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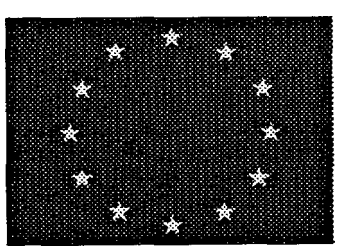

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REDESIGN OF SMALL-
BATCH MANUFACTURING

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1. ABSTRACT

Companies are forced to adapt and improve their production organisation continuously because of irregukr and fast-changing requirements of their customers. These demands can be met by flexible production structures that are adjusted to the products to be manufactured. HOPE is a methodology for production engineering and design especially developed for small and medium-sized companies (SMES) with small-batch production. It aims at increasing the company's strength towards competitors by improving the production structure concerning technological, organisational and human aspects. The HOPE methodology comprises all the necessary steps and efficient time-saving tools for analysing an existing structure, generating alternative production structures, evaluating the expected performance of them and finally implementing the production structure in the company. Considerable improvements at several project partners like halving of throughput times could be achieved by using this methodology.

2. HOPE FOR SMES

Market conditions have changed considerably during the last years. Efficiency, quality, flexibility and customer satisfaction are among the various demands today to which attention has to be paid continuously. These competitive factors are significantly influenced by a company's structure of the production. Increasing complexity and uncertainty in the environment forces companies into an ongoing process of improvements in order to stay capable of fulfting the demands.

Recently developed methods to cope with these problems, like Lean Production and Business Process Reengineering, me time-consuming and focused on the improvement of mass production organisations. Dedicated methods especially suitable for SMES with relatively small production volumes in small batches do not yet exist despite a growing need.

Within the HOPE project a methodology of production engineering and design especially for small-batch production has been developed. It contains an integral and holistic analysis of the company, followed by the development and implementation of a changed production organisation if appropriate. It pays special attention to the human resource and organisational potential. HOPE supports the solution of typical problems like complex communication, long throughput times and waiting times, low controllability of processes and high number of transportation activities. These problems are characteristic for SMES with products produced in low quantities, at a high variety and in a high number of production steps. Traditionally, these companies have been organised in a functional-oriented way. Production departments consist of separate units with complex production and information flows between them. By applying the HOPE methodology improved structures which are more product oriented or group oriented can be achieved to provide low throughput times combined with high productivi~ and flexibility.

3. THE HOPE METHODOLOGY

The HOPE methodology is based on a logical sequence of steps to be performed, with specific tools for each step. An overview of these steps is shown in Figure 1, which gives an overall framework for the various steps in the methodology, including the supporting tools developed within the HOPE project. This section gives an overview of the framework, while in the next section the supporting tools are described.

The framework consists of eight steps for analysing the company and its production structure, elaborating and assessing alternative production structures and implementing the chosen structure. The fust two steps consider the whole company and determine areas of possible improvement. The results of these steps lead, if appropriate, to the decision to focus on the production of certain production areas in the third step. The following steps consider these parts of the company in detail.

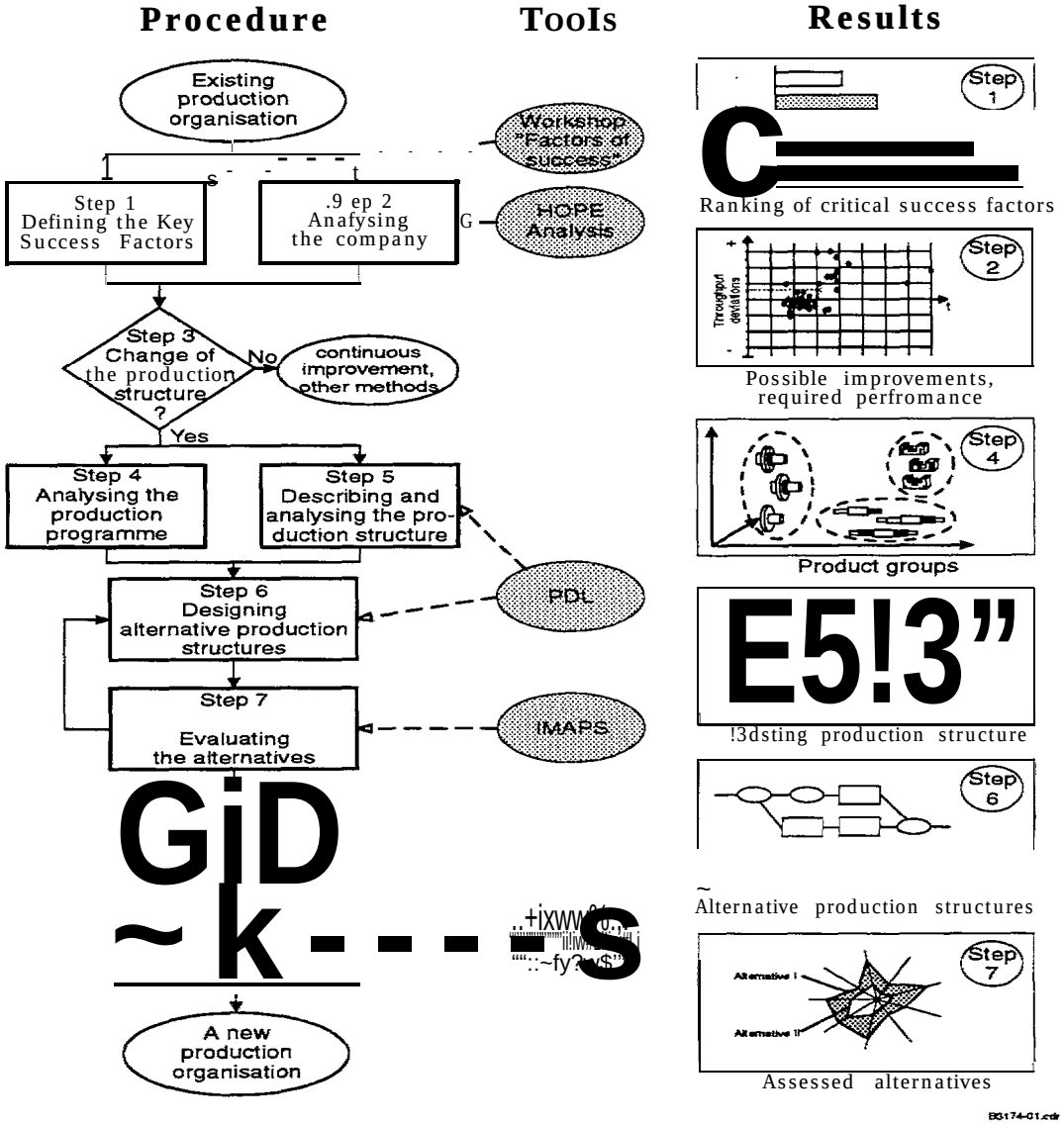
In the f~st step of the HOPE methodology, an analysis is made of the main markets for the company and the requirements which have to be fulfilled to secure a successfid pIace in these markets. These market requirements are compared with the company's strengths in order to identify the most competitive aspects of the company. These aspects are called the Key Success Factors of the company, the factors in which should be invested the most. They are the sting point for the following steps. Furthermore, these factors play an important role in the evaluation of newly developed production structures later on in the HOPE procedure (Step 7). A participative workshop has been developed to determine these Key Success Factors.

A holistic analysis of the company is carried out within Step 2. The analysis is not restric~d to the production organisation only but provides a company-wide overview. The holistic character of the analysis refers on the one hand to the consideration of the whole company with all its departments and on the other hand to the muhitude of aspects which are considered in the analysis. The HOPE analysis puts special emphasis on the so-called human potential, i.e. the knowledge and the abilities of the company's employees. An advanced documentation set has been developed with easily understandable instructions for the collection and presentation of the data. The evaluated information is discussed thoroughly resulting in an overview of the required performance of a company and the possible improvements.

The third step of the HOPE methodology supports the decision in which direction to continue the reengineering process. The management of the company is responsible for this decision that is based on the results that are achieved with the HOPE Analysis. Assuming that improvements will always be possible in an organisation, roughly three possibilities can be distinguished:

- Improvements in the production with a continuous improvement process.
- Improvements in the production organisation by changing the production structure.
- Improvements in other areas than the production departments.

Figure 1. The HOPE framework.



Possible improvements which concern structural changes in the production structure is dealt with in the following steps of the methodology, The other possible improvements have to be considered with other methods and are not subject of the HOPE methodology.

Following the HOPE methodology (thus focusing on the restructuring of the production organisation, the next step consists of the analysis of the production programme (Step 4). The characteristics of the production prograrnme are the basis for an improved production structure. Products are examined on company-specific criteria with regard to equal or similar properties like number of parts, kind of necessary technologies and intervals of demand. The evaluation of these characteristics makes it possible to combine products to certain clusters. Product clusters form the starting point for an improved production structure. The output of this step consists of various sets of product clusters that are used in the following steps.

Together with the analysis of the production programme, a description and analysis of the existing production structure is made (Step 5). In this way, the present structure of a company is made transparent and comparable. Inconsistencies and areas of special attention can be identified. The description offers a standard for measuring the realisation of the production aims and provides a basis to which concepts of improved structures can be compmed and analysed.

Based on the analysis of the production programme and the production structure, various alternatives for improvements are developed in Step 6. The development of more than one feasible new structtut supports the decision-making process, showing different aspects to be taken into account. In this way, an optimal structure of production means and people is achieved in order to produce the required output of a company. For describing, analysing and redesigning production organisations in the Steps 5 and 6, the Production Description Language (PDL) has been developed. The PDL facilitates the design process in a way that several alternatives can be designed in a short time without much effort.

In Step 7 the alternative production structures are evaluated. One of the developed alternatives which corresponds best to the success factors of the company is selected before the company can start restructuring its production structure. An economic and human-oriented comparison of the existing situation and the elaborated alternatives is executed.

Costs and benefits of the alternatives in relation to the existing situation are assessed. Based on this comparison, a decision can be taken on the best suitable structure for a company. IMAPS is the developed tool which supports this process.

Finally the implementation of the new production structure in the company is carried out in Step 8. The implementation realIy is the “proof of the pudding” to validate the developed structure. A project management approach has been ‘ developed in a way that the people who wiIl have to work in the new structure are involved in the implementation process to improve the acceptance of and the commitment to the changes.

The presented framework can be used by external consultants to support companies that want their production organisation analysed and, if necessary, redesigned. This framework is not given as a strict procedure to be followed. It provides an overview of possible steps to take and tools to use. All the tools are developed in such a way that they can be used separately and in various combinations with the other tools. To facilitate this process of selecting tools and customizing the methodology, parts of the tools have been integrated in preceding or following steps and tools.

By providing a framework with various alternatives of possible combinations of steps and levels of detail, the best selection can be made to satisfy the requirements and demands of a specific company. In the next section, the various tools of the framework that have been mentioned already will be presented. This description will give more insight in the principles used in the HOPE methodology and the possibilities to adapt the methodology in a company-specific way.

4. TOOLS OF THE HOPE METHODOLOGY

4.1 THE WORKSHOP''FACTORS OF SUCCESS"

To support the identification of the Key Success Factors of a company, a tool has been developed: the Workshop "Factors of success". This workshop considers the two aspects requirements of customers and the company's strengths. It has a participative character, i.e. people from the company are involved intensively whereas the participating consuka.nts only provide a coaching role. The workshop consists of five steps to be followed in a chronological orde~

- Elaboration of Success Factors by company participants and customers.
- Evaluation and structuring of Success Factors.
- Ranking of the Success Factors.
- Estimation of influence of the production on the Success Factors.
- Determination of profde of priorities.

The profile of priorities summarises the results of the workshop. The profde of priorities is a combination of the Success Factor rankings of the company and customers. It is an individual proffle for the company which takes into account the cornpany-speciilc requirements and provides the basis for the further analysis and redesign steps in the HOPE methodology.

4.2 THE HOPE ANALYSIS GUIDE

The HOPE Analysis Guide contains guidelines to systematically find out the strengths and weaknesses of the company and to indicate possibilities for improvement. The various parts of the guide are designed to make the collection of the necessary data as easy as possible. The required data should be available in almost every company or at least should be able to be gathered without much effort. The guide consists of a number of question and evaluation forms dealing with different topics, The question forms contain brief instructions on how and where to collect the data needed for the forms. Thus the companies are able to collect the data themselves. In most of the evaluation forms standard evaluations are described. They assist the people in elaborating the analysis results.

The analysis guide is divided into the following five parts:

- General company information.
- Product and market information.
- Technical information.
- Organisational information.
- Communicational information.

This broad scope represents a maximum extent from which the necessary items can be chosen. Thus the extent of a specific project is determined according to the company needs in cooperation with the management of the company.

4.3 PRODUCTION PROGRAMME ANALYSIS TOOLS

For the analysis of the production prograrnme no tool has been developed in the HOPE project. A lot of description methods and mathematical tools already exist. Therefore, an intensive literature survey about these tools has been carried out to provide an overview of these tools and the possibilities to apply them.

The formation of product groups can be carried out through one of the following methods:

- Class~lcation method.
- Manual method.
- Production-flow analysis method.
- Multi-variable method.

A survey under companies and consulting fms on the methods they are using showed that the conference table method (manual method) is applied in nearly two thirds of all grouping projects, whereas the cluster analysis (multi-variable method) is used in 20%. Other methods are used very seldom. The HOPE methodology provides details on the suitability of the various tools in certain situations.

4.4 THE PRODUCTION DESCRIPTION LANGUAGE (PDL}

The Production Description Language (PDL) which has been developed completely in the HOPE project supports the analysis of a present company's structure and the elaboration of alternative production structures.

The PDL is based on the systems theory. According to this theory production processes (directly focused on the production) and supporting processes (focused on securing, maintaining and controlling the production processes) take place in an organisation to fulfil its function in the environment. These processes consist of a number of mutual dependent activities that can be grouped into units. A unit (consisting of a group of people and their production means) in which (part of) a production process takes place is called a production module; a unit in which supporting processes take place is called a supporting module. A production organisation can be constructed by combining these production and supporting modules. The PDL gives insight into this organisation by showing the internal structure of these modules and the relationships between the modules.

The PDL consists of the following three parts:

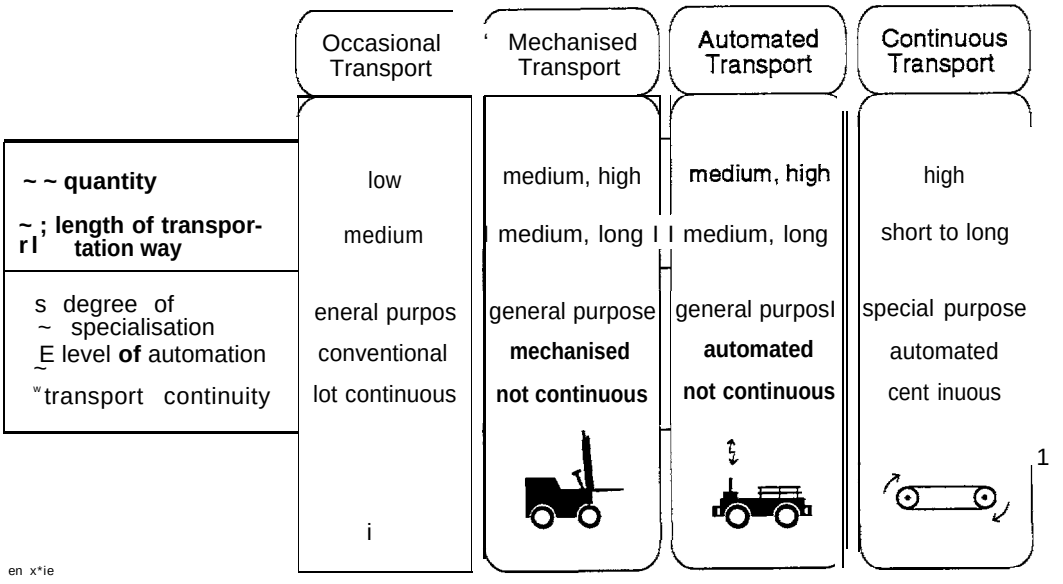
- Basic Types for production and supporting processes.
- Suitability profiies for these Basic Types.
- Combination and configuration rules for these Basic Types.

Additionally, guidelines have been developed to use these tools to describe and analyse an existing production organisation and to design alternatives for improvement.

Basic Types

The Basic Types provide an overview of the possibilities to structure the production and supporting processes. They are not meant to classify production structures but to typi@ them, to identify relevant dimensions for a design of a production structure, and to indicate extreme values for these dimensions. Typical production structures (such as a Manufacturing Cell or a Dock) identified in this way are called Production Basic Types (PBTs). Service Basic Types (SBTS) provide an overview of the supporting processes. SBTS for the eight supporting processes transport, store, process planning, production control, quality assurance, maintenance, tool management and waste disposal have been elaborated. In Figure 2 an example of the SBTS of the supporting process transport is shown.

Figure 2. Main characteristics of the Basic Types of the supporting process transport.



Suitability projiles

Each Basic Type has certain advantages and disadvantages that influence the performance of the Basic Types in certain situations. The performance can be measured by the costs, the throughput time and the quality of the realisation of the required production programme. Specific characteristics of the production programme lead to a choice for different Basic Types or configurations of Basic Types. The Basic Types can be compared mutually on their relative performance in relation to characteristics of the production programme.

In this way an overview is created of the situations in which the Basic Types realise a better or worse performance. Such an overview is called a suitability profdes of the Basic Type. For all Basic Types, such suitability profdes have been elaborated.

The suitability profile for the PBT Manufacturing Cell for instance indicates that relatively high numbers of homogeneous and similar products can be produced. Physically as well as organisationally complex products can be handled. This PBT is less suitable for production programmed with big fluctuations in production numbers and product types per time period because ceUs are designed for certain product groups.

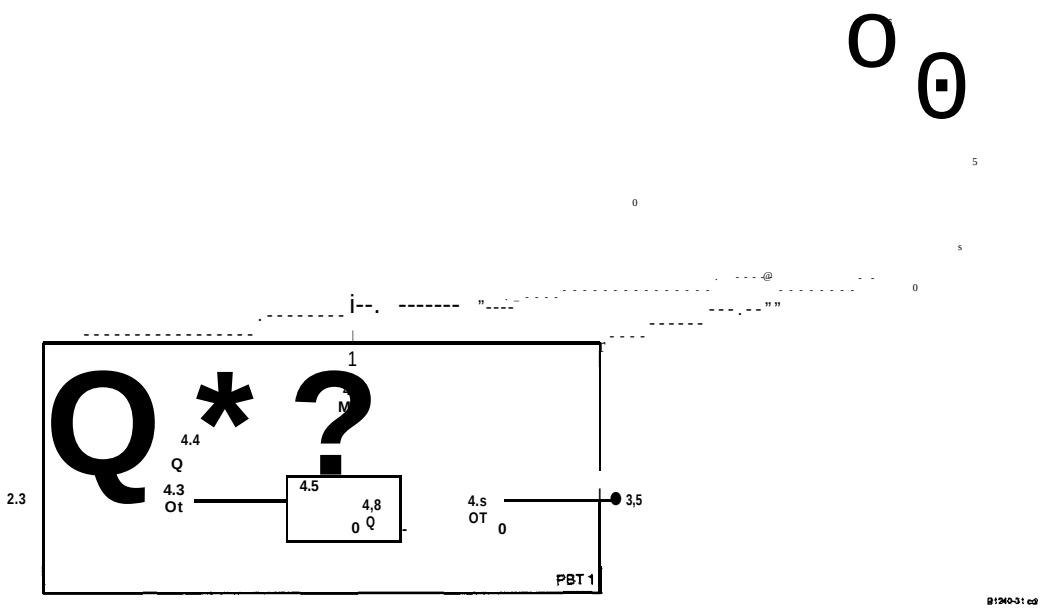
Combination and configuration rules

A production organisation usually consists of a number of production and supporting modules that are related to each other because production and supporting processes are mutually dependent. Supporting processes can be executed in two ways basically: by special departments or integrated in the production process. In the latter case a Basic Type for the supporting process is located inside the Basic Type for production (this is called a combination of PBTs and SBTS); in the former case the SBT is located between the PBTs (this is called a configuration of PBTs and SBTS). To support the design process, guidelines have been developed that give an overview of the possibilities for combinations and configurations of the Basic Types and the advantages and disadvantages given a required performance that has to be realised.

Describing, analysing and designing with the PDL

Figure 3 presents an example of a production organisation described with the PDL. A description of a production organisation is divided into different levels of detail. The highest level of detail describes the relationships between the identified production and supporting modules. The modules are characterised by means of the Basic Types but are further considered as black boxes at this level; the structure of the Basic Types gives enough information. The attention is focused on the relationships between the modules. A lower level of detail is pictured if more information on the structure of the module is required. This information may be required, for instance, for the analysis or redesign of a certain department or the description of all activities of a supporting process.

Figure 3. Example of a PDL description.



The analysis of the PDL description is made in a quantitative as well as in a qualitative way. The quantitative analysis focuses on the quantification of the various relationships. TIE qualitative analysis comprises a comparison of the production programme characteristics with the suitability profiIes of the identified Basic Types and a visual check of the descriptions. In this way, insight can be obtained in the processes of the production organisation.

Based on the comparison of the results of Step 4 of the HOPE methodology (the analysis of the production prograrnme), the product groups, and the suitability profiles of the Basic Types, PBTs are selected that seem to have perspectives for further elabomtion. The further elaboration consists of adaptations to specific circumstances in the environment for which the design is made. Restrictions of companies like available technologies and floor space have to be taken into consideration. The integration of the different supporting processes is started after the production processes have been described in a number of alternatives. Suitable Service Basic Types are selected and adapted to the spec~~c circumstances using the suitability profiles and the combination and configuration rules.

In this process the available capacity of people and means, the education and experience of the people, the influence of integration on the production performance and possible side effects (e.g. for the system of remuneration) are considered.

The result of the design process is a number of alternatives that can be compared to the existing situation to evaluate the improvement potential of each alternative. A big advantage of this procedure is that alternatives are developed starting from the level of modules in an organisation instead of individual workstations. By analogy with product modularisation, an acceleration of the design process can be achieved in this way. The documented knowledge and experience in the Basic Types, suitability profdes, and combination and configuration rules further support this process.

To obtain more information about modelling production structures with the H& see *Verweij, Rotzoli, Mutler,* 1995.

Benchmarking with Basic Types

A validation of the Basic Types and the other elements of the PDL was carried out in a benchmarking project. The concept of benchmarking to validate the PDL was chosen because the structured way in which a company is described and analysed with the PDL potentially contained many possibilities to compare the participating companies. 15 SMES with small-batch production in Germany and the Benelux participated. In the description of the production structures of these companies all the developed PBTs and most of the SBTS could be recognised. No arguments appeared to add new Basic Types to the HOPE methodology. Some SBTS could not be found because some of them, such as the SBT Automated Transport, are very seldom in small-batch manufacturing companies.

To develop a structure to analyse and compare the companies in the benchmark, a set of characteristic numbers have been chosen that provide a good overview of the production performance considering a variety of different aspects. To exclude the effects of company-specific characteristics such as product complexity or level of automation in the production, a number of explanatory factors have been developed to measure the characteristics and to be able to group the participating companies according to these characteristics. In this way, comparable companies were taken together so that it became possible to evaluate their performance.

This evaluation in combination with the analysis of the production structure descriptions led to reliable indications on the production performance of the companies.

More information about the performed benchmarking project is available in *Verwaj,* 1995 and *Tunsho~ Rotzoll, Verweij, Schr6der, 1995.*

4.5 INCORPORATE METHOD FOR THE ASSESSMENT OF PRODUC~IO~ STRUCTURES (IMAPS)

The different akernatives elaborated with help of the PDL have to be assessed before the best one can be selected and the company can start to restructure its production structure. Because traditional evaluation tools for the assessment of structures are limited to financial aspects of investments, an extended evaluation method has been elaborated within the HOPE project: IMAPS (Incorporate Method for the Assessment of Production Smctures). It considers not only financial aspects, but also logistical and human aspects. Financial figures consider the costs of investment and the savings which result from a better eftlciency of the new structure. Logistical figures take into account throughput times, quality and flexibility for product variants. The human aspects mirror the work attractiveness of the structures, for instance expressed by scope of work, level of self-organisation and qualification of employees. Some of these indicators are difficult to measure and have to be estimated by means of expert discussion. Nevertheless they have a reasonable impact on the economic performance of the production structure and therefore they have to be taken into account.

An EXCEL spreadsheet programme has been developed to support the evaluation process. It includes guidelines on how to use this tool. To link the success factors defined in Step 1 of the HOPE methodology with the above performance indicators, their mutual influence has been estimated. A matrix containing the influences of the IMAPS indicators on approximately 20 general success factors is enclosed in the spreadsheet programme. Taking into account these influences and the determined indicators, the most favorable alternative can be selected.

4.6 THE HOPE PROJECI MANAGEMENT APPROACH

The HOPE Project Management Approach has been developed to support the process of planning, guiding and controlling the implementation of a newly developed structure.

For the implementation of the new structure various projects will be created. For the definition and management of these improvement projects supporting tools have been developed. The HOPE project plan defines and describes a project in eight items. These items contain for instance financial and time aspects, detailed goal definitions and activities to be performed. With the help of the HOPE Project Management Approach the control of the projects is supported. Important in this respect are: quality control of activities and results, time control, cost control, organisation and information flow.

5. THE APPLICATION OF THE HOPE METHODOLOGY

To validate the methodology in a broad scope different end-users have been selected to participate in the HOPE project. They manufacture different products, belong to different sectors and have different production structures. The companies have in common that they are all small or medium-sized enterprises (SMES) with small-batch production. They are located in three different European countries. At each end-user the production organisation has been analysed and redesigned. The results obtained in these restructuring projects in which the HOPE methodology has been applicated will be reviewed briefly in this section.

End-user 1. The Frencken Group

The fwst company manufactures high-quality product componenfi and assemblies for manufacturers of high-tech instruments, machines, militmy systems, aircrafts and spacecmfts. These products are made in batch sizes from 1 to 100 with an average of 15 pieces. The two main plants of the mechatronic division that participated in the HOPE project both employ approximately 60 people.

At the beginning of the project the organisational structure of the company was characterised by functional departments with a high variety of routings which led to a complex production control, high organisational effort and high throughput times. The aim was to achieve a reduction of throughput times, a simpler production planning and to keep the existing flexibility to meet the customer requirements in the very short term. A detailed analysis of the production programme using the cluster analysis and the conference table method led to the decision that Manufacturing Cells could be a suitable production organisation for the plant.

To form product groups that could be manufactured in the cells, the product size was chosen as the main cluster characteristic. The machine-based sequences were so different that it was not possible to divide the products according to this often used feature. Establishing and running a pilot Manufacturing Cell led to a considerable reduction of the production throughput time by 75%. The average ratio of throughput time and processing time dropped from 7.8 to 1.5.

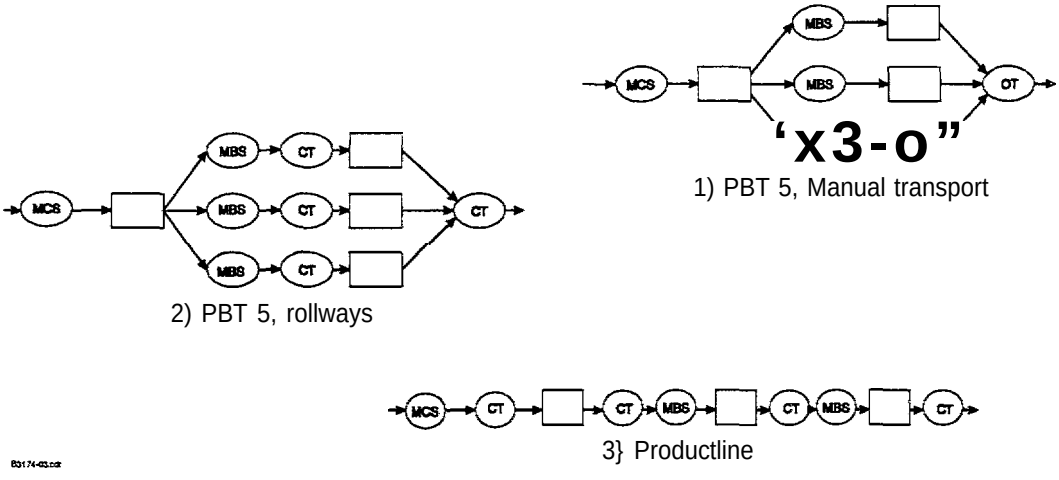
Additional changes in the organisation that contributed to these results were the integration of the supporting processes quality control, tool management, transport and production control.

End-user .2. Ets A & L Verhaegen SAAW

The second industrial company has concentrated its activities on sleeping products like mattresses, box springs and slatted boards. It employ about 180 people, 130 of them in the manufacturing department. Average lot sizes of these products are about 30 products.

Based on the results of the HOPE Analysis, the decision was made to focus the activities on the assembly department for slatted boards. The *reasons* to restructure this department were considerable problems concerning quality, flexibility and efficiency of the existing production line. The pilot project focused on harmonizing the capacity balance between the various workstations in order to fulfii customer requirements during peak seasons and to be able to work efficiently during periods in which market demands were lower. Different alternatives have been elaborated in detail and assessed (see Figure 4). As best alternative the second one has been chosen, which is a parallel flow structure with Iines suitable for different products and with rollways between the work stations. The new structure led to a decrease of the day-to-day yield and the stock levels of intermediates by 20Y0. The quality problems related to the organisation have been decreased by 25%. Furthermore, the planned delivery time for most variants could be decreased by 4070.

Figure 4. Developed alternatives for the production at end-user 2.



More information about this project carried out in this company can be found in *iVelstein, Veiweij,* 1995.

End-user 3. Windho#AG

The third industrial HOPE partner is active in several areas: transport engineering, airport equipment, water processing, construction machinery, and materials handling equipment. The company mainly produces customer-specific products in lot sizes of 1 to 10. It employs about 450 people with 60% on the shop-floor and 257a in the design department.

After the HOPE Analysis had been carried out in the whole company, the HOPE activities were focused on the production area of the construction machinery where the most possibilities for improvements were seen. Furthermore, an enlargement of the existing production programme in this area forced the company to restructure this production area. The number of products increased, whereas the number of repeat orders decreased. These changes led to an increasing effort for stocking, handling, planning and controlling. With the application of the HOPE methodology the management has been supported in its decision on how to restructure the assembly.

At the beginning of the HOPE project the assembly department was organised in a flow structure with two assembly lines. This structure is used for high amounts of products with few variants but is less suitable for different groups of products with a lot of customer-specific variants. On one of these lines two different kinds of building machines were produced: one with a lot of customer-specific components and one with less customer-speci.ilc components. Because high amounts of every type were necessary the line was used for each type for an interval of three weeks before the other type could be produced. High delivery times were the consequence. For this reason an improved structure has been implemented: Two lines were installed on which only standard products are assembled. The few customer-specific components which are still necessary are added to the products in a separate dock. The products with many customer-speciilc components are all assembled in a new dock. Quality assurance is carried out by the employees themselves to shorten the order throughput time. A new paint shop with latest environment technology was adapted to the new demands, being able to permit the painting of different colours for different building machines at the same time. This new product-oriented production structure Ied to a considerable increase of the productivity in the assembly department.

6. CONCLUSIONS

Adapting production organisations to the changing demands of customers requires a methodology that makes it possible to quickly elaborate alternative structures. The HOPE methodology has been developed to support this manufacturing redesign process. A framework with eight steps provides guidelines for this holistic task. It is characterised by:

- Being developed especially for SMES with small-batch production; it takes into account the special demands of these companies such as time and cost efllciency.

- Optimizing a production structure concerning individual company requirements expressed in comptmy-speciilc success factors.

- Being a holistic methodology considering the whole company in the analysis phase, the integral organisational structure of employees and manufacturing units in the production in the design phase, and the combination of efficient production techniques and human-oriented organisational concepts.

- Being fast with regard to the dettmnination and evaluation of alternatives, because new structures are built out of existing basic structures.

In several case-studies of companies from different sectors in various European countries the HOPE methodology has been applied. Supported by the developed tools useful analyses of the companies and detailed descriptions of the production departments have been carried out. They formed the basis for the generation and evaluation of improved production structures for the companies, optimised concerning individual company goals expressed in the success factors. Considerably better results were achieved after implementation of the developed structures. Results included a decrease of delivery time by 40%, a decrease of inventories by 50% and a decrease of quality problems by 25%.

The developers of the HOPE methodology will distribute the results and tools of the project throughout the European countries. For this reason a reference manual has been written on how to use all the developed tools.

The manual provides the basis for workshops to be carried out with interested people and for restructuring projects.

To accelerate the detection of possible improvements in a company, a database will be set up which includes production structure information of a high number of companies. With the help of this data a benchmark can be carried out very quickly to locate weak areas in the production. This benchmark can be seen as a fust step for a company towards an improvement project in which the HOPE methodology is fully applied. The work will be carried out in the EU-funded Technology Validation Project BETTI (Benchmark Tool To Improve production performance). This project will start in December 1995, immediately after the end of the HOPE project.

7. ACKNOWLEDGEMENTS

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