out that manufacturing operations are at the heart of the industrial enterprise and that specifically a long-term view on manufacturing, in other words a manufacturing strategy, is an essential condition for survival for any manufacturing company. They see as the major categories of manufacturing choices, the choices on capacity, facilities, equipment and process technologies, vertical integration, vendors, new products, human resources, quality and systems. So, an important aspect of a manufacturing strategy is the choice of manufacturing processes. In the industrial management literature, however, manufacturing processes are treated in a very abstract way.

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Hayes and Wheelwright, for example, use the dimension interconnectedness (which ranges from 'very jumbled flow' to 'continuous flow') for classifying manufacturing processes. Such a single dimension does not do justice to the technological developments which lead to an increasing range of manufacturing processes and thus lead to an increasing number of alternative ways of making the same product (for an overview see, for example, Reference 5).

To formulate a manufacturing strategy it is essential to be able to compare manufacturing processes regarding their influence on other activities within a company or even on activities outside a company⁶⁻⁸.

In this paper a concept is worked out which establishes a basis for comparison of manufacturing processes. From this concept, the aspects of manufacturing processes which determine the relation with capacity demand (or workload) in process-planning are deduced.

Definitions, restrictions and relevance of the study

A general definition of manufacturing processes is: 'processes which are applied in an industrial environment with the aim to transform materials or objects into materials or objects which satisfy predetermined standards of form and/or function'. The manufacturing processes treated here are processes aimed at making geometrically defined objects. More specifically this means that these processes are aimed at either:

- creating form out of formless material,
- changing the shape of objects,
- connecting objects,
- fixing layers on objects,
- changing the material characteristics of objects

An exhaustive technical classification of these processes can be found in Reference 9.

Manufacturing processes are usually carried out with

a machine. A machine is defined here as: 'an installation aimed at providing the energy and the capability of moving and positioning the tools which transform the material by some physical process'. Tools are: 'the material objects or the physical phenomena which enable a machine to carry out the material transformation'.

In this paper, manufacturing processes are supposed to be applied to products being either parts or sub-assemblies*. The reason for this restriction is twofold.

First, there is a general trend in industry towards increasing the integration of product functions in one part or sub-assembly. This development is propelled by techniques like design for assembly¹⁰. This development also leads to a growing percentage of the cost-price of industrial products being determined by parts/sub-assemblies. Second, there is a trend towards more rapidly changing products and towards offering more versions of one product. This development sets new standards in the traditionally stable production environment that parts' manufacturing was¹¹.

From these two trends one can conclude that parts/sub-assembly manufacturing is an increasingly relevant stage in the total process of making final products and that the restriction of the research to this sector still leaves a relevant field of study.

Conceptual approach to the comparison of manufacturing processes

From an industrial management viewpoint, manufacturing processes are means to make products. In other words, the objective of production is to make products and not to have manufacturing processes: manufacturing processes in themselves are, strictly speaking, irrelevant. Consequently, we are interested in the restrictions that these processes put on producing products in the sequence, in the time-span and for the expenditures we consider as acceptable. However, generally a large percentage of the costs and throughput time for making a product is the result of activities outside, and especially preceding, production. This means that it is interesting to know the influence of manufacturing processes on those parts of the production organization.

For this purpose, a basis for comparing manufacturing processes should be formulated first. As stated, in this article manufacturing processes are seen as a means to make a product. Therefore, a comparison of manufacturing processes can only be made when these processes can be applied for making the same products. The question then is which products are the same products. Does this mean that the shape, material, etc. all have to be exactly the same? In order to answer this

question, we have to go back to what a product really is.

What is a product?

Following the marketing concept, a product is the materialization of a certain need. A need is signalled in a market. A company's design office translates this need into functions¹². Functions are descriptions of what a product should be able to do, in abstract terms, in order to fulfil a need. Functions are translated into sub-functions, probably even into sub-sub-functions and so on. This process of splitting up functions goes on to a level on which physical solutions for carrying out the specified sub-...-function are at hand. The final product is then built up from these physical solutions for sub-...-functions¹³.

Identical products, identical parts

Of course, the process of designing a product is not as straightforward as suggested above. A conclusion that can be drawn from this rough sketch, however, is that from the customer's point-of-view products are identical when they fulfil the same need. A more restricted conclusion is that parts or sub-assemblies are the same when they have the same (sub-...-)function.

For parts and sub-assemblies, however, this equal function is not the only criterion. Since parts and sub-assemblies belong to a final product they have to 'fit into' this final product. This leads to requirements regarding physical aspects of the part or sub-assembly. What these requirements exactly are will differ from situation to situation. This means that, for a given situation, the detailed physical description of a part or sub-assembly can be broken down in a mandatory part and a 'free' part.

A part is fully described physically by giving a description of the part's:

- shape,
- material,
- tolerances,
- surface roughness,
- measurements¹⁴.

For a sub-assembly this means that a detailed description should consist of a description of all single parts (see above) plus their connections (connecting material and connecting surfaces). So, for our purposes, a list of mandatory physical and functional aspects fully describes a part. This full description will be called the conceptual description of a part. All physical realizations of a part that satisfy the conceptual description are to be seen as equal.

Identical manufacturing processes

In practice, more than one manufacturing process will (almost) always be needed to make a part which satisfies the conceptual description. For comparing alternative processes not only the output of the processes has to be identical but the input has to be

*In this article the terms part and sub-assembly will be used as equivalents. Whether or not single parts are meant depends on the context.

comparable as well. In the context of this article this means that standard materials are taken as the starting point for processes which are to be compared. From these two reasons we can conclude that instead of single manufacturing processes, sets of processes which result in an equal part (defined above) and start from standard materials should be compared. These sets of processes will be called manufacturing routes.

Influence of manufacturing processes on the non-recurring activities in production

Sketch of the non-recurring activities*

After the formulation of alternative realizations for product-functions (see previous section), a phase of integration and optimization of the different realizations into product concepts will follow. When the realization has been decided, the concept is worked out in detail design. Detail design produces so-called engineering drawings and a parts list. These documents, or data sets, are transferred to process planning. Process planning translates the information of engineering into instructions for manufacturing and brings the manufacturing processes involved to operating standards.

In reality the process is not as straightforward as suggested above. Iterations will take place and precise activities per stage can differ depending on the particular situation¹⁵. As a basis for reasoning, however, this model of the non-recurring activities is sufficient.

Influence of manufacturing processes

The objective of conceptual design is to generate an 'optimal' conceptual realization of a function¹⁶. The process of generating solutions should be creative and should preferably not be 'blocked' by too many practical considerations. Only when a choice between solution principles has to be made, should arguments like 'manufacturability', costs and delivery time be taken into account. So the effort for this choice process cannot be allocated to a specific solution. Therefore we can conclude that the influence of individual manufacturing processes on the non-recurring activities starts in the detail design phase.

Background and objective

Given the objective and the restrictions of this study, it would be interesting to know how manufacturing processes influence the capacity (of a certain standard quality) required to carry out detail design and process planning. The relation to be found is one of the building blocks for an industrial management view on manufacturing processes. It would enable a manager to relate his choice of manufacturing processes to the capacity needed in an indirect part of the organization.

*Since these activities are carried out once for one product they are called non-recurring (for that product)

The reason for working out this particular relation lies in two developments. A general development for manufacturing companies is a growing specialization. Companies tend to concentrate on making certain categories of parts with certain specific processes. Consequently, other companies that concentrate on designing and assembling final products use specialized companies as their (co-making) supplier. Another development is the increasing speed of change of products, as already mentioned.

Both developments articulate the increasing importance and possibilities of controlling the capacity in product design and process planning.

The influence of manufacturing processes on process planning

Objective

In the remaining part of this paper, the relation between (man-hour) capacity (of a certain standard quality) and aspects of manufacturing processes and manufacturing routes will be discussed for process planning. Capacity demand in process planning partly determines the throughput time. In the industrial management context, the reliability of throughput times is as important as the length of throughput time. Attention should therefore be focused on the aspects of manufacturing processes which influence:

- the tasks that have to be carried out in process planning,
- the workload for these tasks,
- the uncertainty in the process planning activity.

Process planning and manufacturing processes

Figure 1 gives an overview of input and output of the process planning activity. As shown, process planning

Figure 1. Overview of process-planning activities

generally has four main tasks¹⁷⁻¹⁹ First, the translation of engineering drawings into manufacturing instructions Second, the design and manufacturing of specific tools for manufacturing a part Third, the calculation of standard processing times Fourth, start-up of production until normal performance characteristics are reached (sometimes including test-runs or prototypes).

This general picture of the process planning activity was checked in three factories, all manufacturing sub-assemblies/parts for the avionics industry. Table 1 gives an overview of the activities in process planning for each of the three factories. Case 1 is a factory which produces solid aluminium parts. The main manufacturing process is milling Case 2 is a factory which produces plate-shaped parts and sub-assemblies of synthetic material. The main manufacturing process is laminating (the production of three-dimensional shapes by clothing a mould with strips of hardening synthetic material). Case 3 is a factory producing parts from sheet metal. The main manufacturing process here is pressing.

As can be seen in Table 1 the four sub-tasks in process planning are present in all three cases. This is in agreement with the literature mentioned above. However, the sequence of the sub-activities and their status differ from case to case

To be able to formulate hypotheses on the influence of manufacturing processes on the sub-activities in process planning, the sub-activities will now be worked out in detail for the three cases

Task 1. Translation of engineering drawings into manufacturing instructions

In all three cases this task was carried out starting from engineering drawings and a parts list As stated, the manufacturing instructions have to be made for every manufacturing operation of every single part So for sub-assemblies which are equally difficult from a manufacturing point-of-view, the amount of work for this activity is mainly determined by characteristics of the manufacturing route chosen

- the number of operations,
- the number of single parts of the sub-assembly

The manufacturing instructions can be oral, written and/or in the form of an NC program. The instructions are partly directed to a machine and partly directed to operator(s). The format of the machine instructions as well as the importance of the machine instructions relative to the operator instructions, depends on the degree of automation of the specific machine.

Task 2. Manufacture of specific tooling

Specific tooling can be split into specific manufacturing tools and specific fixturing tools.

Whether or not specific manufacturing tools are needed depends on the characteristics of the manufacturing process In case 2 as well as in case 3, specific manufacturing tools have to be made for every different part. The tools are specific because the parts' shape is built into them. Consequently, for these manufacturing processes the capacity needed for making a specific manufacturing tool will likely be a function of the parts' shape and surface area. The available information is engineering drawings of single parts. These have to be translated to tool specifications by tooling design.

Whether or not fixturing tools are needed depends on a combination of the fixturing aids of the specific machine and the shape-characteristic of the raw material or part to be processed. In case 1 a vacuum system is used so the raw material should have at least one big enough and perfectly flat side.

Task 3. Process time calculation

In all three cases, the calculation of process times was a minor contribution to the capacity demand in process planning. In case 1 the calculations were even carried out automatically from CAD information. This task will not be studied in more detail here.

Tasks 4 and 5. Production start-up and possible feedback

In the three cases of Table 1, test runs are only carried out when processes are planned for entirely new or greatly redesigned parts, in other words, depending on the uncertainty of the process relative to the specific part.

Table 1. Schematic view of the process-planning activity in three cases

CASE 1	CASE 2	CASE 3
Writing manufacturing instructions. Determine if specific tooling is needed (If NC machine) NC programming, (if specific tooling) In parallel: design and order of tools	Definition and design of specific tooling Planning of tool manufacturing. Order tools. In parallel: writing manufacturing instructions	Writing manufacturing instructions Determine if tooling is needed (If NC machine) NC program (if specific tooling). In parallel: design and manufacture of tools
Calculation of standard processing-times Define quality-measurement instructions (If new part) Test-run and inspection (if necessary) Feed-back on quality	Check delivered tools. In parallel: define quality measurement instructions. Calculation of standard processing-times. (If new part) Test-run and inspection Feed-back on quality	Calculation of standard processing-times. Define quality-measurement instructions (If new part) Test-run and inspection Feed-back on quality

In the three cases we found that if product specific tooling had to be manufactured, this accounted for about 80% (with a minimum of about 50% and a maximum of about 95%) of the process planning capacity demand of a sub-assembly. Moreover, in the situation where manufacturing processes need specific tooling, the sequence of activities in process planning changes: compare the second case with the first and third. This gives the first aspect of manufacturing processes which influences the non-recurring activities: the tooling characteristics of a manufacturing process. The latter is defined as: 'the extent to which, in a production department, the tooling for the manufacture of a specific part is used only for that part' (measured in %).

The first task, translation of engineering drawings to manufacturing instructions, is carried out per part, per manufacturing process. In capacity terms, this task is second in importance to the making of specific tooling. For a range of parts which is equally difficult to manufacture, the capacity for this task will depend on the number of manufacturing processes needed for the transformation of the raw material into the part.

Other influences

It is important to notice that the standards for the quality of the process planning output differ from company to company. Factors like production speed, the length of the products' life cycle, batch size etc result in different sets of standards for different companies. In this article, these influences will not be worked out further. It is assumed that the companies discussed have production characteristics which lie somewhere between the extremes of:

- mass production: processes are usually built specifically for one or a few products,
- one-of-a-kind production: manufacturing processes in the sense of DIN 8580 are seldom applied.

Quantification of the influence of manufacturing processes on process planning

General

The relation between characteristics of manufacturing processes and the capacity demand in process planning was investigated for the second case of Table 1. In this case the capacity demanded for making laminating tooling and for making manufacturing instructions was investigated by means of the pre-calculated data for 17 sub-assemblies.

The restriction to these tasks in process planning is explained by the fact that over the 17 sub-assemblies the share of the laminating tool-making in total process planning hours was 78% on average, with a minimum of 55% and a maximum of 95%. Together with the making of manufacturing instructions this covers almost the whole capacity demand of the process planning activity.

Manufacturing processes

In this case process planning and tooling is carried out for the following manufacturing processes:

- laminating;
- cutting/drilling;
- glueing

Together these processes form the manufacturing route for the production of three-dimensional, sheet-shaped, synthetic sub-assemblies for aviation applications. Examples of these sub-assemblies are tail-cones, radomes, etc.

The tooling character is the same for all the sub-assemblies investigated: 100% or a specific mould for every part. As mentioned, the hypothesis here is that capacity demand for specific tooling will depend on the shape and size of the part to be made. If parts are categorized depending on their shape this will correct for the difference in difficulty between parts. Interviews with tooling specialists in this factory established that this hypothesis was reasonable. This relation was expected to be a line with a slope > 0 and an intercept > 0 .

Of the other aspects which describe a part (see earlier section), the parts' tolerances are always of the same order of magnitude here. Surface roughness is not taken into account since it is determined by finishing processes.

As indicated above, the hypothesis is that characteristics of the manufacturing route will relate to the capacity demand for making manufacturing instructions. So the number of parts per sub-assembly times the number of process steps was assumed to be positively correlated with the capacity demand for the making of manufacturing instructions. This relation was expected to be a line with a slope > 0 and an intercept > 0 . For the same reasons as above, here again the parts were separated in shape categories.

Results

To investigate the relation between capacity demand for lamination tooling and the shape and size of parts, the sub-assemblies were split into the shape categories:

- flat;
- bent in one direction;
- double bent

Since the first category consisted of only two sub-assemblies, this category was skipped. From the raw data we also skipped the sub-assemblies with very large surfaces. Relations within the normal range of surfaces are of most interest for decision making. The results for the other two categories are shown in Figures 2 and 3.

Figures 4 and 5 show the relation of (the number of parts $\times$ the number of process steps) and the capacity for making manufacturing instructions for both shape classes.

Figure 2. Relation between surface area and tool-manufacturing capacity (bend in one direction)

Figure 4. Relation between manufacturing instruction making capacity and the number of parts $\times$ the number of process steps (bend in one direction)

Figure 3. Relation between surface area and tool-manufacturing capacity (double bend)

Figure 5. Relation between manufacturing instruction making capacity and the number of parts $\times$ the number of process steps (double bend)

Discussion

Regression analysis showed that within a shape category, surface area and capacity demand for laminating tool making are indeed significantly (over the 95% level) correlated. The relations are of the form:

$$y = b_0 + b_1(x^2)$$

where x is surface and y is capacity demand for tool making. For a limited surface area range this relation could be expected. It will cost some capacity to start making tools (b_0) and the increase of surface will lead to a more than linear increase in capacity demand. For larger surfaces the relation will most probably bend off to form an S-shaped curve. The extra amount of capacity needed for larger surfaces will logically lead to a less than proportional increase in hours needed. As expected, the number of process steps times the number of parts is a significant (over the 95% level) indicator for the workload in manufacturing instruction making (within the same shape category). The relations are of the same form as above.

The insights presented here seem to be a useful tool for the industrial management discipline in structuring the thinking about the role of manufacturing in the total process of industrial production. The study presented reveals aspects of manufacturing processes that are relevant to management. The influence of these aspects on capacity demand in an important part of a manufacturing organization has been illustrated. For manufacturing processes with specific tooling there seems to be a relation between the parts' shape and size and capacity demand for tool making. Aspects of the manufacturing route influence the capacity for the mandatory activities in process planning. These insights enable a more soundly based formulation of manufacturing strategy as indicated in the beginning of this paper.

One should, however, be careful with the interpretation of the results shown. The pre-calculation basis of the data is a weakness. The fact that only data for whole sub-assemblies were available puts restrictions to

the usefulness of the data where conclusions for tool making are to be drawn. Although this is somewhat compensated for by the fact that we skipped the largest sub-assemblies from the raw data, the latter should warn against too strong conclusions from these data. Further research is therefore needed to confirm the relations (statistically)

Further research

Further research will be directed to find more quantitative data to support the statements made and to check on the validity of the relations presented here. Data for other manufacturing processes have to be found. Another important field of study will be the specific influence of manufacturing processes on the uncertainty in process planning.

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