# A New Method for Manufacturing Engineering Projects

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## ABSTRACT

This article focuses on challenges and problems related to Manufacturing Engineering Projects conducted by students in companies, and offers a new method to address these challenges.

The goal of Manufacturing Engineering Projects will normally be to improve the operational performance in some functional areas of a company. Due to the fact that many different causes might influence the operational performance, these projects are complex by nature which is challenging. It is not obvious how such problems should be approached. Often it seems to be difficult for students to formulate a comprehensive problem statement or problem specification for a project, and to decide exactly what they should investigate. It also seems to be quite difficult to design and build feasible solutions based on their findings. Literature offers a range of different methods and techniques to run projects and to solve problems. These methods and techniques may be valuable elements, but they do not constitute a complete and sufficient methodology to deal with Manufacturing Engineering Projects. So in general there is a need for a comprehensive and systematic method which can support the formulation of a problem statement and guide the selection of investigations that should be performed in a Manufacturing Engineering Project, as well as support the generation of ideas for solutions.

At the Technical University of Denmark we have worked with the development of such a method. Based on experience from a large number of projects in companies conducted by students in the BSc. Manufacturing Engineering Study Programme, two new tools have been developed to support students in conducting Manufacturing Engineering Projects. One is a general phase model for Manufacturing Engineering Projects, and the other is a tool to support problem analysis. The latter is called a ‘Problem Hierarchy’ and it includes basic ideas from ‘Cause & Effect Analysis’ also known from Total Quality Management (TQM) and Lean Management, and from the method ‘5 times why’ which comes from Root Cause Analysis in Maintenance Engineering.

As a final step the phase model and the Problem Hierarchy are integrated into a new generic method that offers a systematic approach and seems to address the challenges.

## KEYWORDS

Problem Hierarchy, Cause & Effect Diagram, Manufacturing Engineering Phase Model, Standards: 1, 6, 7, 8.

## INTRODUCTION

A manufacturing company finds the productivity of one of their semi-automated production lines to be low overall, with the productivity level also varying too much. Therefore they have asked a group of students to look into this problem and come up with suggestions for improvements. This is a typical example of a Manufacturing Engineering Project. How can the students approach such a problem or similar problems? This paper suggests a systematic problem solving approach. But first we will take a look at Manufacturing Engineering Projects and their relationship to CDIO.

### *The challenge of Manufacturing Engineering Projects*

Manufacturing Engineering students must train and develop their professional skills by conducting real-life projects in companies. As illustrated by the example above such projects will usually focus on improving the operational performance in a specific area where the company has identified a ‘high-level’ problem in their production. The students will study the current operations, collect data, interview key employees, and suggest improvements in processes, organization and technology. A typical time frame for such projects will be 2-6 months.

Manufacturing Engineering projects are special and challenging for several reasons:

The study ‘object’ is a working company with employees and a production schedule. This leaves very limited room for performing experiments with changes of procedures or technology. In general students or consultants are bound to be passive observers. Recommendations that should improve the company’s future operation must be based on studies of the company’s current activities plus theoretical considerations and calculations. Changes of working procedures, machines or equipment, computer programs etc. are typically so expensive and demanding to implement that it is not possible to test different ideas before it is decided to actually implement them. This is a key point. It puts responsibility on project groups to ensure that suggested improvements will actually improve operations, and that the company is able to implement them. They must also convince the company about this.

In order to develop proper solutions it is necessary to fully understand all of the factors that influence the operational performance under consideration, and which of these factors it will be possible to influence. However this is quite complex since there is not a simple relationship between causes and effects in this area. Many different factors might influence an existing problem. Therefore it is difficult to decide which type of analysis a project group should perform, and how ideas for solutions could be generated.

Literature offers a wide range of general methods and techniques to support project management in different fields of engineering; e.g. Life-cycle models to support software development. Different methods and techniques for problem solving are also available. Of course such methods and techniques can also be valuable in relation to Manufacturing Engineering Projects, but there seems to be a lack of an overall method or methodology to address the specific challenges related to these projects. There is a need for a method to support the formulation of a problem statement and guide the selection of investigations that should be performed in a project and finally support the generation of ideas for solutions.

### *Manufacturing Engineering Projects and CDIO*

Manufacturing Engineering Projects are closely related to the concept of CDIO. Directly or indirectly they include aspects from all CDIO phases: Conceive, Design, Implement and Operate.

In the initial stage of a project it is necessary to analyse the current situation to fully understand the operations and the causes of the problems that the project is set to solve. This constitutes the Conceive phase.

Based on the findings from the analysis, solutions must be developed, which will represent improvements. This is a clear Design phase, and since the focus of the design will be on improving future operations it might be called 'Design for Operation'.

In general, manufacturing engineering projects conducted by students will not include implementation of suggested solutions. Implementation is a company responsibility. Therefore company managers and employees must be directly involved in the implementation of suggested changes. However, individual students from the project group will often participate, acting as consultants or student employees. The timing might be a problem - when a project is finished it will normally take some time for the company to study the recommendations, decide upon changes, and define a proper period for the implementation. Most often this will not fit with the students' study calendar, because a project group cannot wait several months after the Design phase to engage with the company again.

Although implementation is not directly part of Manufacturing Engineering Projects performed by students there is still a strong indirect relationship. The project must consider exactly what it takes to perform a successful implementation. Recommendations on how to perform the implementation should be part of all Manufacturing Engineering Projects.

The same goes for 'Operate'. Since the goal of the project is to improve the operational performance, all recommended changes must support this. A solution, which does not improve the operations when it is implemented, is not a solution at all. Therefore a project group must be certain that the desired improvements will actually occur when the recommended changes are implemented. They must also be able to convince the company that the positive outcome will happen, as this will be the basis for the company's decision on whether or not to carry out the suggested changes.

## A NEW METHOD

In the BSc. Study programme in Manufacturing Engineering at the Technical University of Denmark two tools or methods have been developed to address the challenges in Manufacturing Engineering Projects and support students. The first tool is a fairly simple and straightforward phase model for Manufacturing Engineering Projects. The second tool is a method for handling high-level problems in companies called a Problem Hierarchy. Both of these tools have showed to be beneficial in project work, but the real power appears when they are combined into a new generic method, as explained in the following sections.

***The Manufacturing Engineering Phase Model***

The phase model is shown in Figure 1

The starting point is a problem area within a company. Someone in the company sees a potential for improvements and initiates a project with the goal of finding solutions. From here, the project goes through 8 natural phases:

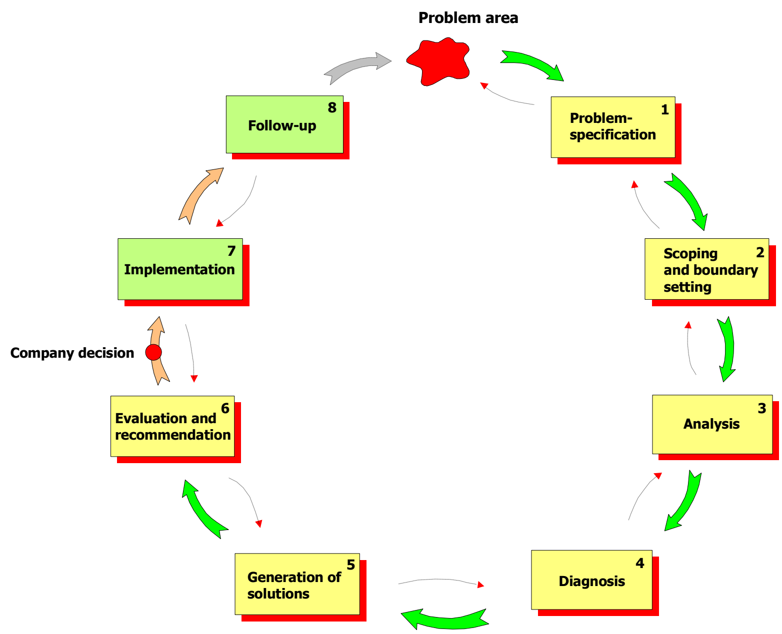


Figure 1: Phase Model for Manufacturing Engineering Projects

1st phase is a problem specification or goal setting phase. The project group must specify in detail what they want to achieve or improve during the project, and what is not included. A preliminary insight into the company and its problem area is required in order to formulate a qualified problem statement for a project. It is important to devote significant attention to this, because it forms the basis for the project's following activities.

2nd phase is a general scoping phase where company restrictions, resources and the time factor are considered in relation to the goal.

3rd phase is the analysis which is necessary in order to understand the system in depth and find out, which factors influence the results and which changes are possible.

4th phase is a diagnosis including general conclusions based on the results from the analysis conducted. This phase will act as a stepping stone for the following generation of solutions.

5th phase represent the generation of practical solutions or elements of solutions in order to fulfill the problem statement. In this phase it is necessary to be creative and explore all 'avenues' and solutions, which in any way could influence the result in a positive way.

6th phase represent a more detailed study of the solutions or elements of solutions. First it is necessary to cut down the number of solutions or combinations of solution elements from phase 5 to a small number. Second it is necessary to evaluate the remaining solutions or elements carefully. This will often include an investment analysis or multi criteria analysis. The result will be recommendation of one specific solution or a few alternative solutions. Recommendations on implementation of the suggested improvements must be part of the solution. When this phase is finished, the company must decide whether to implement the suggested solution or part of it. Of course the work must provide a sufficient amount of information as a solid basis for this decision.

7th phase is the implementation. This phase includes implementation of technical or operational changes, training of operators etc.

8th phase is a follow-up to check if the implemented changes fulfill the original project goal.

This general model is well suited for manufacturing engineering for several reasons. The phases represent a logical sequence of activities, which are all necessary in order to find good solutions to the problems at hand. The process encourages the project goal and any restrictions to be decided very early in the process, which focusses efforts in the most cost efficient way. It furthermore encourages ideas on solutions to be created not in a too early stage, but rather later on when the project group has gathered insights into the processes and is familiar with the company activities. In relation to CDIO phases 1 and 2 represent Conceive, phases 3-6 Design, phase 7 Implement and phase 8 Operate.

## COMPLEXITY IN MANUFACTURING ENGINEERING PROJECTS

### *The element of complexity*

It has previously been explained why problems in manufacturing companies in general are complex by nature. In Manufacturing Engineering Projects we need methods to support the generation of solutions that deal with this complexity. This section will describe two existing methods: 5 x Why and Cause & Effect Diagrams. Finally the Problem Hierarchy will be introduced as an enhanced method.

### *Root Cause Analysis and 5 x Why*

In Maintenance Engineering, Root Cause Analysis has been developed as a discipline. It comes from the concepts Total Quality Management, Lean Manufacturing and 6 Sigma. In Root Cause Analysis, a method called 5 times Why is recommended. It is originally developed by Sakichi Toyoda and Taiichi Ohno at the Toyota Motor Corporation. The principle here is to find the root cause of a problem by continuously asking ‘why?’ a number of times, and follow the answers. The theory states, that in this way you will always find the basic reason called the root cause in no more than 5 successive steps.

A simple example could be a machine producing too many items with errors. The first question is ‘Why is the machine producing too many items with errors’? The answer could be that the raw material does not have a consistent quality. Second question could then be: ‘Why is the quality inconsistent’? The answer to this might be that the quality is sensitive to temperature, which sometimes gets too high. The third question could be: ‘Why is the temperature sometimes too high’? and it could be found, that the temperature gets too high, when the material waits for more than a few minutes inside the machine due to stops. In this way the root course have been found in only three steps as illustrated in Figure 2.

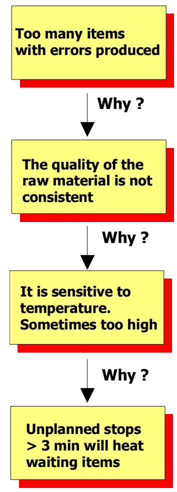


Figure 2: Example of 3 times Why

The method 5 times Why is based on the idea that for each question, we go a layer deeper and change from a more general question to a more specific one. It also assumes that there is one specific root cause, and that the relationships are simple and direct. This is true with many technical problems. But as stated above, this is not the case for operational problems in companies. So in general, Root Cause Analysis and 5 times Why, cannot be used as the sole method for solving these kind of problems.

***Cause & Effect Diagrams***

A method or principle, that actually deals with complexity in relation to problem solving is the Cause & Effects diagrams developed by Dr. Kauro Ishikawa. These diagrams are also called Ishikawa diagrams, CE-diagrams or fishbone diagrams. The idea is, that all factors that has some influence on a specific problem, are listed in a fishbone structure. Traditionally the following 'M'-factors are considered in manufacturing : Man, Machine, Measurement, Method, Materials and Environment (Mother nature) as seen in Figure 3. Often also Management and Maintenance are included. A few references could be: (Nasaaki Imai, 1986), (Melnyk & Denzler, 1996), (Frank M. Gryna, 2001), and material from CQE Academy.

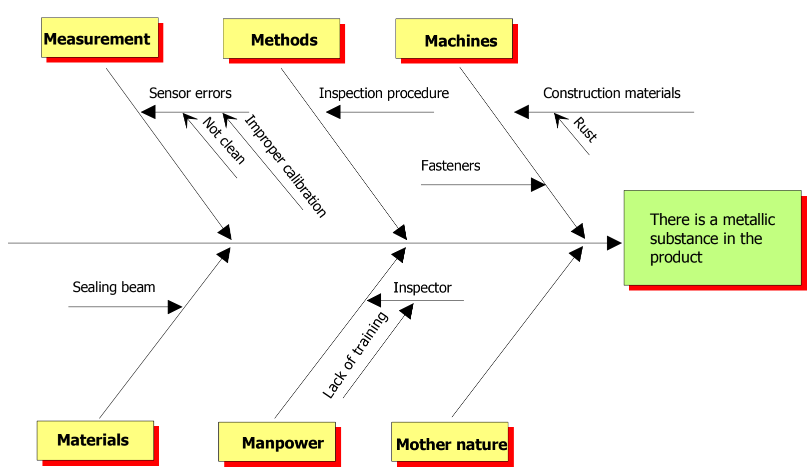


Figure 3: Example of a Cause & Effect Diagram

Cause & effect diagrams have gained widespread usage. They represent a logic and systematic approach to problem solving. But they have a few drawbacks. I will mention two:

- The use of Cause & Effect Diagrams has not developed into a consistent generic method. In literature they are typically used to solve specific individual problems like the one in Figure 3. They might be used for specific problems in a project but they are not suited as basis for a general method.

- Cause and Effect diagrams are difficult to read and difficult to draw due to the shifting orientation of lines and text.

### *The Problem Hierarchy*

The Problem Hierarchy includes logic principles from both 5 x Why and Cause & Effect Diagrams. It is developed to overcome the drawbacks mentioned above, and to function as basis for a general method for Manufacturing Engineering Projects.

A Problem Hierarchy is built up of 'problems'. The general principle states that all problems are decomposed into sub problems which could possibly influence the problem above directly, and hence could be seen as possible causes. The process starts with a selected high-level problem at the top, and it continues as long as each decomposed sub problem in the hierarchy can still be further broken down, into even more detailed sub problems or causes.

The result of this decomposition process is a hierarchy of problems with more general problems at the top, and more specific ones below. It represents a decomposition of a high level problem into a hierarchy of more and more specific problems below. Each of the lower level problems represent possible causes for the problems above. However the low-level problems in the bottom of the hierarchy are much easier to deal with than the more abstract problems at the top. They are much easier to study or to solve. That is the reason for the decomposition process.

To illustrate the process let's now go back to the general problem of productivity from the introduction paragraph. We specify the general problem: 'Productivity is too low, and it is varying too much' as the high-level problem in the top of the Problem Hierarchy. This is a rather abstract problem, which is difficult to address directly because it is too complex. Many factors could lead to low productivity and perhaps other factors are driving the issue of varying productivity. Therefore It has to be decomposed into more specific problems. Possible reasons for low or varying productivity could be inadequate production planning or problems related to operators, machines or materials. None of these decomposed problems can be handled directly since each of them may be caused by several underlying factors. Therefore they have to be decomposed further as illustrated in Figure 4.

The decomposition process continues to a level of possible problems in the bottom of the hierarchy, which can be addressed or analyzed directly. As an example, it is possible to investigate directly if the operators have got the right skills, if they are sufficiently motivated or if the quality of planning data is good.

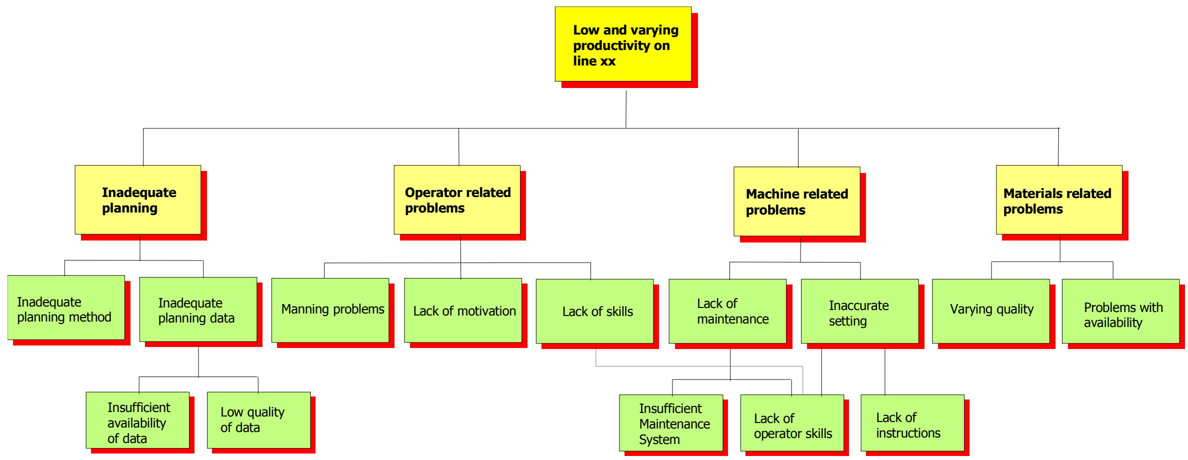


Figure 4: Problem Hierarchy of a productivity problem

A Problem Hierarchy is easy to read and understand, and it is fairly simple to work with. Of cause the text must be very short when the boxes are small. As illustrated in Figure 4, there might be a practical problem with space, when a model has many boxes in a decomposed layer, but this is easy to handle using a modern drawing program.

*The quality of a decomposition*

Can we be sure, that all important factors that influence the top level problem in a Problem Hierarchy are included? That depends on the quality of the decomposition. In principle all important factors should be included when a specific problem is decomposed. But that presumes an insight, which is not always present. If an important factor is omitted, it is not considered and decomposed further. Therefore it is necessary to be careful, and work intensively with the decomposition process. In a project, the Problem Hierarchy should be changed continuously as new insight arise.

*Hierarchy or network?*

Sometimes a specific problem in a Problem Hierarchy could relate to more than one high-level problem. As an example: Both 'lack of maintenance' and 'Inaccurate setting' in Figure 4 could be caused by lack of operator skills. In figure 4 this problem is listed as a machine related problem, but of course it is also an operator related problem as indicated. So in this case three different high-level problems are decomposed into the same lower-level problem.

If a low-level problem is allowed to relate to more than one problem above, the structure is not a true hierarchy. From a technical point of view it is a network. In a project we could handle the decomposed structure of problems as a network by drawing all relevant relations accordingly. However this might lead to a diagram, which is more complicated to read and understand due to crossing relation lines. It is much easier to work with a hierarchy. Therefore it is recommended to keep the structure as a hierarchy, and instead duplicate any low-level problems that relate to several higher level problems, and add a comment to the diagram. For simplicity we will proceed with Figure 4 in the current form.

***How to use the Problem Hierarchy in a project***

As stated earlier the Problem Hierarchy represents possible problems or causes. They are not necessarily actual problems or causes in the company. In order to find effective solutions to the top-level problem the project group must investigate which of the possible problems in the Problem Hierarchy are actual problems in the company.

The best way to do this is by using a bottom-up approach and start with the low-level problems in the bottom of the Problem Hierarchy. The reason being that these problems are much more specific and easier to investigate than the more abstract problems above.

In this way the problems at the bottom of the Problem Hierarchy act as a guideline for which analysis to conduct in the project. From Figure 4 the following investigations could be listed:

- The planning principles and analysis of OEE (Overall Equipment Efficiency)
- The availability and quality of planning data
- The availability of operators
- The motivation of the operators
- The maintenance system
- The skills of the operators
- Instructions and SOP’s (Standard Operation Procedures)
- The variations in material quality
- The availability of materials

The Problem Hierarchy can now be updated with investigations shown as ‘Investigation boxes’ as illustrated in Figure 5:

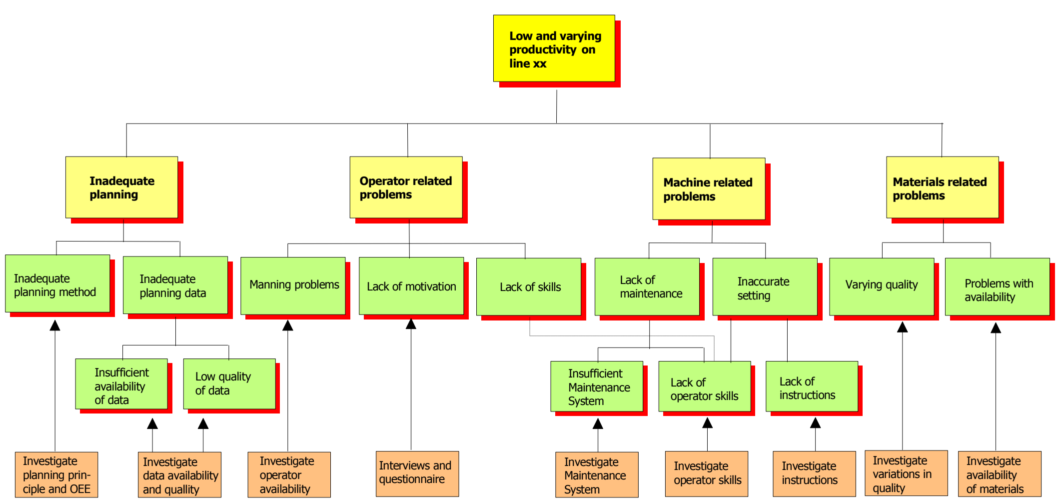


Figure 5: The productivity Problem Hierarchy with investigation boxes

When the studies have revealed which of the potential problems are actual real problems in the company these problems must be solved. Since the problems at the bottom of the Problem Hierarchy are detailed and specific, it should be possible to find and implement relevant solutions. When the actual detailed problems in the bottom of the Problem Hierarchy are solved, the logic from the decomposition process will ensure that the high-level problems are solved as well. Assuming here that the Problem Hierarchy is well developed, and all important factors are included.

## COMBINING THINGS INTO A NEW GENERIC METHOD

In a project the development of a Problem Hierarchy should be linked directly to the phase model in Figure 1. Since the problem hierarchy contains possible problems it can be generated very early in a project. In fact, at a point where the project group has not yet gained detailed knowledge about the company and the activities. It is necessary to have a solid definition of the top-level problem in order to start the process and naturally this is possible in relation to the formulation of a problem specification for the project in phase 1. Therefore the first version of the Problem Hierarchy is suggested to be developed in phase 1. From there on is should be used as a roadmap for the project and changed successively based on further insight.

In the Analysis phase the Problem Hierarchy will act as a consistent and logical guideline for which detailed studies or analysis the projects group should perform. This is supported by showing them as 'Investigating boxes' as shown in Figure 5.

Later, when the results from the analysis phase are ready, the Problem Hierarchy should be updated to show which of the possible problems are identified as actual existing problems that need to be solved. This can be done by marking the relevant boxes in the diagram. An example is shown in Figure 6. The investigations here have revealed four areas that need to be improved:

- The availability of correct planning data must be improved. Sometimes data is missing or late, and sometimes there are too many errors.
- The availability of operators is a problem. Often there are too few operators which result in too much waiting time.
- The skills of the operators are not sufficient in relation to maintenance and required setting of the machinery.
- The quality of materials varies too much. This causes stops and errors on the production line.

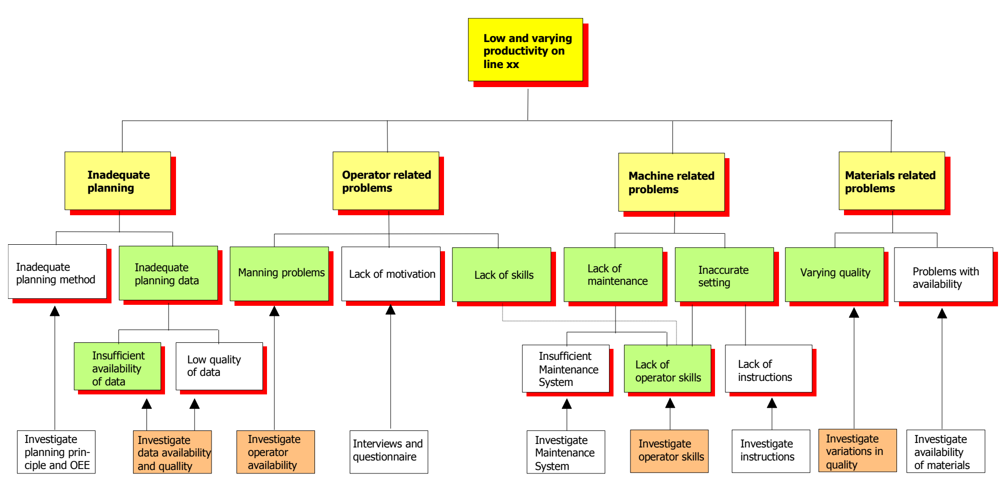


Figure 6: The productivity Problem Hierarchy with recognised problems marked

In phase 5 and 6 the Problem Hierarchy supports the generation of solutions. It gives a complete visual overview of all low-level and high-level problems that needs to be solved. This makes it easy to measure or compare ideas for solutions against these needs.

At the end of the project the Problem Hierarchy specifies which problems have been addressed through the work. It also shows the problems and areas that have not been addressed. This is important information because it could lead to identification of a need for future projects in the company.

The suggested coupling between the phase model and the Problem Hierarchy during a project constitutes the recommended generic method for Manufacturing Engineering Projects. It is illustrated in Figure 7:

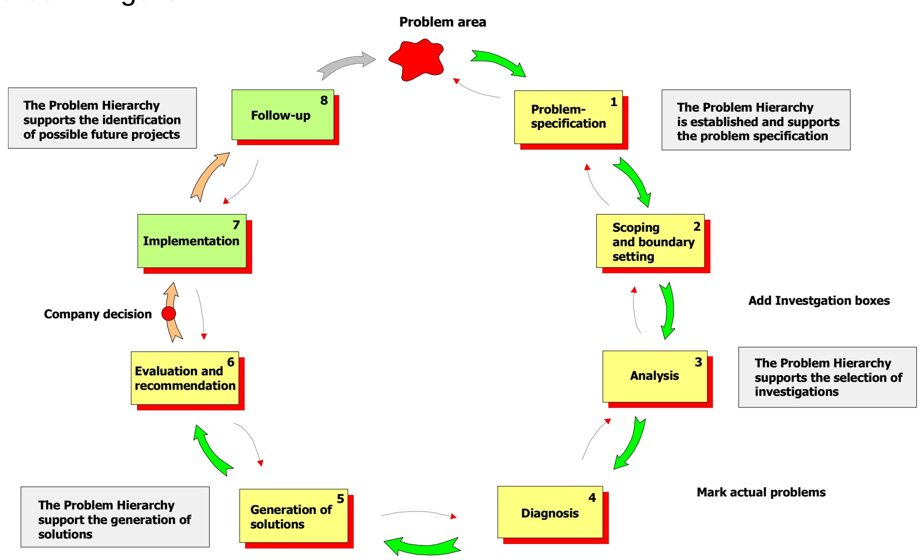


Figure 7 The Problem Hierarchy method to support project activities

## EXPERIENCES AND CONCLUSION

In the BSc. Study programme in Manufacturing Engineering at the Technical University of Denmark, students are running projects each study semester. Here they train to use their skills from the ordinary courses in a problem oriented and interdisciplinary context. During their 4th semester they are running projects in companies where the project group and a company agree upon a problem area, that has to be improved. Normally these projects will focus on improving the operational performance in some areas e.g. a production line or some business processes. Since the companies, their processes and their problems are different, these projects are quite unique as well. However we have gained some common experience over the years from these projects.

In general, the students are quite qualified in performing specific analysis in companies, but in a project context they find it difficult to specify relevant goals for the projects and decide on which analysis and investigations they must perform in order to be able to generate good solutions, as stated previously. This is even if we have been teaching the students principles on how to run projects for many years and also the basic principles of the Problem Hierarchy. We have seen this as lack of a clear methodology for such projects and consequently we have developed a new course: Scientific Theory and Manufacturing Engineering Methods focusing on methodology. In relation to this course that is taught in parallel with the projects the Phase model in Figure 1 and the Problem Hierarchy have been developed as fundamental models, and they have been integrated into the generic method for handling manufacturing engineering projects that is described in this article.

The new course has now been active over a few semesters. Since the projects are supervised by different teachers, we have not collected statistics, but the conclusion so far is that the method described has been adopted well by the students and used with success in many projects. These students find that the method actually gives them a good and consistent basis for their work. In general the method described seems to fulfill the requirements from the introduction paragraph for a generic method to support Manufacturing Engineering Projects.

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## BIOGRAPHICAL INFORMATION

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