Performance Improvement

-A Method To Support Performance Improvement In Industrial Operations

A doctoral thesis
By
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The objective of this research was to: Develop and evaluate a method which supports performance improvement in industrial operations.

This has been done through several case studies and literature research. The result is a scientifically evaluated Performance Improvement Method.

All companies strive for better performance, since a high performance level means greater competitiveness, which in turn generates more money. However, there are an extensive number of change and improvement methods described in many different research fields. Moreover, a number of issues, which are linked to these Performance Improvement Methods have been identified. The issues were summarised as criteria, which were posed on both existing improvement methods and the newly developed method, for evaluation and development purposes. The most important issues with Performance Improvement were found to be that most methods were specialist dependent and did not have competence support.

Efforts to improve performance in manufacturing operations have been important since the start of the industrialisation era. Some of the first well-known and well-documented practitioners in the area of PI were Taylor and Ford, so there have been many attempts to work with Performance Improvement.

A definition of performance, profitability and productivity is presented to show how they can support improvement work. Performance measurement is important to form a basis of facts to link Performance Improvement on. Furthermore, two models, a performance factor model and a performance measurement model, have been developed for use with Performance Improvement.

An evaluation of commonly used improvement methods such as Lean Production, Just in Time, Total Productive Maintenance, Six Sigma, Theory of Constraints and Business Process Reengineering, shows both strengths and weaknesses, which were used in the development of the new Improvement Method. Furthermore, a number of case studies were performed to give empirical input to the Performance Improvement Method for practical use. With these practical and theoretical considerations, a formalisation of the Performance Improvement Method was carried out.

The Performance Improvement Method has been evaluated through 4 full-scale case studies. The case studies showed that the new Performance Improvement Method has higher criteria support than the other improvement methods evaluated in this research.
ACKNOWLEDGEMENTS

I would like to take the opportunity to thank all those people who have contributed to this work over the years. You will always be remembered.

Dr. Stefan Tangen and Dr. Anders Karlsson, without your help this thesis would never have seen daylight. My supervisor, Associate Professor Peter Gröndahl, for the patient and never ending strive of making my thoughts crystal clear. My initial Professor Anders Arnström, who unfortunately passed away before the completion of this thesis.

My supervisors from Posten AB, Serbaz Shali, Martin Löfgren, Erika Ahlqvist and Björn Olsson for supporting this work to its conclusion. My former supervisors from the same company, Anders Carlson, Bertil Nilsson, Troels Nilsen and Bo Alerfeldt for supporting this work in the beginning and throughout times of change.

My colleagues, Lars Persson, Lisbet Karlsson, Torsten Johansson and Björn Gillefalk, who all taught me about the real world. To all colleagues at both GPT and HQ, too many, to mention all, but you have all been important to me.

To all the participants of the case studies, for making them so exciting to follow, especially Katarina Ohlsson and Lars Ax.

My fellow research colleagues in the Productivity Project for all support and good friendship over these years and hopefully over the years to come. Dr. Björn Johansson, Dr. Peter Nordell and Dr. Kerstin Johansen, colleagues with whom absolutely, smashingly and cunningly, discussions have seen light.

All my colleges from The Royal Institute of Technology, especially: Dr Patrik Kenger, Tekn. Lic. Jens Von Axelson, Martin Broman, Dr. Henric Alsterman, Tekn. Lic. Milun Milic, Tekn. Lic. Daniel Axelsson, Tekn. Lic. Kenneth Karlsson, Tekn. Lic. Niklas Tjärnberg, Magnus Sjöberg and Anders Bergdahl, for the inspiring times at Akkurat and the seminars, where many discussions and ideas were born to push the scientific limits just a little bit further. Anders Rimstedt from Gothenburg University.

Finally, my wife Sara and my two children, Matteus and Fanny, who patiently have accepted a long lost family member during the tedious writing of this thesis. Well, it seems like I finally, pulled it off.

Thomas Grünberg
EARLIER PUBLICATIONS


2. **Grünberg T.**, *Postterminalen i Göteborg har bättat sin fläskhals*, Bättre produktivitet med PLAN Nytt, nr 5, 2002


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1. INTRODUCTION

This Chapter provides a background and a motivation for this research. The problem area is also provided, together with the Objective, Sub Objectives, Delimitations and Outline of this Thesis.
1.1. Introducing Performance Improvement

All companies strive for better performance, since high performance means high competitiveness, which in turn generates more money. However, there are different ways to increase performance, depending on which viewpoint you choose to take. Academic areas such as Production Engineering, Logistics, Quality Management, Industrial Economics and Behavioural Science, provide us with performance improvement (PI) methods. Examples of methods from the respective areas are Total Productive Maintenance, Supply Chain Management, Total Quality Management, Activity Based Costing and Organisational Management. However, it is important to see through these academic boundaries to obtain more viewpoints and input to PI work. If this is done, it is believed that it could generate a better performance improvement method.

Furthermore, for this thesis, the aspects of performance improvement include numerous performance improvement methods, such as Kaizen and Business Process Re-engineering. These methods provide structured ways of improving company performance, but can have limitations, such as:

- Specialist dependency
- Not aligned with company culture
- No competence plan for staff
- In some cases too extensive

The attributes of operations, which can be subjected to performance improvement, are many, e.g. lead-times, organisation, product development, losses, machine utilisation, scheduling and inventory. To be a world-class manufacturer all these attributes need to be in a good order. This is why the area of PI is extensive and includes many academic fields. Further, PI as an activity is critical; all operations, no matter how well managed, are capable of improvement (Slack et. al., 1998). Demand and needs, are in constant change, the market fluctuates, the number of actors changes and new technology is invented; this means that a setup used by a company to meet demand and competition will, in time, become obsolete and will need PI attention.

The potential profit from successful performance improvement work is enormous and this is shown in Chapter 1.3.1 Why Use Performance Improvement; however, PI is not just something you easily implement, which is further shown in 1.3.4 Problem Description.
1.2. Retrospect of Performance Improvement

Efforts to improve performance in manufacturing operations have been important since the start of the industrialisation era. Some of the first well-known and well-documented practitioners in the area of PI were:

- Smith (1776)
- Babbage (1832)
- Taylor (1900)
- Ford (1913)

Smith described how splitting the manufacturing of pins into small well-defined steps could improve manufacturing. Babbage developed Smith’s thoughts and talked about lower wages, as work steps are simplified. Taylor talked about “best practice” and how this could be studied in a scientific manner to create improved work methods (Johansson, 1997). Ford was the father of the mass production system, which was manifested as the assembly line (Womack et. al., 1990).

Figure 1: Ford’s automotive factory Highland Park in 1924. (WWW, 2002).

Since the 1950s, competition between companies has increased and there are no signs of this ending. The increased competition creates a need for first-rate improvement methods. Before the 1950s, the competition was lower than today, one can say that all that was produced was sold.

The methods we use today for performance improvement got academic attention mainly after World War II in the US. Implementation of performance
improvement methods were, however, not completely successful in the United States.

Examples of performance improvement methods and were they came from are Total Preventive Maintenance or Total Productive Management (TPM), which came from Preventive Maintenance (PM), (Nord et. al., 1997), and Total Quality Management (TQM) developed by Juran and Deming (Bergman and Klefsjö, 1995). The performance improvement methods were however successfully imported and adopted into a Japanese way of working, most noticeably at the Toyota Company. From these theories, the Toyota Production System (TPS) was synthesised with additions of a number of derivative methods such as Kaizen, 5S and Benchmarking. As a note, the family of Toyoda were highly influenced by Henry Ford’s production system (Levinson, 2002).

It is important to note that the mass production system, developed by Ford, was not able to handle differentiated products in an efficient way. As economy were expansive during this period, the customers started to demand more differentiated products, which created a need for production systems, which were able to handle mass customisation. Earlier, craft production had a highly skilled workforce who took a long time to train and were hard to replace. With Henry Ford’s new way of production, these problems became obsolete.

American industries had difficulties with the transformation of production systems to handle differentiated products and some have still not adopted differentiated manufacturing, (Womack et. al., 1990). The Lean Production concept is a western way to describe the TPS phenomenon, which in turn was imported back from Japan, to help the transformation from mass production to mass customisation production systems

Today the West has realised that the Toyota Production System is a whole concept and not just clean and coloured light production floors. TPS also includes areas such as product design, accounting and organisation. Further, a number of methods were developed and described as a competitive counteraction to the Japanese movement, e.g. Theory of Constraints (TOC), Business Process Reengineering (BPR), Demand Flow Technology and Business Process Improvement (BPI).

All these methods have similarities in their aims, namely to improve operations, but differences in how this is accomplished exist, which will be shown later.
1.3. The Scope

To make a sound case of the research area, arguments of why and where performance improvement should be used are discussed. In addition, arguments of what performance improvement should focus on, are provided. Further, the problem description deals with the problems and issues of performance improvement today.

1.3.1. Why Use Performance Improvement

This research shows that there is a large amount of losses in Swedish manufacturing, and this is supported by others. Some people even believe that in many cases there are up to 50% losses (Janbring, 2002). For example, Johansson and Kinnander (2004) state that improvement potentials of up to 25% are possible to attain by using cheap performance improvement methods such as SAM and MTM. Furthermore, Kinnander argues that an increase of 80% is possible, if an investment is made in product development and workstation improvements. Further, Kenger (2006) show that lack of quality can stand for 30 – 40% of product total cost. Olausson states that a pilot study showed that production capacity could be increased by 14% with little effort (Bengtsson et. al, 2005). In addition, Bengtsson et. al. (2005) have shown that companies with a focused manufacturing development have a better efficiency and financial development than companies, which have used an outsourcing strategy.

Unfortunately, the need for performance improvement is often not evident before a company is in crisis. In other words, improvement work is often crisis driven, which can lead to hasty decisions such as outsourcing even if the improvement potential can be greater with PI (Bengtsson et. al, 2005).

It is important that companies keep operations efficient to gain profit over time. If manufacturing is kept in good condition performance improvement should not be very costly, as it should attain return on invested money. However, a poorly maintained manufacturing can indeed cause an entire company to collapse. The impact of efficient manufacturing as well as that of an inefficient one is great, since it affects all other parts of the company, in terms of customer responsiveness and market advantages.

Performance improvement is critical for companies to remain competitive. It is also essential to increase company performance from a national point of view as it affects welfare; this will be shown later. A company is rarely alone in a market; if a company is losing competitiveness, another company will be ready to take over. This is even more important today, due to increasing global competition.

These are reasons to use Performance Improvement at Company level.

At an aggregated, level the Manufacturing industry accounts for a large part of the Swedish Gross Domestic Product (GDP), 22% (Vinnova, 2002). This implies that
at least 10% of the GDP is a potential for decreased costs, if the improvement potential in manufacturing is 50%. This increased potential of profit can be assessed with performance improvement tools.

However, company performance is as important at a national level as it is for the companies themselves. Right after the Second World War Sweden had one of the highest living standards in the world, with an annual Gross Domestic Product per capita (GDP) growth of 2.5–3 percent. All industrialised countries had their peak years in the beginning of the sixties and have since then, never achieved those levels of growth again. Sweden however has lost more than the average industrialised country. In the beginning of the 1990s Sweden was in sixteenth place (OECD) with only Switzerland having less annual growth (Krantz, 2000).

To complicate the situation, companies are outsourcing production to low wage countries as a way to decrease costs, rather than improving their operations. This is a dangerous behaviour from a national perspective, as manufacturing accounts for large part of the GDP and many jobs are lost due to outsourcing. Wigström (2004) states that 75 000 industrial jobs have moved from Sweden in the last ten years. Fölster (2004) argues that even more jobs are lost since they are placed outside our country as they are created. Even more troublesome is the fact that direct labour accounts for a smaller part of the total product cost. Materials and overhead costs account for the bigger part, for example, Hewlet & Packard have less than 4% in direct labour cost, (Costanza, 1996). Often, reduced direct labour is the only argument for outsourcing. With PI, this outsourcing of manufacturing may be unnecessary. This implies that processes such as manufacturing and product development should be improved to get more out of performance, instead of focusing on direct labour in a short-term perspective.

Today there is a debate about Swedish industries’ tendency to outsource manufacturing to other low wage countries.

This is a dangerous behaviour if we want to maintain our welfare standard. Unfortunately, outsourcing affects the productivity in a positive way, without increasing the GDP. This occurs since the inefficient businesses are moved and the remaining manufacturing sites are the more efficient ones.

Tangen and Gröndahl (2005) states:

“Many Swedish companies are considering moving their manufacturing to low-wage countries. The reason is mainly to reduce costs. At the same time, it is a fact that many Swedish factories still look like they did in the 70s; functionally grouped machines where many of them are not in operation. We shall maybe not only discuss the pros and cons with outsourcing but also ask ourselves; Is there an improvement potential in Swedish industry? The answer is ‘yes, and it is large!’ The means is productivity improvement”

Welfare is a common concept of the status of humans in terms of economic, health, education, living and working conditions and standards. In economics,
welfare is expressed as the individuals’ economic resources (Nationalencyklopedin, 1996).

Welfare is affected by the GDP in terms of a potential welfare. The GDP in itself does not say anything about the distribution of resources among the people. However, GDP is the commonly used comparison of welfare. As an indicator of national productivity, it is a good constitute when comparing countries. The GDP is a measure of the aggregated value of commodities and services for final use (Nationalencyklopedin, 1996).

A problem with GDP measurement is different price levels and currency adjustments; hence, there are different methods for adjusting these diverging figures. The numbers used here give a clear picture of the trend and situation while other calculations give smaller differences but they indicate the same trends (Krantz, 2000).

![Figure 2: The growth rate in %; GDP per capita from 1870-1992 of Sweden compared with 16 industrialised countries. Source: Krantz, 2000](image)

In Sweden, after the Second World War, commodities and services were made available to a larger number of people. This started an economic spin-off of trade. Sweden’s production systems were not destroyed during the war and the need for steel and wood was great from countries who had participated in the war. However, even if Swedish sales increased after the War, there was a lower GDP increase in Sweden compared to other industrialised countries, see figure 2.

The industries’ ability to manufacture efficiently, affects our living conditions as it creates goods to satisfy different needs among customers and it render economic spin offs (Sohlenius, 2000). Manufacturing systems are important for the maintenance of our welfare.
From 1870 to 1950, Sweden had a greater GDP growth than the rest of the industrial countries in the world, see Figure 3. Nevertheless, in the 1950s the other countries passed Sweden. The reason for this is partly an equalising effect in comparison to the other countries. At the same time a loss in Swedish productivity occurred. This decrease occurred in all countries, but it affected Sweden more (Krantz, 2000).

The decrease in the GDP growth rate is not solely a Swedish problem but one shared by the western world as a whole. As Asia and other continents increase their productivity, their productivity growth will probably be much faster than it originally was in the West. Figure 2 and Figure 3 shows that Sweden has lost the advantage in growth rate from the fifties. This could be a result of the monetary decisions, which failed in the beginning of the 1990s. One reason for lost productivity in Sweden is the depreciation of currency over the years and a result was lost incentive for making real productivity increase instead of currency earnings (Eklund, 1992).

Hulten and Schwab (1991) have showed that company productivity has a strong impact on economic growth in the US. This relationship is apparently true for the rest of the world. This relationship shows that support for company productivity is important in order to maintain welfare through economic growth in Sweden as well as in other countries.

Sweden has moved from fourth place in 1970 to 17th place in 2001 (Tyter, 2001). During recent years, Sweden has experienced a peak growth rate regarding productivity per worked hour, which can be seen in Figure 4. Nevertheless, this increase has had a minor effect on the GDP growth rate. This could be an effect from outsourcing, i.e. reduced production in Sweden. However, the outsourcing leaves us with fewer employment opportunities.
It is important to illuminate the relationship between our welfare and companies’ competitiveness in Sweden today. It is important for both government and companies that company performance is the focus (Sohlenius, 2000). Performance improvement should be used to increase company competitiveness and increase national welfare. For company competitiveness and nation welfare, the use of Performance Improvement is essential.

1.3.2. WHERE PERFORMANCE IMPROVEMENT SHOULD BE USED

Customer value is mainly created at the operative level and it is here that PI efforts should be focused.

Much waste is initiated in manufacturing, e.g. actions performed by manufacturing that are not demanded from customers. Quality and Delivery precision are affected by an unstable production, and create waste, such as rework and scrap. Often this type of problems shows symptoms in having many routines and large administrations, which initially was needed to solve problems that no longer exist. Later, when new layouts and machining techniques are introduced, the old routines are not adapted to new situations; instead new routines are developed and put on top of the old ones.
Customer value is created in the value streams of operations. For example, Lean Production has its focus directed towards value streams of companies (Womack et al., 2003). This makes it important to decrease losses in the value streams as it has high customer impact.

A general definition of how a company is organised is provided by Mintzberg (1979) and is described here to explain where the main emphasis of performance improvement ought to be placed. Performance improvement methods attempt to find losses in the operating core. Often the routines and standards are set by the Techno structure (a division, which analyses and standardises work, e.g. PI) but the losses of these standards are measurable in the operational core. The value is created in the operative core and it is here that improvement efforts must reside, since it is here, customer value is created.

Further, Mintzberg (1979) shows that an organisation consists of different parts, Strategic Apex, Middle Line and the Operating Core. The operating core consists of operators who perform the basic work of the organisation. They are processing input into output, i.e. producing products or services. Management of the company is divided into two parts, the Strategic Apex and Middle Line management. Middle Line management interprets and executes the vision of top management and exists due to the size of the company. The Support Staff consist of functions that are not directly connected to the processing of input into output. Examples include cafeteria, cleaning, payroll and legal counsel, development, etc. The Techno structure standardises and analyses the work of others in the organisation.

Figure 5: The parts of an organisation, which forms the operations in a wide definition (Slack et al., 1998).
The value streams and operating core is important but one has to consider other factors as well, when conducting performance improvement. The activities in the value streams are controlled by many other factors, such as product design, product development and organisation, but emphasis should emerge in the value streams in operations. Performance improvement is aimed at operations, i.e. the way that organisations produce goods and services (Slack et al., 1998).

Operations management in a wide definition is what a company does. To support operations the company needs marketing, purchasing and engineering, see Figure 5. Performance improvement should be used in industrial operations to improve the value streams in the operative core.

1.3.3. WHAT NEEDS TO BE IMPROVED

Of course, performance should be improved. At the operative level, performance improvement is about identifying value streams and reducing waste. Definitions of waste and losses, e.g. downtime and rework, are included in most Performance Improvement methods.

The performance objectives used in this thesis are speed, quality, flexibility, cost and precision of operations as described by Slack et al. (1998). The reason for using these performance objectives, is that they are of a general nature and are widely accepted, see Tangen (2004). Furthermore, it is important to find the improvement factors with high impact on performance.

Company boards and management, as well as employees, have to focus on productivity and quality rather than have a strong focus on immediate return on investments only. Otherwise, the risk might be great that we destroy our welfare motor (Nicolin and Swärd, 1990).

An important factor is lead-time (according to some, lead-time is the only competitive means companies have today). Often a product’s lead-time in manufacturing accounts for the majority of the total lead-time, either as inventory or as work-in-progress. Therefore, improvement work in manufacturing has a great potential to affect the total lead-time, which in turn has a great impact on performance.

1.3.4. PROBLEM DESCRIPTION

To be able to reduce losses in manufacturing companies should use Performance Improvement Methods. However, many issues and problems are associated with performance improvement and these obstacles are important to overcome to attain the potential profit described in 1.3.1 Why Use Performance Improvement. According to Millar (1999), most problems are related to poor planning, poor measurement of improvements, and lack of understanding of the change process and lack of competence preparation. Failure of improvement programmes is extensive. A survey of 500 US companies shows that only 1/3 of the companies
experienced any significant impact from TQM programmes. Another survey showed that out of 100 UK companies, only 20% showed significant impact from initialised quality programmes. A third survey of 350 US executives showed that only 30% of BPR programmes were successful (Povey, 1998).

The reasons for these improvement failures are many. Some are mentioned here. One reason for the failure of many improvement projects is that the human element is not recognised when it comes to culture (Campbell and Kleiner, 1997). This is tied to resistance to change and lack of support for the improvement programme, which is important to obtain. Change management stands out as the most severe source of difficulty to improvement implementation (Povey, 1998).

Baines (1997) writes that one reason for failed productivity improvement programmes is that they tend to concentrate on reducing inputs rather than on increasing outputs. Most improvement methods fail to recognise the importance of a diagnostic stage (Valiris and Glykas, 1999). This implies need of performance improvement.

Further, it is important to use tools for performance analysis to pinpoint current state in order to track change. To be able to improve performance effectively, it is important to identify which factors of performance that needs to be worked with. However, factors identified in the literature are often tightly connected to separate local cases and purposes, and are therefore difficult to generalise for wider purposes.

Performance improvement can be divided into two types: day-to-day improvement and specialist improvement. For specialist improvement, consultants or specialists are often used when implementing improvement programmes such as Six Sigma. For both types of improvement, competence is required to get good results, and competence-enhancing activities are often left out.

Competence refers to issues such as operations set-up, materials flow, layout, organisation and improvement tools themselves. Most methods are for specialist use rather than oriented to be used by managers and people who want to carry out improvement in their organisation (Valiris and Glykas, 1999). The specialists are often consultants who run improvement programmes. This way of work makes implementation more difficult as there is a handover phase within the improvement programme. Courses and consultants are often inspiring but the path to implementing improvement in operations can be difficult.

Where to start and how to start is often still a question, which needs to be answered as this differs from one company to another. A problem is that consultant work methods and concepts are rarely well documented, which complicates delivery of those work methods. However, this type of improvement competence should be present in companies and should be utilised before any crisis appears. If this approach is used it would give companies more freedom of
action, since they are not forced to take emergency action to cut costs. Instead, they can invest for future.

Harrington (1998) gives a number of reasons for improvement failure such as methodology misuse and misleading reported results. Harrington (1998) further states that the negative impact of improvement on organisation was poorly defined and not considered in the implementation, and the cycle time of improvement project was too long.

Further, performance improvement should be aligned with company strategy to give further boost for improvement results. The strategy connection ensures that the improvement work does not go against commitment from management, which is another factor that is important for successful implementation.

According to Slack et al. (1998), a defined part of operations should be improvement work, see Figure 6, as there always exists an improvement potential, no matter how well managed the operations are.

Further, some PI methods do not clearly give support to decisions on which performance issues to improve; and when it comes to practical measurement of these factors, there is little support, often since many methods depend on specialist handling. In the performance literature, there are often numerous measurements listed, which easily gives a very static approach as operations are far from static in its demands and needs.

According to the Productivity Project description, detailed in the next Chapter, there has been less attention put on performance and productivity issues at the operative level since the 1970s, which has lead to a need of competence in this area of improvement engineering.
An important part of improvement is implementation, which indeed is difficult, e.g. due to organisational resistance. Unsuccessful implementation of improvement programmes are numerous as was seen above. Approaches to handle organisational resistance, such as leader commitment, do exist in different methods. However, implementation does fail and needs to be restarted or terminated for different reasons, such as specialist dependency.

Consultants are often used to initiate improvement programmes, which makes the companies dependent on those consultants. Furthermore, the reason often is, that they often have a complete improvement program to implement but culture and methods already in use by the company are often not taken into consideration and this can jeopardise the actual implementation. However, consultants have an advantage in that they are not bound by company culture, which gives them freedom to act. On the other hand, consultants are expensive and this can hinder smaller companies from investing in a performance improvement program. This could be overcome with methods, which can be implemented without specialist help. It is one aim of this research to develop a specialist independent improvement method.

A model developed by Bessant and Francis shows that organisations can be categorised into five levels of maturity regarding continuous improvement (Bessant and Francis, 1999). It is important to identify which methods that are suitable for the different levels of maturity. If this is ignored, there is a risk that the improvement work will fail.

Dabhilkar has shown that many investigated Swedish companies have a low improvement maturity, which was shown in a survey (Bengtsson et. al., 2005). This shows both that there is improvement potential and that there are companies in need of improvement methods appropriate for their level of maturity. Further, Von Axelson (2005) describes numerous ways to classify organisation improvement maturity; one example is:

- Strategic
- Systematic
- Sustainable
- Extensive
- Learning
- Values

Von Axelson (2005) further states: “To be able to develop methods and tools it is important to understand the context and environment”. This implies that it is important to consider what prerequisites a company has before choosing a performance improvement approach. This is also supported by Herron and Braiden’s (2006) method for deciding this.
Ljungström (2004) presents six criteria, which he uses to evaluate some improvement methods:

- No or small structural changes
- Easy to understand
- Usable directly in daily work
- Fast results
- Possibility to evaluate economic benefits
- Involves all personnel

These criteria imply that improvement work should be performed hand in hand with the value stream and overall strategic goals. Further, the people who work in the value stream should be involved with the improvement methods used, which should be easy to use on a daily basis. This requires competence from both leaders and workers, which takes time to obtain, but when achieved it will contribute greatly to the implementation of performance improvement.

McKee (2003) summarises characteristics of productivity tools, which should be fulfilled to make an effective tool:

1. It should include performance goals, objectives and timetables.
2. It should declare its values about what constitutes efficient organisational performance, e.g. a desired future state.
3. It should address rewards, which reinforce values, goals, timetables and purpose.
4. It should be structured in the form of an integrated set of tools, which lend the consistency and coherence necessary for sustainable change.
5. It should provide information about external benchmarks, exemplary practices, useful improvement tools, customer satisfaction and measured progress towards the performance objectives.

In summary, the following list is an overview of the problems found, which this research aims to make less problematic:

- Specialist dependent

Specialist dependency often makes improvement work fail. Many of the improvement methods used, see Chapter 5 Performance Improvement, are difficult to use, which creates problems for companies aiming at performance improvement. The methods normally include too many specialist aspects, such as statistics or routing planning issues. For an improvement method to be fully understandable for non-specialists, it must be adapted to the specific companies’ improvement maturity level. If an improvement method is understandable for non-specialists, it should alleviate progress of improvement work. Further, if a specialist method is used, it is difficult to explain improvement suggestions and
results for those affected, so they understand suggestions and results in
the same manner as the improvement derivers usually do. This problem
also creates more problems, i.e. if a method is heavily specialist dependant
it would probably affect the support and implementation aspects. Non-
specialists and blue-collar workers should be treated the same way.

• Lack of support
  Many improvement methods imply new ways to work and often, all new
  ways are issued for implementation simultaneously. This implementation
  strategy has drawbacks such as; organisation can feel a loss of control.
  This can make organisation resistance too high and make the whole
  improvement programme fail. Improvement methods used should be
  compatible with existing ways of work, i.e. if there is a functional quality
  work, do not implement a new one to override the present work, focus
  on the parts missing or not working.

• Competence
  Many methods do not include a competence plan to increase knowledge
  about intended new improvement methods. This need for competence
  regarding improvement work is often neglected, which further can fail
  improvement work. If competence regarding problems and solutions are
  increased, acceptance can more easily be obtained.

• Implementation
  If an improvement method has lack of support and lack of a competence
  plan, it can make implementation difficult. Further, even if a method has
  support and a competence plan, implementation can be difficult to
  execute. There is often another set of people making implementations
  than the ones that found the improvement areas. Furthermore, the
  specialist dependency can also fail implementation of improvements.

• Measurement
  A method that does not build on measurements often suffers from vague
  problem descriptions. This in turn, can create ad hoc solutions that do
  not solve any problems, as the problems from start were not well defined.
  Further, if improvement is not measurement supported it is difficult to go
  beyond discussions with improvement work.

• Choice of improvement object
  Many improvement methods do not clearly imply what to improve. For
  successful improvement work, it is important to address correct objects
  to improve, i.e. objects with improvement potential. Furthermore, if
  choice of improvement objects is clearly pointed out it is easier to start an
  improvement work.

The list above was used to create an evaluation basis, which is used to formulate
the criteria listed in the following section, Chapter 1.4 Objective. The criteria
should be seen as list of requirements for improvement methods to be fulfilled to avoid the problems listed above. If this is done, it should increase ability to implement performance improvements. The most important criterion for improvement work is specialist dependency, as this correlates to the improvement maturity level at companies. If the improvement maturity level is low, specialist methods will probably fail to generate results. The specialist problem also affects other areas as organisational support and implementation support.

1.4. Objective

The objective emphasises that a desired result is wanted. The objective of this research is to:

   Develop and evaluate a method, which supports performance improvement in industrial operations.

To be able to evaluate the results of the developed method, a number of evaluation criteria are listed here. The criteria are derived from the problem description above, which show the common problems associated with performance improvement.

The evaluation criteria:

- C1: It should be usable by non-specialists
- C2: It should be competence enhancing
- C3: It should be implementation supportive
- C4: It should be based on performance measurements
- C5: It should be supportive regarding choice of improvement object
- C6: It should not act against organisational resistance

It is believed that if a developed method gives good results regarding these criteria it would be a good contribution to both academic and industrial community regarding performance improvement. Further if these criteria are fulfilled it would fill an academic gap in the improvement methods reviewed here. In addition, it will fill an industrial need for structured improvement methods that is easy to use at an operative level.
1.5. Sub Objectives
To split the objective into smaller parts, a number of Sub objectives are used and they are listed here.

SO 1: Define a research problem addressing Performance Improvement
This objective is about defining a relevant research problem, i.e. to find a problem, which is generally accepted by both industry and academia.

SO 2: Define measurements of Performance, which fit PI
As described by the Productivity project, see context in Chapter 2.1 The Research Context, there is an aim to develop productivity measurement guidelines. This sub objective adapts that aim to this research.

SO 3: Describe and evaluate existing Performance Improvement methods with respect to the criteria
This Sub objective should provide with information on other performance improvement methods, thus forming the frame of reference for this thesis.

SO 4: Design a Performance Improvement Method that meets the criteria
When designing a performance improvement method it is important that the method actually meet the needs from the problem description. This implies that the new method should be designed in respect to the derived criteria.

SO 5: Evaluate how well the developed method meets the criteria
This Sub objective deals with the quality of the developed method and connects to the evaluation of the method.

1.6. Delimitations
The area of performance improvement is extensive as it deals with issues from all aspects of company activities. This includes knowledge from literally all scientific areas, e.g. Medical Science in the form of Ergonomics, Behavioural Science in the form of leadership, organisation and job satisfaction, and Mathematics in the form of Statistics. Of course, not all of these areas can be covered to a complete extent in a work such as this, so the focus is on issues such as definitions and measurement of performance. Furthermore, focus is on improvement methods and the use of these. However, during this research, some areas have shown to be important and therefore will be recommended as areas for future research.

The area of product development and product design is not covered in this thesis, as focus of the thesis is performance improvement at an operative level. However, Product development and Product design has great influence on operative performance and should be considered in performance improvement attempts.
Change management is an important part of improvement work, as a large part of improvement is about changing attitudes. However, this aspect is not included here since it is improvement methods that are analysed.

An evaluation of which type of business that certain methods are applicable for, is not made since this is not covered by the scope of this thesis’s. However, there is a brief discussion on this matter to show that there are differences in methods. Some recommendations are given in the future research section since this should be a relevant research area in itself.

1.7. Outline Of This Thesis

This thesis consists of eight Chapters. The logical connections between the Chapters and the Sub objectives, written papers, methods used and courses taken are shown in Figure 7. The papers contribute knowledge to the different Chapters, e.g. the problem area and the analysis of improvement methods. The papers and reports, present results used in this thesis, see the list of earlier publications, page III. Furthermore, a compilation of scientific methods which have been used and where they have been used is shown in Figure 7, see more for methods in Chapter 2 Research Approach. The Chapters, which correspond to each Sub Objective, are also shown in Figure 7. The results, which correspond to each Sub objectives, are thoroughly discussed in Chapter 8 Conclusion and Critical Review, as a part of the evaluation of the scientific quality of this research. For courses taken, see Appendix.
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Figure 7 A description of the research outline with methods, Sub Objectives along with thesis contents.
2. **RESEARCH APPROACH**

This Chapter provides considerations of scientific theory and research methods applied in this thesis. A description on how the research has been conducted and the Research context is found in this Chapter.
2.1. The Research Context

This research is a part of a larger research project called Productivity Development in Manufacturing Systems, which started in the year of 2000. The project was started in order to increase knowledge about productivity and its improvement, measurement and control. The aims of the project were:

- Change industries’ view of productivity
- Develop productivity improvement methods for industrial operations
- Identify factors influencing productivity
- Develop measurement guidelines to measure productivity
- Combine industry and academia work together for synergy effects

Three areas of Productivity Management were initially defined by the project members, namely Pre-engineering, Manufacturing and Logistics, see Figure 8.

Figure 8: A map of Productivity Management, the particular research areas and the participant affiliations.

This project has included a number of participants from academia and industry, see Figure 9.

However, most of the work has been carried out by five Ph D Students and their works were concluded in the following doctoral thesis’s:

- Collaborative product introduction within extended enterprises, 2005 by Kerstin Johansen, Flextronics, LiTH, Proper.
• On Virtual Development of Manufacturing Systems - Proposal for a Modular Discrete Event Simulation Methodology, 2006 by Björn Johansson, Chalmers, Proper.
• Evaluation and revision of performance measurement systems, 2004 by Stefan Tangen, Woxéncentrum, Proper, KTH.
• Set-up based operator training method in automated manufacturing, 2007 by Peter Nordell, SKF, Chalmers, Proper.
• This Thesis by Thomas Grünberg, Posten, KTH, WoxénCentrum

Figure 9: The participants in the productivity project.

2.2. How This Research Was Conducted

The approaches of Operations Research, Actions Research and Case Study Research form the path in this research, see later in this Chapter. The approaches consist of four phases, which have been adapted here: Problem Definition, Frame of Reference, Proposed PI Method and Evaluation of Method, see Figure 10. Applied research uses elements from both theoretical and empirical areas of science. This is beneficial for validation purposes, as it gives several sources of input to work with.

The first phase of this research was to formulate a relevant research problem and this was directed by both the aims of the productivity project and the aims of this research. The problem definition was made through literature studies and discussions amongst the participants of the Productivity project. The literature studies concerned the relevance of the research project. Given the problem area,
both theoretically and empirically, an objective of the research linked with Sub objectives could be formulated, see Chapter 1.4 Objective, this corresponds to Sub objective 1.

Figure 10: A general description of the research’s empirical and theoretical parts together with analysis and synthesis work.

The second Phase comprised gathering both theoretical and empirical knowledge, which form the frame of reference concerning definition of performance, measurement and PI methods, corresponding to Sub objective 1 and 2. Further, explorative case studies regarding PI were carried out to gain more empirical knowledge of Performance Improvement. The literature study in Phase 2 concerned Performance measurement and Performance factors, which were synthesised to performance factors.

The third Phase included the proposal of the actual PI method, which was derived theoretically and empirically from literature and case studies performed in Phase 2. The literature study concerned PI methods. Sub objective 3 is linked to this phase.

The fourth and last phase consists of the evaluation of the new Performance Improvement method, which corresponds to Sub objective 4. The evaluation is made against the criteria presented earlier.

Throughout all four phases, an approach of analysis and synthesis, has been used, see Chapter 2.3.6 Analysis and Synthesis.
2.3. Scientific Methodology Applied In This Research

The purpose of this Chapter is to form a vocabulary for the researcher, to enable a description of how the research has been conducted. Further, it gives the researcher methods and approaches to organise the research project in a scientific manner. In addition, it describes and explains the results derived from the research for validation purposes.

The methods and the theoretic considerations described here are used in the Chapter 7. Case Studies, and Chapter 8. Conclusion and Critical Review for Validation Purposes. Further, it has formed the work path of this research as described in Chapter 2.2 How This Research Was Conducted, see the different scientific parts described in the sections 2.3.1 Operations Research, 2.3.2 Action Research and 2.3.3 Case Study Research.

Science etymologically comes from the Latin word scientia meaning having knowledge (Webster’s dictionary, 2002). In Swedish, science, (Swe. vetenskap) comes from German, wetenskap (Swe. kändedom), (Eng. having knowledge).

Science is organised knowledge, as an activity a systematic and methodological retrieval of knowledge within a specific area (Nationalencyklopedin, 1996). However, the above definition of science is not sufficient without documentation since scientific results must be possible to be refuted for validation purposes. Therefore, a suggestion is that the definition should be reformulated as:

\[ \text{Science is organised knowledge, as an activity it is a methodological retrieval, documentation and validation of knowledge within a specific area.} \]

For example, social Science differs from Natural Sciences in the sense that the natural sciences have higher repeatability, meaning that an experiment or examination can be done several times, with the same results. The Social Sciences usually do not have high repeatability, i.e. the researchers must explain, interpret and document their investigations and experiments more thoroughly for others to be able to interpret and validate the results in the same way as the researcher does.

Engineering Science has aspects of both high and low repeatability issues, e.g. development of a new machine has high repeatability whilst developing a new type of organisation has low repeatability. If an experiment produces different results at different times, the experiment has low repeatability; if an experiment produces same results at different times, it has high repeatability, see Figure 11.

This implies that engineering research projects with low repeatability need more focus on method description compared to higher repeatability engineering research projects. The classification of analytical, system and actors approach is not fully appropriate since this research uses elements from all three approaches.

Measurements of, for example lead-times and cycle times, could be treated in an analytical way, if the measurements are regarded as isolated from, e.g. the
organisation. However, in operations, there are spin-off effects, which creates non-measurable effects and the scientific approach of the Systems view could be applicable. Of course, the researcher also has impact on the results, which is the main issue of Action Research.

![Figure 11: The relationship between repeatability and variety of results which, increases difficulty to validate results as repeatability decreases and variety of results increases.](image)

2.3.1. **The Operation Research Approach**

Research within the disciplines of Economics and Operations includes a large portion of measurement and analysis and interpretation of collected data are important to consider. In Operations, a number of easily measurable affects give easily measurable effects and intangible effects. In addition, there can be intangible affects, which give traceable effects and intangible effects, see Figure 12. However, this has an impact on low repeatability research projects as causes and results must be interpreted. This is a common effect and the researcher has to build models and argue for their validity. Taylor and the Scientific Management School can be considered as the root of Operation Research (Bertrand and Fransoo, 2002). This was not, as the name implies, a science, but a systematic way to study managerial problems. After the Second World War, Operation Research started to take on the form that we can see today.

A traditional approach in Operation Research constitutes the following steps (Simon et al., 1996):

- A statement of the problem
- A review of the literature
- Construction of a hypothesis
The collection of data using questionnaires, interviews and experimentation
An analysis of data to test hypotheses; and
Conclusions and implications consistent with the production and analysis of the generated data

These steps are used throughout this thesis, except for the step of formulating a hypothesis. Instead of a hypothesis, an objective is used.

Figure 12: Traceability of affects and effects.

Today, the Operation Research approach is divided into three phases (Simon et al., 1996). Phase 1 consists of crucial concepts using a variety of means such as literature review, participant observations, interviews and content analysis of relevant documents. In phase 2, the research is elaborated through open-ended non-standardised interviews. Phase 3 consists of data gathering using appropriate measuring instruments.

More detailed, Bertrand and Fransoo (2002) describe the approach this way:

- Identification of process or problem assumptions
- Identification of types of operational process and decision problems considered
- Developing operational definitions of the operational process and the decision system
- Derivation of hypothesis regarding process behaviour
- Development of measurements system
- Results of measurements and observations
- Interpretation of data and observations in relation to the hypotheses
- Confirmation and/or rejection of the theoretical model assumptions
Again, in this research, there is no hypothesis formulated. Instead, an objective is formulated and used in the same way as the hypothesis is described here. Otherwise, this research project is intended to follow the Operation research approach and this is validated in Chapter 8 Conclusion and Critical review.

### 2.3.2. Action Research Approach

Action Research has several different approaches within the discipline. The bearing is that this research has many human interactions. The Action Researcher is present in a complex, ever changing and interacting world. As the researcher is a part of this world, he/she has an effect on the results derived from the research.

![Diagram of Action Research Approach](image)

**Figure 13:** Factors constituting the organizational work setting (Adapted from Porras and Robertson, 1992).

For the natural scientist, it is not possible to work with fixed variables in real life situations. The setting to be studied is built up from several interacting variables, see Figure 13, so concern regarding the whole is a necessity. As stated by Kaiser (19xx) the natural scientist and the engineering scientist is involved in real life
situations, leaving him or her in a situation of considerable complexity. The Action Research approach is formed for this type of research.

One major difficulty of Action Research rests in the defensiveness of human beings, their ability to produce self-fulfilling and self-sealing systems of action and justification, often with patterns of escalating error (Reason, 1994).

Ideas on Action Research arose in the 1940s from the psychologist Kurt Lewin. He wanted to find a research approach, which would help the practitioner. Lewin was convinced that even if there were serious ambitions to solve practical problems, there was little understanding of how to do this. Most attempts to solve problems did not come any further than the planning stage (Westlander, 1999).

A brief description of Lewin’s ideas is condensed in Kurt Lewin’s two dicta “In order to understand something, try changing it” and “There is nothing as practical as a good theory” (Porras and Robertson, 1992).

Chein (1948) showed different approaches, e.g. the diagnostic and the participatory approach. In the diagnostic approach, the researcher makes an analysis and then hands over the results to the client to act on. A participatory approach is made when the researcher is working with the client and with the implementation.

During the 1970s, Sanford was critical to Lewin’s idea of the researcher having the power to formulate the problem. Sanford meant that the actual cooperation between the researcher and client should be more articulated.

Today Action Research has developed more towards full partnership with the client. This is called Participant Action Research and the most distinguished feature of this approach is the researcher’s full involvement with the client in all phases of the change project.

In Interventions theory, there are different steps, which can be utilised. Intervention theory has emerged within the Organisational Development (OD) field. The following steps are included, according to Porras and Robertson (1992):

- Client selection
- Entry
- Contracting
- Formulation of an ideal model
- Diagnosis
- Designing alternatives
- Goal selection
- Planning
- Action/intervention
- Monitoring and evaluation
- Institutionalisation/stabilisation
The researcher has indeed been involved in all steps of the research reported in this thesis. The involvement has been of full partnership.

2.3.3. Case Study Research

Three main case study approaches exist according to Yin (1994):

- Exploratory
- Explanatory
- Descriptive

All three types of case studies have been in use during this research project. The exploratory case is usually performed early in a research project and the main aim is to formulate the problem. Explanatory case studies are, as the name implies, used to explain and answer “how” research questions. This is usually used to explain issue such as “How did George W Bush win the presidency?” The descriptive approach searches for causality links and tries to answer questions such as “How presidencies are won?” The case studies in this research are of all three types, exploratory to find input to the research, explanatory to see certain outcomes, and descriptive in the evaluation cases as it is a method that should be evaluated. However, the evaluation of this research is made in an explanatory way.

A drawback with case studies, according to Simon et al. (1996), is that the case study is largely descriptive and usually only describes positive aspects and generally does not analyse issues. However, the method in itself is not the problem. Instead, it is the researcher’s responsibility to avoid these obstacles, which should be done by using an explanatory approach in the evaluation phase.

A case study usually contains the following phases (Yin, 1994):

- Define & Design
- Prepare, Collect & Analyse Data
- Analyse & Conclude Results

The definition and design step consists of problem and theory formulation. In the next step, the actual case studies are performed and the preparation of the case studies and analysis of the cases are done. The last step is analysis and synthesis of the case study or studies, and conclusions are drawn.

2.3.4. Observation

For a sufficient method description for this research, a word on the subject of observation is needed. Much effort has been put into the subject of knowledge, epistemology, since Greek philosophers, first defined their thoughts on knowledge. An important aspect of science is observation. For an observation to be mediated, a language and a theory connected to the observation are needed. The theory and the language specifications affect and limit the observation. As shown in Figure 14 the observation itself can make explanations difficult.
As stated, the observation requires intermediation. In the scientific world, written language is mostly used. Further, an interpretation of the observation is made. There are two important historic views of this interpretation: phenomenology and hermeneutics (Ekman, 1981). These are important notions for action, case study and Operations Research, since the researcher often affects results, both directly with interpretation and with interaction.

The observation is tightly connected to data collection and there are different sources for this (Yin, 1994):

- Documentation
- Archival records
- Interviews
- Direct observations
- Participant observations
- Physical artefacts

Some sources of observation are hard to measure and interpret, which is tied to the repeatability of the investigations, see Figure 11.

2.3.5. **LITERATURE RESEARCH**

Literature research is normally done early in an Operations Research process right after the problem has been defined or even before that. The purpose is to clarify the problem and to see what other attempts have been like (Routio, 2002). Literature research is an on-going activity throughout the research mainly for updating purposes and validation of results.
Talking to other people is an important input to formulate a problem description (Eberle, 1999). A way to formalise the literature research is to provide information on which sources that have been used. This is found in the reference section. Information regarding databases and keywords which have been used, can be provided if needed. Numerous literature reviews have been forming the frame of reference in this thesis, see figure 7.

2.3.6. ANALYSIS AND SYNTHESIS

Two important parts of a research project are the analysis and synthesis of data. According to an analytical view, each part of a system can be considered in isolation from each other, which needs high repeatability. This is not the case of a systems approach, since the different parts of a system affect each other in a not always predictable way, i.e. low repeatability. However, analysis is needed to divide a large problem into smaller manageable parts. Awareness of the problem of cross-relationships between analysed parts is important.

The other important phase of research is the synthesis. The meaning of synthesis is that different units are put together to form a whole, the parts usually come from an analysis. This is a natural way to work since the researcher, after an analysis, has decided which analysed parts are relevant to use when forming a new concept. The analysis and synthesis process are used throughout this thesis, see Figure 10.

2.3.7. VALIDITY AND RELIABILITY

The descriptions of methods given here are of course of a generalised nature and it is difficult to classify a conducted research to a specific research genre. As stated earlier a common classification of research methodologies are the analytical, the systems and the actors approach (Arbnor and Bjerke, 1994). However, this is mostly a historical classification, where the case study approach makes no distinction between these views.

The methods have much in common but emanate from different research areas and do, historically, have different assumptions. However, it seems as if a convergence between the views has taken place and the concerns about basic views of the approaches are mostly of historical interest.

According to the systems view, a validation of the results is made by using multiple sources (Arbnor and Bjerke, 1994). In practice, to make a validation, the researcher must look for multiple sources of evidence for each of the important elements (Stuart et. al, 2002). This can be made by literature research, case studies, interviews, observations of the research object, and publications.

In this type of research, with low repeatability, validity and reliability are as difficult as in the Social Sciences. However, a discussion should be included in the documentation, according to Ejvægård (1993), that points at the validity of the
results and reliability of the measurements. Arnbor and Bjerke (1994) argues that the scientific view affects this possibility to prove validity and reliability, i.e. that the actors approach does not support this validation process. Instead, the actor researcher argues for acceptance amongst the actors. Acceptance in the research community is an important way to validate the results and methods.

Reliability deals with how appropriate a measurement or an instrument is for a specific problem, e.g. is the case study method suitable for evaluation of improvement methods?

For an issue to be valid it is demanded that it is reliable, but the opposite is not true, i.e. an issue can be valid and unreliable but not reliable and invalid. It is noted that validity models only implies truth, i.e. a subject can be validated and found to be valid but it can still be untrue.

The presentation of academic articles is a way to test the quality of methods used and assumptions made in research. This is a judgement made by other researchers in the area and provides some information on validity and reliability.

This research has been validated trough these principles of acceptance, multiple sources and unambiguous results from the case studies.

2.3.8. The Academic Paper

The academic paper as we know it today was introduced in the 1660s. This happened at the same time at both The Royal Society in London and at the Academie des Sciences in Paris (Stromholm, 1984). Earlier, this form of scientific discussion was carried out by letters between scientists, but over time, the number of scientists grew too large for this type of discussion to be effective. The purpose of the academic paper is to spread research results and to get refutations on the results, for validation purposes.

A scientific thesis usually has a list of relevant publications of the research results, to show that the papers have been refuted. This is a way of providing information of where the research earlier has been refuted. Further, for validity purposes the academic paper is used in this thesis.
3. DEFINING PERFORMANCE MEASUREMENT

The terms Performance, Productivity and Profitability are explained in this Chapter. Moreover, how they are linked to Efficiency and Effectiveness are described as well. The opposite of PPP, waste is discussed.
3.1. Introducing Performance

For improvement work, it is crucial to measure, since the measurements create a foundation of facts to work with. Furthermore, measurement is a means to set goals, track changes, follow improvement progress and give feedback on the improvement actions. In terms of performing measurement, it provides understanding and measurements, which are as crucial for improvements as for understanding, (Whiting, 1986). Further, according to Slack et. al. (1998) all operations need some kind of performance measurement as a requisite for improvement.

However, measurement and improvement regimes are often built without a clear understanding of what is being measured or improved (Tangen, 2005). It is therefore, in this thesis, first necessary to explain some of the most commonly used terms within this field, such as performance, profitability and productivity (PPP). Unfortunately, these three terms have many different definitions and meanings to different people and are often confused with each other. To ease understanding and make the terms accessible for improvement work, a presentation of definitions and the relations between the terms and how they can be measured are made in this Chapter.

Furthermore, it is important to have in mind, when dealing with measurement, that it is the measurement we are dealing with and not the system itself. Measurements can give understanding of a system, and if used in the right way, it can be a powerful tool to describe a system. Further, it can be decisive when it comes to decision making. Many measurement systems are designed for maximisation and this can be counter productively. A well-known system the Nature never maximises, it optimises and this, according to Johnson and Bröms (2000), is the explanation behind Toyota and Scania’s success as they strive for optimisation and not maximisation.

3.2. The Triple P Model

An effort to create a terminology on the subject of PPP has been done by Tangen (2005), which resulted in the Triple P model see Figure 15. This model gives a basis for the meaning and linkage between the terms used in this thesis.

In short, productivity is the central core of the Triple P-model and has a rather straightforward operational definition of productivity as the relation between output quantity (i.e. correctly produced products which fulfil their specifications) and input quantity (i.e. all resources which are consumed in the transformation process). It is argued here that even though it is difficult to measure different quantities by the same standard, the concept of productivity is purely a physical phenomenon and must therefore be defined as such. Profitability is also seen as a
relationship between output and input. However, the influence of price-factors (i.e. price recovery) is included in this monetary relationship. Performance is the umbrella term of excellence and includes profitability and productivity as well as other non-monetary factors such as quality, speed, delivery and flexibility. The two terms effectiveness and efficiency are cross-functional when it comes to the other three terms. Effectiveness represents the degree to which desired results are achieved; Efficiency represents how well the resources of the transformation process are utilised (Tangen, 2005).

![Figure 15: The Triple P Model showing the relations of the terms Performance, Profitability, Productivity, Effectiveness and Efficiency, (Tangen, 2005).](image-url)

### 3.3. General Measurement

The next question to deal with is how these terms can be measured. An often used distinction is to separate overall and partial measures. The overall measures are of a general kind and can be used as indicators of trends, such as the number of units manufactured per month. However, with these measures it is difficult to get information on specific issues, due to the lack of detailed information. The partial measures, on the contrary, give detailed information on single issues. However, one should keep in mind that these measures do not say anything about the whole picture. In conclusion, it is therefore necessary to use a combination of different types of measures as well as on different hierarchical levels in order to support the improvement activities correctly.
Performance profitability and productivity can be described as a company’s ability to provide customer value. As PPP is often described as ratios, the generic description would then be summed up as\(^1\)

\[
\frac{\text{customer value}}{\text{resources}}
\]

However, this ratio is difficult to put to practise and needs to be reworked to fit improvement work.

PPP measurements can also be used to focus on certain problem areas, which need improvement. The influence of a measurement system is extensive, but it can be difficult to predict behaviour affected by a measurement system. It is important to be aware of these effects as they can lead to sub-optimisation. To avoid sub-optimisation one has to balance the specific measures used. An example of this can be if cost is used as a single measurement, this can lead to difficulties with quality due to cheap but defective components. To avoid this, a flexible measurement system must be used, which can easily be changed if undesired behaviour is gained from the measurement system.

Another common problem with measurements of operations is not what can be measured, but to reduce the list of measurements to measure desired attributes of operations (Neely et al., 1995). Tangen (2004a) argues that a large number of performance measures increases the risk of information overload; it becomes difficult to know which performance measures should be prioritised. This is usually a problem in operation projects, where the practitioner has an overload of measurements to choose from and it is a problem to decide which measures that is relevant for a certain problem.

### 3.4. Performance Measures

As described by the Triple P model, performance is the widest term compared to the others and covers both overall financial and operational aspects. Performance can be classified into five characteristics as shown in Figure 16. These characteristics describe a company’s abilities to compete and meet customer expectations. Further, companies often use these performance characteristics to define strengths and weaknesses. Identified weaknesses of course need attention in the form of improvement to increase competitiveness.

---

\(^1\) As defined by the Productivity Project, see research context Chapter 2
The five performance characteristics are:

**Speed**: This performance characteristic describes how quick a delivery can be performed.

**Quality**: This is how a company meets customers’ perceptions about products/services, and technical quality as well as defects.

**Cost**: Price to customers and internal production cost are described via the performance characteristic of cost.

**Dependability**: This describes stability in the processes to deal with delivering goods and services at the right time.

**Flexibility**: Finally, the flexibility characteristic deals with how a company reacts to changed demands and requirements of both customers and the line of business.

![Diagram](image)

Figure 16: Performance characteristics (Slack et al, 1998).

Furthermore, the performance characteristics have two sides, one internal and one external. The external side focuses on customer aspects such as price and delivery times. The internal reflects the company aspects such as throughput and technical quality. For example, costs are internally treated as labour, material supply and energy costs, and externally it is price to customers. Delivery is internally dependent on reliable processes; externally it is a result from delivery to customers. This also connects to the terms of effectiveness and efficiency, see section 3.7 Effectiveness and Efficiency.
These five characteristics can also be linked to different types of performance measures. Such measures are used here as aggregated overall measures, suitable for monitoring and goal setting. Examples of these performance measures are given in Figure 17.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Customer query time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Order lead-time</td>
</tr>
<tr>
<td></td>
<td>Frequency of delivery</td>
</tr>
<tr>
<td></td>
<td>Throughput time</td>
</tr>
<tr>
<td></td>
<td>Cycle time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quality</th>
<th>Number of defects per unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level of customer complaints</td>
</tr>
<tr>
<td></td>
<td>Scrap level</td>
</tr>
<tr>
<td></td>
<td>Warranty claims</td>
</tr>
<tr>
<td></td>
<td>Mean time between failures</td>
</tr>
<tr>
<td></td>
<td>Customer satisfaction score</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flexibility</th>
<th>Time needed to develop new products</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range of products/services</td>
</tr>
<tr>
<td></td>
<td>Machine change over</td>
</tr>
<tr>
<td></td>
<td>Average minimum/maximum capacity</td>
</tr>
<tr>
<td></td>
<td>Time to change schedule</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost</th>
<th>Utilisation of resources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Labour productivity</td>
</tr>
<tr>
<td></td>
<td>Added value</td>
</tr>
<tr>
<td></td>
<td>Efficiency</td>
</tr>
<tr>
<td></td>
<td>Cost per operation hour</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dependability</th>
<th>Percentage of orders delivered late</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean deviation from promised arrival</td>
</tr>
<tr>
<td></td>
<td>Proportion of products in stock</td>
</tr>
<tr>
<td></td>
<td>Average lateness of orders</td>
</tr>
</tbody>
</table>

Figure 17: Some performance measures classified according to five performance characteristics (Slack et. al. 1998).

When it comes to performance improvement, it is important to connect the activities to performance measures and set targets, which should be achieved,
based on the strategy of the company. According to Ljungström (2004), it is important to support Continuous Improvement at a strategic level as well as to give the Continuous Improvement work strategic direction to maintain positive effects. This is also true for generic improvement work. In this way, it is possible for all participants involved in the improvement to work in the same direction. If the improvement work is well established at all company levels, all resources can more easily be focussed on the same targets and objectives. If improvement goals are connected with strategy goals that could in turn fuel up the performance-objective results, see Figure 18.

The goals used in strategic work should not be formulated in absolute numbers, since they are used for guidance, whilst objectives should be formulated in real numbers, e.g. Hewlet & Packard has the goal to maintain leadership in high technology and the objective is to introduce a number of new products every year. The goals and objectives are often linked to a company’s mission, which is the fundamental reason for a company’s existence (Barney and Griffin, 1992).

Another issue is that company strategy can quickly change due to fast market changes, but the investments made at the operative level are often set for many years (Skinner, 1969). In practice, this means that PI objectives have to be in agreement with those in charge of the processes that are subjected to improvement. Further, a continuous contact between all parts in the PI project must be taken. This could be of good help in the implementation phase.
3.5. Profitability Measures

For improvement purposes, profitability measures can be used to see if the improvement actions have desired results, since in the end the purpose of business is to make money. However, the profitability measures must not be confused with productivity measures, as profits can be gained from monetary effects such as inflation, devaluation and currency effects, regardless of performance and productivity effects. In fact, a company can increase its profit and at the same time decrease productivity as long as product prices increase. Of course the opposite can occur.

Profitability can be defined as:

\[
\frac{\text{revenue}}{\text{cost}}
\]

Profitability will be the same thing as productivity if the output and input are translated into physical units. However, Bernolak (1997) suggests that the difference between profitability and productivity ratios could be explained by the basic theoretical difference between the two concepts. That is, productivity is output volume per input volume; profitability is output volume times output unit price over input volume times unit costs, or in other words includes monetary units:

\[
\text{productivity} \times \frac{\text{unit price}}{\text{unit cost}} = \text{profitability}
\]

The linkage between productivity and profitability is further described as price recovery, which is the same as unit price/unit cost (Miller, 1984).

The measurements of profitability can be seen in financial reports as various ratios. A couple of examples will be mentioned here as they complete the picture of PPP.

Cash flow is a comparison of how the cash amount differs between two points in time. This measure momentarily indicates if the company is profitable or not. The basic profitability ratio is defined as revenue/cost, but other profitability ratios exist. A common profitability ratio is Return On Assets (ROA), which is calculated by dividing net income by average total assets. Return On Investment (ROI) shows profit in relation to the investment and the Return Of Sales (ROS) indicates profit in relation to sales.
3.6. Productivity Measures

The simplest definition of productivity is:

\[
\text{Productivity} = \frac{\text{output}}{\text{input}}
\]

However, the question is what the ingredients of the formula should be when measuring productivity. The name productivity implies that it reflects a company’s production ability. Furthermore, these measures usually show the utilisation of the production processes. Nevertheless, the utilisation of a production process is important to improvement work, since the aim often is to reduce waste, see section 3.9 Waste. Moreover, productivity measures are more focused than the five characteristics of performance.

There are many different examples of productivity measures used in companies and organisations. These measures are used both for monitoring and development of daily operations as well as for long-term strategic considerations of the business. The productivity measures can broadly be divided into three categories (Hannula, 1999, Stainer, 1997):

1. Total productivity
2. Total factor productivity
3. Partial productivity measures

These three categories of productivity measures are hierarchically arranged where the first category describes productivity from an overall point of view, while the last one relates productivity to a specific type of resource. A total productivity measure is an aggregated ratio of output and all input factors. The output is often expressed as invoiced units sold. The typical total productivity measure could be expressed by (Hannula, 1999):

\[
\text{Productivity} = \frac{\text{output of all products sold}}{C + L + E + M + Q}
\]

Where:

- C = Capital inputs
- L = Labour inputs
- E = Energy input
- M = Material inputs
- Q = Miscellaneous inputs

If outputs and inputs are expressed in monetary units, the productivity needs to be calculated with deflated factors. However, this value makes productivity measures similar to profitability.
A similar, but not as comprehensive as the total productivity measure is the total factor or the value added productivity measure. This productivity measure is defined as (Hannula, 1999):

\[
\text{total factor productivity} = \frac{\text{value added}}{\text{labour + capital}}
\]

However, this measure is based on monetary units, which has its disadvantages. Some of the inputs may be excluded depending on the kind of industry.

The partial productivity measures have quite many appearances. In the general form, partial productivity is the ratio of one single output to one single input (Hannula, 1999, Stainer, 1997). Examples of partial productivity measures are:

- \( \frac{\text{product or service produced}}{\text{labour hours}} \)
- \( \frac{\text{product or service produced}}{\text{machine hours}} \)

Other typical partial productivity measures can be (Johansson, 1967):

- \( \frac{\text{production volume}}{\text{number of employees}} \)
- \( \frac{\text{production volume}}{\text{hour}} \)

A major advantage of partial productivity measures is that they are simple to understand and to measure in real life (Tangen, 2003). A strength is the possibility to design specific measures for smaller areas, functions or divisions in a company. The responsiveness for these kinds of productivity measures is good, meaning that it may be possible to pinpoint a specific problem with a partial productivity measure. Total productivity measures do not have this ability. On the other hand, partial productivity measures do not cover all operation areas or cost categories of a company. It is therefore necessary to combine total and partial productivity measures in order to get a good picture of the company.

Monetary units are often used in the productivity measures as output and input factors. However, it is difficult to include monetary units in the productivity ratio so that productivity is properly reflected. The major drawback with monetary units in the productivity measures is that they need to be deflated, i.e. adjusted for price changes. This involves difficulties when calculating the measures. In fact, an approximation of the price changes needs to be used to make handling of the
calculations practical. Many researchers, for example Wolff (1990), Lofsten (2000) and Edgren (1996) point out this problem and recommend adjusting for price variations of the input factors when calculating productivity. Thus, the price-changing problem is a source of error for productivity calculations. Edgren (1996), states that monetary units should be avoided in productivity calculations to measure true productivity. For improvement work, it is strongly recommended that monetary units are kept separate from the productivity ratios and instead used as profitability measures.

In addition, a mixture of monetary and physical as well as only physical measures (hours, kg, pieces, kWh, etc) is in use in industry.

**3.7. Efficiency And Effectiveness**

In general terms, Efficiency means ‘doing things right’ while Effectiveness means ‘doing the right things’. This dualistic view is needed since high efficiency without high effectiveness is no good. An example of this is that the efficient production of concrete lifejackets is probably not too effective, and should surely give negative profitability results.

Effectiveness can be seen as how well a set of results is accomplished, while efficiency reflects how well resources are utilised to accomplish results (Sink and Tuttle, 1989). In conclusion, if high values of both effectiveness and efficiency are achieved, performance, productivity and profitability will be high.

To link the terms effectiveness and efficiency to performance the following can be used:

\[
\text{performance} = \frac{\text{effectiveness}}{\text{efficiency}}
\]

However, this ratio is not intended for use in calculations, it is intended to explain the relationship between the terms described here. This ratio implies that effectiveness is connected to customers and efficiency is connected to internal company performance.

A way to measure efficiency and effectiveness in manual assembly is presented by Jackson and Petersson (1999):

Effectiveness could be measured as:
- Time due to difficult operations
- Walking time
Efficiency can be measured as:

- Rework
- Idle time
- Speed losses

Efficiency and effectiveness measures in form of time losses and waste will be described in more detail in the sections 3.9 Waste and 3.8 Time measures.

### 3.8. Time Measures

The advantage of time is that it is easy to measure. Time can be used to express productivity as (Jackson and Petersson, 1999):

\[
\text{productivity} = \frac{\text{total value added time}}{\text{total lead time}}
\]

According to Tangen (2004b), there are difficulties with this measure as it is difficult to conclude what value adding time really is, however this must be made from definitions. The total lead-time, on the other hand, is easy to use for improvement purposes, as improvement actions should affect lead-time in a positive way.

Examples of different lead times, Olhager (2000):

- Product development lead time
- Delivery lead time, from customer order to delivery
- Manufacturing lead time or throughput time
- Inventory lead time
- Purchase lead time

These measures are useful for visualisation as they are easy to understand and facilitate the sharing of knowledge. Furthermore, lead times can be used to define a Customer Order Decoupling Point (CODP). This describes a relation between delivery lead-time and total lead-time and can be related to a physical point in the manufacturing site. If the delivery time is shorter than the manufacturing lead-time, the company must use an inventory to satisfy their customers. If the manufacturing lead-time is the shorter one, the company can use this to produce directly to customer order.
3.9. Waste

Everything we try to measure includes waste to some extent. This waste can be defined as the difference between the actual outcome and the ideal potential outcome from a process, e.g.:

\[
\text{actual lead time} - \text{ideal lead time} = \text{waste}
\]

The activities and results from not doing the right things in the right way is waste. Waste is defined, as actions done that have no positive effect on the finalisation of products, e.g. non-value-adding operations. Improvement work is about reducing waste to make processes more efficient and effective to increase performance, profitability and productivity.

The Toyota Production System uses a number of categories to divide waste within production. This way of viewing manufacturing came along with Just In Time (JIT) thinking during the 60s in Japan (Womack et. al., 1990). The 7 + 1 sources of waste are described according to Liker (2004):

- Transport or conveyance, unnecessary WIP
- Inventory, excess WIP in inventories
- Movement, unnecessary walking, reaching, looking etc
- Waiting, lot delays, materials shortage, etc
- Overproduction, producing unordered items
- Over processing, taking unneeded steps to process items
- Defects, producing defect items
- Unused employee creativity

Examples of ways to measure this waste are (Liker, 2004):

- Lead-time, total time spent in manufacturing system
- Value added ratio: Value added time / Lead time
- Travel distance of the product
- Travel distance by people

Measurements of waste are covered by the terms of Performance, profitability and Productivity described earlier.

Another approach to measuring waste in connection to machining resources is Overall Equipment Efficiency (OEE). Here waste is defined as losses and is displayed as time utilisation of machine resources.
OEE offers a categorisation of three types of losses (Nakajima, 1992):

1. Downtime losses:
   - Failures
   - Set-up

2. Speed losses
   - Idling
   - Reduced speed

3. Defect losses
   - Process defects
   - Reduced yield

Quality rate is measured in %

These six losses are measured at an aggregated level as:

\[ \text{OEE} = A \times P \times Q \]

Where:
- \( A \) = Availability, calculated by Total time – Downtimes – Set-up
- \( P \) = Performance efficiency, calculated by Total time - availability - idling – speed losses
- \( Q \) = Quality rate, calculated by Total time – availability – performance efficiency – defects.

Availability measures how well a resource is utilised in terms of downtimes. Performance efficiency measures how well a resource is used in terms of planning and demand. Quality rate measures the yield in terms of scrap and rework. OEE is a part of the method Total Preventive Maintenance, which supports change and improvement of resource utilisation. This method will be described in more detail in Chapter 5.2.1 Total Productive Maintenance.

This Chapter provided background for performance measurement; how it can be used for performance improvement is described in Chapter 4 Performance Factors and Process Measurement.
This Chapter describes performance factors and how they could be linked to process measurement and improvement.
4.1. Performance Factors

To ease improvement work it is suggested that performance factors, should be used. A model of performance factors, which influence the performance of operations, is presented and the factors should work as a guide to show areas of waste and losses. This is especially important when involving non-specialist workers in improvement work, as they probably will need more support than well-trained specialists do. This is one of the criteria in Chapter 1.3.4 Problem Description.

Further, to support improvement work it is vital to find performance factors that are aligned with the performance strategy used by the company. Since many improvement methods do not provide help on where to start, a proposal is presented to support practitioners in their improvement work.

A literature survey carried out for this research showed that many performance factors were too dedicated to specific cases. On the other hand, many of the factors are very general and include several other factors. Logistics for example is mentioned by Waters (1999) and Bilberg and Alting, (1994). However, Logistics includes factors such as lead-times and material flow. Logistics as a factor is tough to improve, as Logistics need to be decomposed into smaller factors.

Other authors such as Ong (1997) and Gunasekaran and Cecille (1998) have their performance factors tightly connected to the specific case study described in their articles. Ong (1997) concludes that two major areas; improvement time and company’s budget, are of importance while working with improvement of a company’s productivity and quality. Gunasekaran and Cecille (1998) found some important performance factors in their case study, such as bottlenecks, layout and material flow. These factors were adapted for the respective cases since they were suggested for improvements specific to the respective company. Further, Baines (1997) gives some examples of common factors, which are dealt with in companies, such as restructuring organisation and redesigning products and processes. Bilberg and Alting (1994) found in their case studies that performance factors could be divided into categories, see Figure 19. Their approach was developed from ten different case studies and they have developed a more general approach than other authors have.

Elimination and reduction of waste is important in the attempt to increase productivity (Pettersson, 2000), (Slack et. al., 1998). For example, one of the three key issues in JIT is elimination of waste (Slack, et. al., 1998). Pettersson (1991) gives examples of productivity factors in his case study. These factors are substantial but the factors are connected to only one case.
Waters (1999) presents the most extensive performance factors with the following categorisation:

- Strategic decisions
- Tactical decisions
- Operational decisions.

However, this categorisation only includes the manufacturing processes but omits the product design’s impact on manufacturing performance.

An economic approach gives the CLEM (Capital, Labour, Energy and Material) categorisation (Heshmati, 2000). Inputs to manufacturing are in general decomposed into the traditional elements of capital, labour, energy and material. These elements are of a very general nature and give clues on what to approach in improvement work.

The factors in Figure 19 form the basis for the performance factor model presented below. Further, the performance factors are categorised into four categories. This categorisation is not an attempt to sort the factors into the correct categories nor is it an attempt to mention all possible factors. The purpose is to guide practitioners to find and analyse potential improvement factors and above all provide a starting point for the improvement work.

---

Figure 19: List of performance factors synthesised from the literature survey.

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The factors in Figure 19 form the basis for the performance factor model presented below. Further, the performance factors are categorised into four categories. This categorisation is not an attempt to sort the factors into the correct categories nor is it an attempt to mention all possible factors. The purpose is to guide practitioners to find and analyse potential improvement factors and above all provide a starting point for the improvement work.
The categories used are process, resources, product and control. The *process* factors concern matters such as shop-floor logistics, cycle-times, bottlenecks and factors regarding the company’s processes. These factors mostly affect speed and precision. The *product* category deals with product design, design for assembly and product variety. Customer quality and assembly efficiency could be affected by these factors. The product can be used to increase performance with improved product design. *Resource* is about the people and machines that are used for the transformation of service/products in operations. A factor in this category could affect, for example, flexibility and technical quality. To control operations, administration and financial functions are used. To affect cost, these factors could be suitable because of the financial impact generated from the category of *control*.

![Figure 20: Model of factors influencing the performance of operations.](image)

In addition to the factors found in the literature there has been a contribution of factors to all categories, such as absenteeism in resource and prognosis in the control category. These factors are derived from case studies in this research that have shown to be of importance to improvement works.

The factors can affect each other and the outcome of this is not always predictable, e.g. if improvement is implemented in the factor of utilisation this can affect lead-times. This, might be problematic since not all effects are desired. The same improvement in utilisation, as above, can for example give overproduction. Some factors have a short impact time, while others take a long time before any results are retrieved, e.g. cycle-times give effects as soon as the change is implemented, while an organisational change’s positive effects may not materialise for well over a year. This varies from case to case and time, but it is important to keep this in mind.
Further, the model can provide a good picture of a specific manufacturing site for feasibility purposes. As companies constantly change due to changing demands, the performance focus must be changed to reflect the real situation. The factor model can then be used in the analysis work, to meet new demands. The factor model can also be used as an analysis tool to describe how a company’s performance is connected to the factors. This has successfully been done in a Master thesis project performed at Posten (Börselid and Jensen, 2001). Further the factor model can be used to prioritise, e.g. from the strategic performance objective goals, decisions can be derived, of which category, to search for relevant factors. When an appropriate category is chosen, one should use Pareto analysis to decide which factor that should be chosen for improvement. This way of working could give high impact on the improvement work conducted by practitioners.

A disadvantage of the model is that the categorisation of the performance factors can be discussed in terms of where the separate factors should belong. However, the categorisation is intended to sort the many factors as a way to give clarity to the great variety of factors, which should provide guidance.

4.2. Evaluation Of Factors

These factors should be evaluated and assessed to see if there is any improvement potential that can be found, i.e. “are there are any problems within this factor”. However, for a more thorough analysis, measurements should be used, see Figure 21 for suggestions of measurement for the respective factors. To assess the factors a description is needed, e.g. to assess organisation it can be described with an organisation chart. Further, the measures and descriptions are examples of how the factors can be monitored and evaluated. This can of course be done in several ways.

The factors marked with * are also used in process measurement described in the next section.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Explanation</th>
<th>Measure or Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late deliveries</td>
<td>Backlog of production.</td>
<td>% failed deliveries</td>
</tr>
<tr>
<td>Lead times*</td>
<td>Time, between two physical points in operations, e.g. from a loading platform to customer delivery Can be used to form CODP</td>
<td>Time</td>
</tr>
<tr>
<td>Bottlenecks</td>
<td>This is a constraint in the production and needs control in terms of capacity and tact</td>
<td># of bottlenecks</td>
</tr>
<tr>
<td>Material flow*</td>
<td>Flow of material per time unit</td>
<td># of moving ones</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottlenecks</td>
<td>This is a constraint in the production and needs control in terms of capacity and tact</td>
</tr>
<tr>
<td>Material flow*</td>
<td>Flow of material per time unit</td>
</tr>
<tr>
<td>Inventory*</td>
<td>Material stored in inventory and buffers</td>
</tr>
<tr>
<td>Transport*</td>
<td>Materials and goods transported in operations</td>
</tr>
<tr>
<td>Cleanliness</td>
<td>This is an assessment of the orderliness within operations</td>
</tr>
<tr>
<td>Integration</td>
<td>Describes how the resources are physically connected.</td>
</tr>
<tr>
<td>Volumes</td>
<td>Number of units produced during a time interval</td>
</tr>
<tr>
<td>Layout</td>
<td>Connected to integration and describes how the layout supports uncrossed, short and effective flows</td>
</tr>
<tr>
<td>Tact times*</td>
<td>Customer demanded capacity need.</td>
</tr>
</tbody>
</table>

**Resource**

| Organisation | Describes how well the organisation supports efficient manufacturing. | Organisation chart, \# of people |
| Utilisation | Describes how well resources are used. | OEE |
| Efficiency* | Describes how well resources are used. | OEE |
| Maintenance | How many emergency repairs are made | OEE |
| Scheduling | How are the jobs scheduled, do they support small batches and levelled production close to customer | Batch size |
| Reset times | Set-up times between jobs. Do terms such as Internal and external reset time exist. | Reset time |
| Work methods | Describes how structured work analysis methods are used and spread. | |
| Absenteeism | Employee sickness | \# of days / time |
| Capacity* | How many units can resources produce | \# of units / time |
| Ergonomics | Are the workstations ergonomically designed | \# of bad operations |
| Motivation | Are the workforce motivated to meet demands | Attitude |
| Competence | Do the employees know their job well | Competence charts |
| Satisfaction | Are the employees satisfied with their work | |
| Accidents | Number of accidents | \# of incidents |
| Scrap & Rework* | Yield of manufacturing | \# of parts per million |

**Control**

| Development | Development of processes, products, resources and technology | Planning plans and development |
| Visualisation | Are the operations visualised by work descriptions, is it possible for workers to follow operation progress in real time, storage | Which factors are visualised |
4.3. Process Measurement

To form an easy and relevant concept of measurement to use in improvement work, a process model is synthesised. As the performance factor model should be used as a feasibility tool, the process model on the other hand supports which measurements one should use. Furthermore, the model also supports process mapping (Grünberg and Karlsson, 2002). The results from this model are later used in the Performance Improvement Method described in Chapter 6 The Performance Improvement Method.
Improvement work should include process measurement, to get actual performance status of the improvement object to be studied. The measurement is also vital in order to follow progress of the improvement work.

The characteristics of the process model are Process, Total Lead-time, Waste, Input, Output, Capital, Labour, Energy, Parts per Time Unit and Information. These characteristics are also found as performance factors described in Chapter 4.1 Performance Factors. For PI, perhaps the most important factor in the process model is waste, since it is the causes for this waste, that PI work aims to reduce or avoid. Of course, the other components have losses as well, which should be addressed with PI. If waste is reduced, there should be significant changes of the other elements of the measurement model.

A short total lead-time affects the possibility to be flexible, to keep inventories down and work-in-progress low. Short lead-times give freedom of action to work with quality. Waste and losses in processes can be monitored with lead-times.

The term information includes planning, control of the process such as materials handling, and production scheduling. Capital and energy deals with costs and are suited for benchmarking purposes.

Labour defines the efforts performed by personnel.

Large processes have longer lead-times than small processes, since more preparation and planning are required which naturally take more time. This even includes identical processes that only differ in size. The number of parts per time unit is needed to complement the lead-times for this reason.

Figure 22: The generalised process model.
In non-service processes, there is *material in* and *material out*. The *Process* is where the transformation takes place. In service operations, this stage usually consists of transformation of information. However, there is still an input to and an output from the process.

The process model can be linked to the PPP model in the following ways:

- Productivity and performance are ratios, which measure the relation of output and input. Lead-time and parts per time unit also correlates to productivity and performance.
- Profitability links to the same ability but includes monetary units and is also affected by capital, labour and energy in terms of costs, but also in terms of pricing.
- Efficiency and effectiveness link to the process, lead-time and non-value adding time.

The reduction of waste in manufacturing processes affects the results of productivity and performance (Grünberg et al., 2002). However, this work should start with measurements and to measure the process model factors a number of performance factors should be measured to describe a process for improvement work, see Figure 23. These factors are also found in the performance factor model, which has been described in Chapter 4.1 Performance Factors.

The measurements of factors used to describe the process model are:

<table>
<thead>
<tr>
<th>Process part</th>
<th>Explanation</th>
<th>Measure figure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity</strong></td>
<td>Recourses ability to produce</td>
<td># of units / time</td>
</tr>
<tr>
<td><strong>Tact time</strong></td>
<td>Which number of units resources that should be produced connected to customer demand</td>
<td># of units / time</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>Resources broken so they cannot be used</td>
<td>OEE</td>
</tr>
<tr>
<td><strong>Scrap</strong></td>
<td>Products with such poor quality that products have to be thrown away</td>
<td># of parts per million</td>
</tr>
<tr>
<td><strong>Rework</strong></td>
<td>Produced goods with quality errors that can be fixed</td>
<td># of parts per million</td>
</tr>
<tr>
<td><strong>Inventory</strong></td>
<td>Buffers and inventories</td>
<td>Flow profile</td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td>Transports of materials</td>
<td>Time or distance</td>
</tr>
<tr>
<td><strong>Material Flow</strong></td>
<td>Flow of material per time unit</td>
<td># of units in queue</td>
</tr>
<tr>
<td><strong>Organisation</strong></td>
<td>How many people there are in the process</td>
<td># of people in process</td>
</tr>
<tr>
<td><strong>Lead time</strong></td>
<td>Time from a process start to a process end</td>
<td>Time</td>
</tr>
</tbody>
</table>

Figure 23: Measures of a process model

All these measures are partial measures, except lead-time, which can be used as an aggregated total measure. Furthermore, these are the measurements that later are used in the development Performance Improvement Method.
It is often argued that the used performance measures are an effective way to increase the competitiveness and profitability of a manufacturing company as well as to support and encourage productivity improvements in various manufacturing operations within the company. Appropriate performance measures can ensure that managers adopt a long-term perspective and allocate the company’s resources to the most effective improvement activities (Tangen, 2003).
5. PERFORMANCE IMPROVEMENT

This chapter provides a presentation of a number of improvement methods and a review of them.
5.1. Improvement Methods

So far, the necessity of performance improvement and how performance could be measured have been discussed. The means to assess performance through the performance factors described in Chapter 4 Performance Factors and Process Measurement has been discussed. Furthermore, specific measurements suitable for process performance have been described. It is now time to start looking at how to improve performance in practice. This Chapter presents a number of performance improvement methods and a review of their strengths and weaknesses, some notes on their applicability, which types of phases they consist of and most importantly how they fulfil the evaluation criteria, which were presented in Chapter 1 Introduction.

A number of methods, see Figure 24, have been studied. However, the choice of improvement methods that actually were analysed were restricted. The methods studied are from the areas of Logistics, Quality, Production Engineering and Behavioural area. The aspects of the methods are described from a production view. This also means that the methods chosen have a clear production linkage. Here is a categorisation of the methods described. However many methods have components that belong to several academic areas, but the authors view used in this research is represented by the list below.

- **Logistics**
  - Just In Time (JIT)
  - Supply Chain Management (SCM)
  - Theory Of Constraints (TOC)

- **Quality**
  - Total Quality Management (TQM)
  - Business Process Improvement (BPI)
  - Six Sigma

- **Production engineering**
  - Total Production Maintenance (TPM)
  - Lean Production
  - Demand Flow Technology (DFT)
  - Read a plant fast
  - Simulation
  - Process mapping
  - Single Minute Change of Die (SMED)
  - Five S

- **Other**
  - Decision Support
  - Continuous improvement

Two terms need to be stipulated to break down the improvement methods, namely improvement concepts and improvement tools. Concept is a broad
improvement method; a focused work method that often includes a number of tools. Lean Production is an example of this. Tools are more detailed. An example of this is 5S, which can be used in several concepts as well as separately.

Figure 24: A number of performance improvement tools and concepts.

These methods span a variety of academic fields and have evolved from many different needs and functions. JIT comes from the Logistics area, TQM from Quality and TPM is a production related concept. The similarities of the methods are that they have a number of phases and that performance is targeted for improvement. This makes the methods comparable to each other even if they emanate from somewhat different needs and functions.

In more detail, the improvement methods are similar in the way that they have pre-phases consisting of some sort of planning, goal setting or personal involvement. Simulation has a data collection phase (Johansson and Grünberg, 2001). Kaizen includes a problem identification phase (Hawkins, 2001). Concepts such as TPM, TPS and TQM require the involvement of top management and personnel involvement in the active phases (Jostes and Helms, 1994), (Hawkins, 2001) and (Gunasekaran, et. al., 1998). Theory of Constraints focuses on bottlenecks (Goldratt, 1999) and BPR/BPI focuses on processes (Lee and Chuah, 2001).

The middle phases of the methods typically consist of goal setting, measurement and implementation, e.g. TQM with statistical control (Gunasekaran, et. al., 1998), BPR with process mapping (Vakola and Rezgui, 2000) and Simulation with measurement and goal setting (Johansson and Grünberg, 2001).

The last phase usually consists of evaluation and a restart of the improvement work. Almost every method has evaluation as a phase, such as OD (Porras and
Robertson, 1992) and Lean Production. The last phase of continuous improvement work is a restart. These phases are used in the developed method. Performance improvement could be divided into specialist improvement and operator improvement, where operator improvements are similar to continuous improvement, i.e. Kaizen, while the specialist improvement often requires some skills that are usually gained through education. Examples: simulation, fleet route planning and machine engineering improvements. Berger, (1997) refers to this as expert task force continuous improvement and group continuous improvement. These improvements can be either integrated with the day-to-day work or treated as separate parallel tasks to be solved. For better results from PI, it is necessary to be able to distinguish these two types of improvements, in order to give the improvement groups problems adequate for them to solve. Further, it is important to coordinate different improvement efforts so they are not counterproductive.

Although the methods are similar in structure, there are differences in aim among them. Operations Development (OD) has more focus on human interaction than the other methods reviewed here. This is explained by the fact that OD emanates from behaviourists such as Lewin in the Thirties (Westlander, 1999). The method of OD is not of a continuous character compared with, e.g. TOC and Kaizen.

Benchmarking has comparison between businesses as its main aim. This is a good way to find improvement areas, visualised by other companies' results (Harrington 1998).

The TPM, TQM and JIT concepts focus on reduction of waste even though their overall focus is important (Sui-Pheng and Khoo, 2001), (Karlsson and Åhlström, 1996), (Hawkins, 2001) and (Gunasekaran, et. al., 1998). In Chapter 5.2 Improvement Concepts and 5.3 Improvement Tools, there are descriptions of the methods reviewed and the review is summarised in Chapter 5.4 Review of the Performance Improvement Methods.

5.2. Improvement Concepts

Descriptions of some well accepted improvement concepts are provided here. Strengths, weaknesses, and an analysis from the criteria are invoked here, but summarised in Section 5.4. First, concepts are described with the tools, which are associated with the respective concept.

The concepts, TPM, TQM and JIT can be summarised as TPS or Lean, however, these concepts have different approaches:

- TPM: A resource utilisation approach
- TQM: A quality approach
- JIT: A Logistic approach
These concepts are described from this viewpoint. However, some common tools are described in Chapter 5.3 Improvement Tools such as SMED, Five S and Process mapping.

Furthermore, the methods described here contain much more information than brought up here. However, focus is to analyse strengths and weaknesses to find obstacles to avoid and to find opportunities to use.

5.2.1. **Total Productive Maintenance**

Total Productive Maintenance (TPM) is a waste reducing approach to stabilise utilisation of machining resources. TPM focuses on improving machine availability and includes monitoring of machine equipment called overall equipment efficiency to visualise losses of utilisation. Implementation of TPM usually starts with a pilot project (Jostes and Helms, 1994). TPM is often associated with TPS, as these concepts are related to each other. TPM offers both measurement aid and improvement schemes. Since improvement work aims at reduction of losses, some ingredients of TPM are presented here. The measurement system which is used is called Overall Equipment Efficiency; a product of availability, efficiency and quality yield. The equipment losses are divided in four different hierarchically categories which can be measured with time or units (Nord et. al, 1997). When the losses are subtracted from the corresponding category, it equals the next category, e.g. Availability – Losses = Operative Efficiency. The list below shows TPM losses divided in four categories, as subsets of each other.

- Availability
  - Operative Efficiency
    - Net Operative Time
    - Value Added time

In the first category, losses depend on machine failures, set-ups and tool shifts. The second category includes losses due to idle running, small stops, bottlenecks and speed losses. Net operative time corresponds with quality losses. Lastly, the value adding time remains. The ideal goal of TPM is to make the availability time equal to the value adding time (Nakajima, 1992).

TPM is an extensive approach, which involves mainly two parts of an organisation, i.e. production and maintenance. It is therefore crucial that TPM work involves leaders of organisational level, also emphasised in TPM as leader commitment. Further, the implementation is supported by defined implementation steps, both for production and maintenance (Ljungberg, 2000). TPM should start with a pilot phase, which has a certain outcome to get organisational attention on the results this approach would give. The decided pilot approach is recommended for use when starting concept improvement work.
These implementation steps vary in number, from Ljungberg’s (2000) 7 steps, to Nord et. al.’s (1997) 12 steps. This description is adopted from (Ljungberg, Ö, 2000):

- Step one, Initial cleaning of equipment and work area
- Step two, Finding and fixing causes of dirtying
- Step three, Creating standards and checklist of cleaning
- Step four, Education of inspection
- Step five, Creating standard and checklist of inspection
- Step six, Organising of the workplace
- Step seven, Autonomous operator maintenance

The first step is further explained in Chapter 5.3.5, Five S, as the first step consists of the use of 5S and is also used in other concepts. It is important to revise these steps properly to follow progress and to see what is missing before taking TPM to the next level. TPM can also be benchmarked via a TPM award application. This procedure is similar to the awards in TQM, e.g. EFQM, see Chapter 5.2.3 Total Quality Management. The companies applying for TPM should establish a report, which is evaluated by a prize committee. If the report gets a good score, the company can be subjected to an onsite evaluation by TPM experts to be further evaluated for the TPM prize (Nakajima, 1992).

Implementation of TPM moves day-to-day maintenance and repair tasks from the technicians’ department to the production department. To avoid conflicts it is necessary to develop the work of the technicians. Further, as TPM is much about a competence transfer it is important that production and maintenance work without friction on these matters. TPM is competence and resource demanding and it is important to give proper education to the people concerned, to form a foundation to be able to run TPM in an autonomous way, independent from consultants and specialists.

TPM is an extensive concept, which takes time to implement and requires resources, which usually, at the start, are not present, and therefore need to be assisted by consultants. This in turn creates a dependence on the TPM implementation specialist. The competence demand is also high when it comes to the OEE measurement, whilst the OEE provides valuable information it can also be difficult to interpret. Further, in TPM implementations there should be a Pareto decision to work with maintenance tasks that gives the most effect.

The anticipated effects from a successful TPM implementation can be enormous, and this makes many companies opt for TPM despite the implementation efforts.

TPM is an extensive, resource and competence demanding approach with risk for conflicts among the involved departments. Further, TPM implementation is time consuming and according to standardised implementation schemes it can take as long as five years to implement to its full extent. Due to the resources and competence demanded, it is specialist dependent. TPM is clear about what to
improve and should not be used for anything else. Further TPM offers strong support for measurement, choice of improvement objects and implementation. TPM is suited to companies, which have a lower degree of improvement maturity, as TPM starts at a basic level, namely 5S.

5.2.2. **JUST IN TIME**

Just In Time (JIT) is a logistic approach to reduce waste and throughput-time for an ideal stockless production with planned elimination of waste (Hawkins, 2001). As with TPM, JIT is also strongly connected to the TPS concept, described later. Single pace production is used to reduce work-in-progress and inventory levels. The lead-time reduction induces shorter throughput times and more stable processes. Further, the reduction of work-in-progress and inventory reveals underlying problems, visualised by the Japanese sea (Slack et. al., 1998). See, Figure 25.

JIT is an extensive approach consisting of several tools and techniques that are related to TPS (Slack et. al., 1998):

- Basic work practices
- Operations focus
- Layout and flow
- Set up reduction
- Total people involvement
- Visibility
- Supply

![Figure 25: The Japanese sea, where the underwater rocks symbolises problems, which is visualised with a lowered water level. Source Eva Kraft, 2003.](image-url)
JIT includes control and planning aspects such as Kanban and pull scheduling in contrary to large-scale production push scheduling techniques. This counter relation makes JIT a radical change compared with traditional push production methods and requires new methods of scheduling, material planning and inventory handling, such as reduced lot sizes. To increase product flow it is also necessary to revise layout concepts, which costs money and demand resources.

Further, an important aspect of JIT is the levelling of production. Levelling actions, should be tightly linked to customer demand. Customer demand should pace the production. This is treated likewise in Lean Production. In practise, this means that products are mixed in the same flows in small lots. To be able to implement JIT it demands quick changeovers, which further needs a highly trained staff. For levelling, the P/D-relation must be considered. It describes the ratio of delivery lead-time and production lead-time (Shingo, 1981). If the P/D ratio is negative it means that customer demanded lead-time is shorter than production lead-time and must be shortened with the use of inventories. This in turn demands the use of forecasts. It is in industrial sites, which have a negative P-D that JIT can make a great difference if properly implemented.

JIT does not imply completely stockless production in all manufacturing applications, as buffers are used to compensate for system failures, but it is important to use relevant levels in these buffers that should neither be too high or too low. The need for buffers comes from the fact that series production multiplies downtimes, e.g. if there is product flow through four resources with respective downtimes of 10% it means that the system will have a downtime of 35%.

Lot Reduction is also a JIT approach that is intended to increase throughput in manufacturing. The waiting time the lots create are called lot delays and decreases with decreased lot sizes. It should be borne in mind that Toyota does not use any MPR system, they use the Kanban system, which is a remarkable difference from other manufacturers (Johnson and Bröms, 2000).

As mentioned above JIT includes several aspects, which involve great change when dealing with improvement. Some points of potential conflicts with the existing company culture are:

- Scheduling principles – reduced lots
- Control principles – Kanban system
- Planning principles – reduced inventories
- Layout principles – flow oriented layout

The aspects listed above makes JIT very hard to implement even with top management commitment, as these changes not only affect all employees but also requires that all employees act in new ways.
Of course, some ingredients can easily be adopted, but to be a true JIT company all parts of the JIT concept must be at place. The implementation of JIT is time and resource demanding. Measurements, which exist to support a JIT implementation, are extensive, such as inventory turnaround, lead times, work-in-progress and changeover times. The choice of improvement object is not clear, as there are many things in need of improvement. However, an articulation implies that levelling flow is a good starting point, but it is, in practice, difficult to see what a kind of a start this gives.

To be able to implement JIT successfully the company should be improvement mature, meaning that there should be a strong need for change, either from crisis or from desire. As to the extensiveness of JIT, it is very specialist dependent, both process and method experts.

5.2.3. **Total Quality Management**

Total Quality Management focuses on control of business processes and customer satisfaction. Activities such as improvement, statistical control, supply control and quality engineering are ingredients of TQM (Bergman and Klefsjö, 1995). TQM as a concept emanates from the academic field and has contributors such as Feigenbaum, Juran and Deming, this differs from other concepts such as Lean Production.

TQM has Kaizen as a tool for continuous work. This is visualised by the Deming’s wheel (Hawkins, 2001). To use this method, the improvement is first planned. The second step is implementation of the improvement. During the third step observation is made of the effects and the last action is to learn from the change imposed. After these four steps of improvement, it is time to find a new problem.

Statistical control is a powerful tool to gain control of manufacturing defects and it correlates to measurement. Further, there are many concepts of TPS found in TQM, such as Kaizen and Process Mapping. These tools are covered in Chapter 5.3 Improvement Tools.

TQM and Six Sigma are related in the way they deal with quality. One difference is the organisation review part of TQM, which is described here. Other tools and approaches are omitted since they are similar to Six Sigma and described later in this thesis.

An interesting part of the TQM concept is all quality awards offered by the different foundations such as Deming Price, European Foundation of Quality Management (EFQM), Malcolm Baldridge and the Swedish Quality Award (USK). These awards are used for evaluation of company operational development. The awards are given to companies and organisations, which apply, and are approved for the prize according to a number of criteria (Bergman and Klefsjö, 1995). The purposes of these prizes are to increase the awareness of quality issues and
processes in companies and organisations. Other effects of these prizes are stimulation of the self-awareness and support self-analysis. However, many companies do not compete; they only use the evaluation structure.

The evaluation criteria used in EFQM are shown in Figure 26. These criteria are used for evaluation as they have been empirically proven to be good indicators for successful development. Enablers are a term used much as performance factors, see Chapter 4 Performance Factors and Process Measurement, which is used as means for improvement. Results are different areas where results should be shown if the right enablers are used. Further, there is a Kaizen approach called Innovation and Learning, which can be obtained by benchmarking. These evaluation criteria are adopted from Baldridge’s assessment framework, which is widely, used (Senapati, 2004). After an evaluation, the criteria are weighed. This can induce problems, as this is an estimate of what is good for companies. One example is found in a Danish survey, which shows that companies tend to focus on enablers and not results. However, it is difficult to judge whether this is good or bad (Eskildsen, et. al., 2002).

![Figure 26: The EFQM Excellence model with evaluation areas, enablers and results.](www.qualityscotland.co.uk/assets/newsletter-2007-02/efqmbsc, 2007)

The evaluation process is, in all awards, made as an evaluation divided in a number of criteria’s, e.g. USK:

- Leadership
- Information and analysis
- Strategic planning
- Employee competence development
- Operation processes
- Operation result
Customer satisfaction

This evaluation is a type of measurement, which can be used for improvement purposes as it can point out strengths and weaknesses.

The actual improvement approach used in EFQM is called RADAR; Results, Approach, Deployment, Assessment and Review. Results should be chosen to follow improvement progress. After that, Approach are used to improve the chosen results. This phase correlates to the Enablers in Figure 26. The Deployment phase regards how systematic and to which extent the approaches are used. Assessment and Review deals with earlier steps, e.g. were right approaches used and were they deployed to the right extent.

As a summary, the evaluation approach gives strong support on what to improve as weaknesses are flushed out via the measurements. However, there is little support on how to improve. Furthermore, there is support for improvement maturity, which is a good thing when implementing improvement work, as company resistance can be lesser. The concept of TQM can give competence, so benchmarking could be used to accomplish this. TQM is an extensive method and requires specialist or consultant help, which can endanger the implementation.

5.2.4. Lean Production

Lean Production is an adoption of the ways of work at Toyota called the Toyota Production System (Womack et. al., 1990). The concept of TPS was developed from Ford's factories during the 20s. TPS is the most extensive approach described here and includes many aspects of the other improvement methods described here, e.g. JIT, TPM and TQM.

Total quality control is an important matter as sampling quality control actually misses parts, which, eventually can end up in customers' products. For consumer goods, this is especially important, even if there is a 99.999% quality, when the customer that actually gets a defect product it can be a 25% outcome for that customer, provided that 4 products is bought during the lifetime. This differs from higher frequency products which customer buys such as food or drink where a faulty product has lower impact on that customer's total purchases. To accomplish 100 percent functionality there must be 100 percent quality inspection. The classical way of solving this is to have a final product quality inspection and after inspection, the products are sent for adjustment or correction. This work method is time consuming and often finds defects that come from early stage manufacturing, which makes correction more difficult. A better solution is to build in quality inspection alongside the whole production chain. This approach increases feedback to earlier manufacturer steps and makes correction needs less frequent and cheaper.
The ultimate goal is to manufacture products after an order is made, however many products do have a production lead-time that is too lengthy to be acceptable to customers.

A first approach to improvement with Lean Production is levelling of flow, from tactual production to customer need; also called Heijunka, and similar to JIT. This is often described as mixing a variety of products in the same line in the same way as the products are ordered, e.g. if products A, B and C are ordered in quantities of 5, 10 and 15 The products should be made in an CCC, BB, A to level the flow (Johnson and Bröms, 2000). This approach requires more set-ups compared to classical batch production, which in turn requires set-up reduction. This is also covered in Section 5.2.2.

Andon is an important part of Lean dealing with visualisation of production waste and production controls to reduce waste. A large manufacturing site is too big for personnel to get an overview of. As a means to give the large site the advantage of a small site, there must be actions to over bridge this lack of overview. This can be done in numerous ways, e.g. production information boards where management can inform of today’s customer demand, resource availability, which workers that are present, and so forth. Andon is also used as a feedback system, e.g. for quality in the form of self-inspection. The classical example is the Andon cord at Toyota, where operators have the ability to stop production when a problem occurs. The point of this is to visualise the problem to an extent where it has to be fixed. This is connected to the work of reducing inventories as inventories normally hide such problems.

Jidoka is the term for autonamation, which means automatic defect detection, which is used to detect problems as early as possible in production (Shingo, 1981). This is important, as one does not need to wait for a quality inspection to find defects and in this way avoid further work on already defect parts.

Poka Yoka is the tool for fail proofing in manufacturing. A goal is to make parts easier to assemble by reducing the number of parts and exchanging screws for clips (Slack, et. al., 1998). This is also used to alleviate quality inspections. Another example of Poka Yoka is the SIM cards in mobile phones, which can only be placed in the phone one way.

Muda, waste is pursued in an ever-ongoing activity in Lean production. This is dealt with in kaizen groups. As Lean is so extensive there is always a tool to use for a designated problem, the problem is really to find the right one, which makes the scope of this method difficult.

This list of losses is adopted from the Toyota Production System (TPS), which is categorised in seven different origins (Kasul and Motwani, 1997):

- Waiting
- Defect goods
Tachi Ohno (1978):

“All we are doing is looking at the timeline, from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that timeline by removing the non-value added wastes.”

Lean is the most comprehensive concept of those ones described here and involves all departments of a company, from sales point to delivery point. This also makes this approach the most difficult to implement, as changes are normally huge compared to other approaches. Further, the implementation time is often highly underestimated as an implementation of Lean takes from five to ten years to accomplish. To quote Shiego Shingo (1981):

“It took Toyota 20 years to develop and implement Lean and it can be copied by others in ten years.”

Lean is also sometimes referred to as Mean Production as these improvement tools are sometimes used to downsize, which in some sense is not what Lean is about. The critics argue that Lean is a persuasive way to increase control and exploitation (Green, 1999). The people involved in a Lean transformation need to have competence in many different areas as to avoid sub-optimisation and to use the advantages to coordinate company divisions. Another obstacle is the financial models used in companies; it is easy to see what many improvement initiatives will cost, but not what they can give, e.g. wrong measurements are used to support lean implementation.

The extensiveness of Lean makes it both specialist and consultancy dependent. However, a successful Lean implementation is the approach that gives most results. The choice of improvement object is hard to distinguish as there are many starting points to choose from, and they are often required to be used simultaneous. The organisation resistance is hard to tackle with Lean, as this concept is a very extensive method to use for improvement. Implementation support is lesser with Lean as in many cases it merely describes desired results, not how to acquire them.

5.2.5. BUSINESS PROCESS RE-ENGINEERING

Business process reengineering concentrates on radical change to improve operations (Vakola and Rezgui, 2000). The radical change allows new revolutionary ideas to evolve which can help to improve operations more than a Kaizen approach. This is called Kaikaku in Lean Production terms.
Business process re-engineering was introduced by Hammer and Champy in the early 1990s and has an approach of breakthrough changes. They state that small changes give small effects and small earnings whilst the radical change gives radical increases in earnings (Povey, 1998). As with TQM, this is not taken from a company phenomenon. The BPR main ideas are that the operations should be organised around the process instead of around functions. An important part of BPR is process-mapping, see the section about process mapping later.

Business Process Improvement (BPI) is related with BPR but puts its emphasis on Continuous Improvement, and not only on breakthrough change. The need for BPI evolves from the fact that the change’s positive effects decline some time after the implementation. To resolve this, further attention should be focussed on the change.

A BPI Project has many similarities with the Six Sigma project structure. The project is divided into 6 phases (Harrington et. al., 1997):

- Organisation
- Documentation
- Analysis
- Design
- Implementation
- Management

Improvement work in BPI standards starts with organisation of the improvement project. The project must complement the organisation in the company and it must involve all company functions. The project constellation is terminated once the project is ended. Phase 2 involves activities to describe flows and processes, this is used with process mapping, see later. Phase 3 is the analysis phase. This is about finding improvement opportunities and it is done via data analysis, e.g. completion on time and cycle time analysis. Phase 4 deals with the design of a new process to take advantage of the opportunities found in Phase 3. This phase is also the main BPR phase. Phase 5, implementation, defines how to implement the designed improved process. The last phase, management, is how to transfer the breakthrough improvement to a day-to-day continuous improvement work method.

The extensiveness of this concept varies with the choice of improvement scope, it can be advantageous, but it requires competence, which makes the approach difficult to use in improvement immature organisations.

A big difference between Lean and BPI is that the improvement work in BPI is organised in a project form. The advantage of this is that this can render quicker results as the organisational conflicts should be fewer. This concept is very specialist dependent, which in turn requires help from experts or consultants. Results emanating from this concept can be hard to communicate, which makes
implementation harder. Although, as Lean tells what the future state of an
improvement project should be like, there is little support on how to achieve this,
in BPI it is opposite, there are much help to reach a future state, but yet, the
future state is undefined. There is also too little support on what to improve as
this is an open question when a BPI project is started. This is also true when it
comes to Implementation.

5.2.6. **Six Sigma**

As with BPR and BPI, the Six Sigma concept gives much support on how to
organise improvement work. Six Sigma also gives a basis for competence tracking
with the Green Belt, Black Belt and Master Black belt system. These competences
are given as courses, which also includes some sort of case study.

Six Sigma as a concept came from the Motorola Company in the mid 80s. An
engineer at Motorola named Bill Smith concluded that increased complexity in
manufacturing made it difficult to maintain quality standards. Bill Smiths idea to
improve this was to set a quality goal of Six Sigma to get a satisfactory final
product quality (Bertels, 2003).

Six Sigma is a concept to decrease variation in manufacturing processes with the
use of statistical tools and supporting software (Bendell, 2006).

According to Pande and Holpp (2002), three key characteristics separate Six
Sigma from quality programs in the past:

- Six Sigma is customer focused, keeping the external customer needs in
  plain sight, driving the improvement effort
- Six Sigma projects produce major returns on investment
- Six Sigma changes how the management operates as it is more than just a
  set of improvement projects. The intention is that senior executives and
  leaders throughout the business are learning the tools and concepts

In many ways, Six Sigma is about putting the notions of working smarter, not
harder, into practice. However, Six Sigma is not unique. There are other concepts
with customer focus, such as TQM and Lean Production. Bullet 2 above is also
true for any successful improvement project and the opposite could be true about
Six Sigma, since Six Sigma projects also can fail. However, point 3 implicates that
Six Sigma has an organisational structure that can penetrate organisational
resistance.

Six Sigma is based around the problem-solving model called DMAIC:

- Define
- Measure
- Analyse
- Improve
- Control
Define, is about defining a problem to be solved. Tools used in this phase could be project chartering, Process mapping, Cause and Effect matrix and FMEA.

Measure is the data collection phase. This phase is unique to Six Sigma, compared to many other improvement concepts the emphasis on validating the measurement system is by doing a thorough measurement system analysis.

Analyse is a phase where many different methods could be used. The goal is to analyse the collected data in order to support decisions, in other words fact based work. A method commonly used here is FMEA, but the Analyse phase is a phase where numerous statistical methods such as regression analysis could be used.

Improve, is the phase where the suggested improvements are implemented.

Control, is a phase where the improved performance is verified. This phase often includes a measurement system analysis as a follow-up, especially if a new measurement system has been introduced. An addition can be used called R, as in Report, as it is important to communicate results (Senapati, 2004).

A Six Sigma practitioner should keep an attitude of questioning towards assumptions and common knowledge, as well as towards the data collected. Six Sigma is therefore heavily data driven and many methods used are based around statistical analysis, which often makes the availability of specialists necessary.

The specialists are trained within a Six Sigma program in the form of Green belts, Black belts and Master Black belts, meaning that specialist training is a part of Six Sigma. Hence, the idea is that the company should be self-sustaining when it comes to supplying specialists.

The standard Six Sigma methods are focused on finding the actual root cause of a defined problem. Tools for the development of the actual solution are rare. Such tools can be found in the Design for Six Sigma concept (DFSS), which is structured in ways similar to Six Sigma. Methods often used in DFSS are: Simulation, Design for Manufacturing/Assembly, QFD Matrix and Kano models.

Six Sigma can be combined with Lean Production and is then called Lean Sigma. There are many books about the success of such a combined programme. Nevertheless, there are reports on unsuccessful cases, due to sub-optimisation issues (Bendell, 2006). However, there are suggestions that Six Sigma is a good method for problem solving in an overall Lean or TPS programme.

The Six Sigma concept is, as concluded above, very specialist dependent, which can jeopardise implementation. However, there is strong support on how to implement improvement work. Furthermore, Six Sigma as well as BPI has a weak support on where to start improvement and the choice of improvement object. As to competence, there is very strong support regarding education in Six Sigma;
measurement support is also strong. Lastly, the open-minded choice of improvement tools can be advantageous. This is true when practitioners know what and how to use them; if not it can be difficult to use Six Sigma.

5.2.7. DEMAND FLOW TECHNOLOGY

Demand Flow Technology (DFT) as a concept started in the early 1980s when Costanza worked at Hewlet & Packard (Kumar and Meade, 2002). The concept was further developed by an American government initiative to meet the Japanese and Asian movement of productivity. The concept of DFT is an extensive approach and involves logistics, customer focus, material flow, layout, product design, quality, financial and employees (Costanza, 1996). DFT is a customer demand concept, which uses Kanban to connect the customer demand directly to the company processes. Continuous Improvement in this concept is called Continual Improvement, but has the same meaning.

A main difference between DFT and Lean is that DFT focuses on flow whilst Lean focuses on reducing waste. Furthermore, the DFT concept deals with suppliers and to increase their delivery performance. Another difference is the bill of materials and MRP treatment, which does not exist in Lean, as Toyota does not use these systems to control flow.

The view on DFT here is that it is an early interpretation of Lean production with the same tools, but adapted for American industry. It must be borne in mind that this book was written at the same time as the Lean concept was evolving from the motor manufacturer survey called IMVP.

As the extensiveness of DFT is as great as Lean, this concept is highly dependent on specialists. There is weak support on how to overcome organisational resistance. The tools of DFT are not designed to increase competence about the concept. Another note on DFT, is that it is difficult to find scientific results on this concept.

5.2.8. SUPPLY CHAIN MANAGEMENT

Supply Chain Management (SCM) is the name of activities, which aim to create efficient material flows from the source to the end-customer, see list below. SCM has many similarities to JIT in creating lean flows to pursue waste (Slack et al., 1998). However, SCM is not as well defined as the other concepts described here. In fact, what SCM is all about is very unclear (Burgess et. al., 2006). The main difference between JIT and SCM is in the materials planning, where SCM mainly deals with material flows such as Master Planning Schedule (MPS) and Materials Requirements Planning systems (MRP). This is dealt at Toyota with Kanban and not with MRP (Johnson and Bröms, 2000).

Many companies have a large number of articles to assemble in their products, which in turn create complex environments to coordinate. To alleviate this
complexity, an important activity is supplier relations, which focuses on a small but reliable number of suppliers, enabling greater control of materials flows (Vollmann et al., 1997).

SCM include activities such as:

- Forecasting
- Supplier relations
- Planning and control
- Material flow improvement
- Inventory control

The main activities included are material flow improvement, planning and control. Material flow improvement is about levelling flow and lowering inventories to reduce Work In Progress (WIP). Tools to reduce WIP, which can be used, are Kanban, see Chapter 5.2.2, Just In Time, and Conwip. Instead of ordering material from every upstream process, as in Kanban, materials can be pulled from customer of the first process and pushed from that point. Alternatives to these principles are the use of Customer Order Entry Point (COEP) and Order Specification Entry Point (OSEP) for order releases. COEP is the time when the order enters the physical flow and OSEP is when an order needs attention ahead of production (Karlsson, 2002). This is a variant of Customer Order Decoupling Point used by Shingo (1981).

CODP can be seen as the point in production where the P/D equals one. Another way is to define a point where the products differentiate from customer orders and place the order point there. From an improvement point of view the first action should be to release fewer orders to decrease inventories and as far as possible, connect orders to the start of production.

Another traditional activity in logistics is to decide order quantities to maximize order and specific cost, this differs from Toyota where they tend to connect purchases to customer orders as far as possible, resulting in far more transports called milk runs.

Supply chains are often very long and it is difficult to connect upstream processes, directly to customer order, which make forecasting important. However, in a complex supply chain, small differences in forecasting and actual outcomes in late stages of the chain often evolves to large fluctuations in the early stages; this is called the bullwhip effect (Lee and Padmanabhan, 1997). Scheduling principles for using resources could also be seen as a part of SCM. Production scheduling is a systematic way to control demand variation. Factors, which can be used (Anderson, 1994):

- Demand variation
- Time
- Buffer size
• Capacity yield
• Flow
• Staffing

An example of a scheduling principle is Johnson’s algorithm. This can be used on a production system with two machines in series:
1. Find the job with shortest finishing time.
2. If the job has the shortest job time on the first machine put it first on the sequence list, otherwise put it last.
3. Begin from start

This algorithm provides the shortest waiting time in the system. However, this can result in a bottleneck at the second machine. Furthermore, in systems with more than two machines the scheduling becomes heuristic, which means that it cannot be solved without comparing all the alternatives.

As a concept, SCM is difficult to evaluate, as there is no stringent definition of the components of SCM. However, it is clear that this concept is very specialist dependent. By using SCM tools, there is a risk of sub-optimised work, since the use of production scheduling often optimises machine utilisation, regardless of WIP. Further, there are no components to deal with company resistance. SCM has strong measurement support, which comes from computerised MPS and MRP systems. From an improvement point of view, these systems are often very conservative and difficult to change. There is clear initiative to reduce variation in the supply chain with help of CODP, COEP and OSEP.

5.2.9. Theory of Constraints

TOC pays attention on bottlenecks. It is important to increase throughput to the maximum in production bottlenecks (Rahman, 1998). TOC is very system-oriented compared to, e.g. OD, which focuses on human interactions.

Eliyahu Goldratt’s book *The Goal* had a great impact on management literature with its new presentation approach as a love story when it first came in the mid-eighties. Optimized Production Technology (OPT) was, according to Goldratt, the western industries’ opportunity to be able to compete with the Japanese movement of highly efficient Japanese companies.

The main issue of OPT is that managers shall optimise flow and not capacity to customer demand (Goldratt, 1993). To make control and planning easier, one is urged to find a production system’s bottleneck and subordinate the rest of the system’s production to the bottleneck. This is the essence of OPT. However, OPT can effectively be complemented with price differentiation, which is also a flow-oriented approach. Compared to the planning methods of MPS and MRP, OPT is much easier to use. Further, the factory capacity is clearly exposed. The theory says that a plant cannot produce more than the bottleneck can produce.
The continuous improvement method of five steps suggested in *The Goal* were later summarised as Theory of Constraints (TOC) (Goldratt, 1999).

1. **Identify the system’s constraints**

A system often consists of several resources with differences in capacity and uptimes. These resources create a flow in parallel or serial. Bottlenecks are usually revealed by queues in front of the resource. However, this is not sufficient. Measurements must complete the analysis of queues.

2. **Decide how to exploit the systems constraints**

By identifying the systems constraint dependability, answers regarding weaknesses can be obtained. Examples of exploitations are reduced set-up times, capacity increase and reduced downtimes.

3. **Subordinate everything else to the above decision**

Since efforts put on a non-bottleneck resource have no effect on output, it is important to coordinate efforts to the bottleneck, to receive the highest impact. It is sufficient to use the capacity of the bottleneck to control the system’s capacity.

4. **Alleviate the system’s constraints**

This includes the actual implementation. The implementation is tightly connected with the two previous steps. The identified exploits form the basis for implementation and the subordination of resources to alleviate the bottleneck. If control is focused upon the bottleneck, conditions for a slimmed production are created.

5. **If in a previous step, a constraint has been broken, go back to step 1**

When step 4 alleviation successfully has been implemented, another resource should now be a bottleneck. Go back to step one.

TOC is a continuous improvement work method that focuses on bottlenecks, while OPT is a wider material handling strategy. The identification of bottlenecks can be done by queue analysis of the production floor.

A problem in a complex plant, with many products and flows is that the bottleneck is not easily detected, since it moves. Different products have different bottlenecks, and are hidden when the flows goes in a mixed layout.

Some parts of TOC are easy to use, while the production ordering, demands specialist competence. However, the concept is easy to communicate, due to queues a front of bottlenecked resources. TOC gives a clear picture on what an improved future state should look like, which makes it implementation supported. Further, TOC gives strong support on what to improve, but this can be a drawback, as this is not always, what needs to be improved. The measurement support is weak. Some parts of TOC are suitable to use in an improvement immature organisation, due to the easiness to communicate what to improve.
5.3. Improvement Tools

Here are descriptions of improvement methods that have a smaller scoop than the concepts of improvement. Some of the tools are used in several concepts, such as Continuous Improvement and 5S.

5.3.1. Read A Plant Fast

To give a quick grasp of a plant or a manufacturing site a pre-study is recommended, prior to a larger improvement project. The “read a plant fast method” offers a structured way to do this.

Read a plant fast was developed by Eugene Goodson in the early 1980s. The company was expecting visitors from a Japanese competitor and the visit was granted on the assumptions that a brief tour would not give away too much information. A demand on the Japanese visitors was that they should give Eugene and his colleague’s feedback on the tour. The site visit lasted not more than an hour, but still the report that was produced by the Japanese shocked the managers at the company. The report was, considering that the visit only lasted for one hour, incredibly detailed regarding sales estimates, technology level, of the plant. This experience stimulated Eugene to develop a method called Rapid Plant Assessment (RPA).

This method consists of a questionnaire with eleven questions. The practitioners grade their observations and impressions according to the questions below.

1. Customer satisfaction
   The question regards how employees percept their part in customer relations both internally and externally.

2. Safety, environment, cleanliness and order
   Observations on air-pollution and noise levels are considered here.

3. Visual management system
   Are tools, which give information about cues and product direction easy to see?

4. Scheduling system

5. A central scheduling system, often over or under produce goods, a single pace system would grade better.

6. Use of space, movement of materials, and product line flow
   The best plants use their space efficiently; materials are moved in efficient ways and over short distances.

7. Levels of inventory and work in progress

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How many goods and materials are found in the manufacturing?

8. Teamwork and motivation
   Are the goals of the plant, in terms of productivity and quality, clearly posted in the manufacturing? Are the measures used by the employees?

9. Condition and maintenance of equipment and tools
   Are the machines clean and well maintained?

10. Management of complexity and variability
    How is complexity and variability managed and reduced? This question can be difficult to answer during a short tour, but one can look for data-collecting procedures, forecasting and if employees are searching for lost products.

11. Supply chain integration
    Good plants work closely with a small number of dedicated suppliers.

12. Commitment to quality
    Are there visual signs of commitment to continuous improvement?

The Japanese visitors had divided these questions among them, as they could not use any paper and pens during the site visit. In this way, they could memorise what they had seen. Further, the questions asked are of a very general manner so no one ever suspects that they can be used to get a comprehensive picture of an entire plant. The questions posed, can be, e.g. how many employees do you have at this plant, is there much trouble with this machine, and so on.

Even if this tool is very simple to use it requires a lot of experience to get good results from RPF, this makes it specialist dependent. The use of this tool can draw attention to some improvement areas, which need to be attended on. The measurement base is weak but it is intended, to be as quick as possible. By using this method, improvement areas can be found.

5.3.2. Discrete Event Simulation
Simulation often acts as a decision tool and is not necessarily an improvement tool, but it can justify improvement ideas (Johansson and Grünberg, 2001). The term Simulation has many meanings, but is usually seen as a representation of a bigger and more complex activity (Seila, 1995). Production simulation is a method to model and evaluate real industrial systems. Further, a simulation model should, in predefined respects, emulate a real or suggested system. What is meant by simulation is Discrete Event Simulation (DES), which is a type of simulation that is triggered by events. Simulation could be used as a tool for manufacturing preparation, education, training and decision support (Johansson, 2006). Simulation of production systems is at focus, since it works as decision support,
when optimising production, comparing new investments and reconfiguring production resources.

Simulation is often a cost effective way of evaluating production systems without the need of tampering with the real system (Johansson, 2006). Some typical data used for simulation (Johansson, 2006):

- Cycle times for processing products
- Buffer capacities

Figure 27: A simulation methodology (Johansson and Grünberg, 2001).
- Quality outcomes such as waste and rework
- Resource down times, both scheduled and unscheduled
- Machine capacities
- Transport lead-times

This approach is also useful to evaluate new non-existent conditions, e.g. investments of new machines and layouts. Further, a thorough evaluation of manufacturing plants, often requires simulation techniques due to the manufacturing complexity. The effects of a change or improvement are not always evident and simulation is therefore a useful tool for evaluation.

For this thesis, the data collection phase is a vital part of an improvement project. Often, not all information in need is present, but has to be gathered from the production set. However, this data can then be used as background material, simulation and other improvement projects (Johansson, 2002).

A possible drawback with simulation is that results often are very convincing and difficult to scrutinise. To base decisions solely on simulation can be fatal; the fact that simulation is a model of a real system with errors can show wrong results. A model is nothing more than an approximation of reality and is by default wrong. To avoid these obstacles, input and output data must be carefully investigated by, for instance, experienced production personnel. Further, if there is a chance to compare the model with a real system to see if the model generates the same output as a real system with the same set of input data, this should be taken. This procedure is called validation of the model and is one way of testing the accuracy of the model (Sargent, 2005).

Figure 27, shows a way to perform a simulation study and, at an early stage, formulate aims and goals with the simulation study. It is important to avoid open-ended goals; if these are used it is difficult to show when the simulation study is finished. If the goals are clear and unambiguous, it is easy to terminate the simulation study when the goals have been reached.

Simulation is a specialist tool in several aspects; the software used is often complex, data collection places high demands on the persons doing this, cause of evaluation on relevance and accuracy of input and output. The complexity of a simulation study can make the support of decisions difficult. Simulation does not give any support on how to implement improvements or which methods to use for implementation. The support for measurement is strong as it forms the foundation for the entire simulation study.

5.3.3. PROCESS MAPPING

This activity is an important tool in many improvement concepts such as TPS, TQM and BPR. In Lean, it is called Value Stream Mapping (VSM). However, for a process mapping activity to become a VSM tool, the future state needs to be mapped.
An improvement project often includes the use of some process mapping (Olhager, 2000). Different techniques exist for improvement projects and analysis, e.g. IDEF 0 and BPR process models. These models act as a support for practitioners in their analyses, in order to find areas of improvement.

Process mapping is an ideal way to get understanding of operation processes (Ljungberg and Larsson, 2001). However, these process models usually do not include lead-time and losses, which are very important components in operations today (Slack et. al., 1998). Improvement of lead-time is an excellent way to increase operations’ performance since lead-time affects many other operations aspects. Shorter lead-times give the flexibility to identify improvements in quality, precision, speed, and cost.

There are three main methods for process mapping (Olhager, 2000):

- Process flow maps
- Material flow maps
- Layout flow

Figure 28: An example of a simple process map divided in different improvement areas.

In process flows, the work progress is in focus, i.e. which actions are used in the transformations of a product or service. When studying materials flow, the paths and order of processing operations, are put under the microscope. Lastly, layout flow considers the actual layout of the manufacturing. The two first methods cover process times. The process flow method takes into account if the operation is value adding or not. However, this is supported by the methods and not the
models and this needs to be generalised to be applicable for wider use. Process attributes to be mapped for losses could be cost, process flow time, flexibility and quality (Anupindi et al., 1999). Further, resources and control are also important to consider. However, it is important to connect all improvement work to performance goals set by the organisation, see below.

Ordinary process models do not support detection of problem areas. This could be a problem for method practitioners, since people may not agree on what and where the problems actually exist. However, with use of process mapping and time-measurements, facts can be gathered to support improvement work. Process mapping is easy to use and it is an easy way to communicate results. It gives support on what to improve but not how to improve.

5.3.4. **Single Minute Exchange Of Die**

Set-up time is waste, which can be reduced. Set-up time is especially important to reduce in bottleneck resources as an effect on overall throughput is gained.

SMED, Single Minute Exchange of Die, is a reset reduction approach, which can be found in TPS, that was developed in the 1950s. Resetting time is an important type of waste, which creates waiting time. Further, it makes companies use lot production schedules, which further increases waste. The basis for JIT is the ability to use quick resets. The method to reduce set-up time was formalised by Shingo and described as Single Minute Exchange of Die, SMED, (Shingo, 1981).

Set-up of resources can be divided into 4 parts (Nordell, 2007):

1. Retrieving, checking and preparing of materials and tools
2. Removing tools and materials from the prior batch run
3. Measuring, setting and calibration of new batch run
4. Producing test runs and adjusting to settings

An important aspect of SMED is the separation of external and internal resetting. The external resetting can be done without any loss in machining operating time, internal resetting cannot be done while the machine is running. Further, the improvement lies in the way of converting internal set-up time to external set-up time, or even eliminates the need for resetting (Kaiser, 1999).

Further, the method of SMED can be summarised as (Nordell, 2007):

1. Identify the internal and external set-up steps
2. Convert internal setup time to external set-up time
3. Improve all setup steps, both external and internal set-up
4. Eliminate the need for set-up

Examples of improvements are, exchanging screws for snap solutions, which reduce the time needed for tool exchange; products can be redesigned to reduce
required resets; if cleaning of a machining part is needed, have a spare part to use while the first part is being washed.

Shingo divides SMED into 8 distinct steps to reduce set-up time (Shingo, 1981):

1. Separate internal set-up time from external setup time
2. Convert internal to external set-up time
3. Standardise dies to reduce the need for different fasteners
4. Use clamps or eliminate fasteners
5. Use intermediate jigs
6. Adopt parallel operations, for example two people instead of one
7. Eliminate adjustments
8. Mechanisation of set-up

SMED is an easy tool that in the start is easy to apply, which makes it a suitable start for larger improvement attempts. The support for what to improve is also clear. However, the latter steps in SMED, which needs specialist help is redesign of tools and products. The identification of internal and external set-up step needs to be measured thoroughly, which is an advantage as this creates a foundation of facts to work with. A little warning must be issued here as SMED can increase overproduction if gained capacity is used carelessly; however using SMED on bottlenecks should be very beneficial.

5.3.5. **FIVE S**

Takashi Osada developed the Five S method in the early 1980s, which can be found in concepts such as TPM, TQM and JIT (Sui-Pheng and Khoo, 2001). It consists of five steps. These steps contain workable aspects to improve for increased efficiency:

- Sort – Arranging
- Set in order– Neatness
- Shine – Cleanup
- Standardise – Discipline
- Sustain – Ongoing Improvements

The first step of 5S work should be to sort. It is easier to find sources of problems in a well-organised plant, since disorder tends to hide problems. All things, which are not needed for production, should be sorted out. Usually a red tag procedure is used to help with the sorting. Items, that is hard to decide if they are needed or not, can be placed in a red tag area for proper evaluation.

To set in order, means that the remaining needed items are arranged so that they are easy to find, use and be stowed away after use. Shine means clean, e.g. remove dirt from machines, floors etc. This step also includes eliminating sources of dirt
Standardise is the fourth pillar of 5S and is the method to maintain the first three pillars. An example of this is to make 5S revisions and use checklists to do follow ups. Sustain is nothing more than keeping to the plan and continuing to work with the four previous pillars. Like SMED, 5S is a direct tool, which is easy to understand and implement, this makes it very suitable for starting improvement attempts. However, the difficult part here is the last pillar Sustain. It is usual that 5S efforts die after a while. 5S has a clear goal of what the results should be, which enhances implementability.

5.3.6. **Continuous Improvement**

Kaizen is the Japanese word for Continuous Improvement. It originates from a Japanese work method, which uses a continuous work method, which in turn was adopted from Deming and Juran. Deming himself referred to the PDCA cycle as a Shewhart cycle, which consists of four phases (Deming, 1986):

1. Plan a change or test
2. Carry out the change or test
3. Observe the effects of change or test
4. Study the results of the change or test and learn from it

Deming’s wheel describes how continuous improvement work can be performed.

![Deming’s wheel of improvement and progress of improvements](image)

*Figure 29: Deming’s wheel of improvement and progress of improvements. Source: Eva Kraft.*
The activities are Plan, Do, Check and Act, PDCA. Plan includes data collecting and analysis, Act incorporates standardisation, Check deals with measurement and finally Do is the implementation phase.

In some way, this is the same method used by scientists, and the PDCA cycle can be viewed as a scientific experiment.

As Deming (1986) puts it:

“Any step in the Shewhart cycle may need guidance of statistical methodology for economy, speed and protection from faulty conclusions from failure to test and measure the effects of interactions. The effect of a change that is suggested may sometimes be studied by calculation on paper, or by simulation, or by change of an engineering drawing, avoiding actual experimentation”

Most of the extensive methods mentioned here, include Continuous Improvement. Kaizen and PDCA are found in many work methods and are closely connected to TQM, JIT and TPS.

Seven QC Tools or Seven Management tools is a set of tools to support Continuous Improvement. They include simple tools such as Ishikawa diagrams, Pareto analysis, and histogram generating techniques. The focus of these tools is that every decision should be based on facts. For improvement purposes, this is important when communicating results. The work with PDCA should be designed as a mini experiment, which builds on a scientific method.

Standardisation is the basis for Continuous Improvement. The reason for this is that a current state needs to be well defined before any actual continuous improvements can take place. Without standardisation, the way work is performed differs from person to person. If this difference is present it is difficult to conclude if a proposed change is an improvement or not (Spear and Bowen, 1999).

As with some of the tools described, CI is easy to start but hard to sustain. Another difficulty is when the first rounds of improvement are made, and the improvements need more facts to be identified. There is a risk that the CI work ends without proper standardisation. CI implies that measurement should be made in the PDCA work, and a suggestion is to use Seven Management tools; however, in practice this phase is not stressed enough. There is no support on how to increase competence with this tool. Lack of improvement objects also makes this tool more difficult to use.

5.3.7. DECISION SUPPORT

There are often different sources of a problem, and different opinions regarding which source that is best to approach. Pareto analysis is a simple tool to use when deciding which single cause has greatest impact on results, see Figure 30. To get quick results in improvement work it is best to work with the largest causes.
Tools for decision support can be found from different sources such as QC tools and the Seven Management tools. Two common tools are described below, as they are very easy to use. Advanced tools for decision support can be found in Six Sigma; an example of this is the statistical processing software Minitab, which is used to show statistical relations and distributions to use in improvement work. The drawback with tools such as Minitab is that it is a specialist tool and the results are difficult to communicate.

A popular way to use decision support is the use of factorial design; however, these approaches are specialist dependent. Decision support is included in tools such as Minitab. The advantage of decision support is that the number of experiments can be reduced and still show relations between factors. This tool is powerful in situations where full repeatability exists. However, sometimes these factorial designs are used on soft factors such as market advantages or employee satisfaction. The results from these experiments can be very difficult to interpret, because of vague input. Another drawback is that it can lead to faulty decisions because it is hard to measure input. The recommendation on these matters is to use factorial design on soft matters with great care.

An example of Pareto analysis: if there are 4 different causes for a problem, measurements reveal that one single cause accounts for most of the effect, see Figure 30. With this information, one should choose to work with cause one, for the largest and quickest impact on the improvement work.

The specialist dependency of these tools is dependent on how they are used. If, for instance, a matrix diagram is used to summarise a discussion, it is easy to use. On the other hand, a factorial design with soft factors can be difficult even for an.
expert. However, these tools give a good foundation on which to base decisions, which is a good start for improvement work.

Another, useful tool for decision support on soft matters is a matrix diagram. If it is difficult to measure causes and effects, estimates can be useful. However, as with factorial design this should be used with care. To use the matrix diagram, estimate if an effort is low or high and if the impact is low or high. Score the estimates in the diagram and use the outcomes, which first show up in the green area, the most preferred ones, see Figure 31. These decisions demand little effort but give larger effects. The yellow areas should be used after the green area is emptied. Finally, the red area should be used last, if used at all.

![Matrix Diagram](image)

Figure 31: A matrix diagram for decision support.

Using these decision tools can act as a way to make a quicker start with improvements. The tools can be used to decide which improvement object should be attended to. Further, it can be used to decide how to make suggested improvements.
5.4. Review Of The Performance Improvement Methods

At first glance, it cannot be said that one concept or tool is better than another. The reason for this is that all concepts and tools have both positive and negative components and the situation and where it is used affects the applicability. Another aspect is that not all concepts and tools are applicable in all businesses. It is important to see what that needs to be accomplished with a specific method, so that an adoption to dominant conditions can be made. How to do this is not covered by this thesis, as the objective is to develop a new method. Nevertheless, to further increase support of improvement implementation one should consider where the methods are applicable. To show that there are differences in the concepts and tools described here, that can be categorised and evaluated the following reasoning of applicability is presented. However, this description is not thorough enough to be supportive for an improvement method choice. For lean methods applicability, see Herron and Braiden (2006).

5.4.1. Evaluation Basis

To form a base for evaluation of the improvement methods described here, different criteria are used. In short, they are used to find improvement issues in existing improvement methods. How these criteria are derived from the problem description is presented in Chapter 1 Introduction.

The environment, where the improvement is supposed to take place, also affects the results, in terms of which type of company environment that is present. Factors, which can affect implementability of improvement methods, could be:

- Improvement maturity of organisation
- Competence, regarding both improvement and methods
- In which type of production environment, improvements take place

A categorisation of different operations characteristics, i.e. Volume, Variety, Variation in demand and Customer contact, is presented in Figure 32.

An example is that some aspects of Lean Production are difficult to implement in environments with high volume variation, with high uncertainty, where TOC could be more suitable (Börselid and Jensen, 2001). Börselid and Jensen’s model was adapted from Persson and Virum, where a categorisation is used to evaluate JIT, TOC and MRP from a number of criteria:

- Production layout
- Product complexity
- Production series size
- Demand
- Mix of products
• Ability to handle uncertainty

These criteria are similar to Slack et. al’s criteria listed below.

Figure 32: Typologies of operations management (Slack et al. 1998).

Examples of suitability, e.g. with high variety of product variants, DFA approaches are applicable or that high volume with low fluctuations is JIT friendly. This implies that a general method should have some sort of adjustment to which type of business the improvement object is situated in.

Ljungström (2004) evaluates a number of attributes. 5S, TPM, Six Sigma and CI are some of them presented here, see Figure 33.

For instance, a popular approach is to mix Lean Production and Six Sigma and this approach of measurement is understandable as Six Sigma has a framework which the Lean concept lacks; in addition, Lean has a desired future state which can act as goals for the structured Six Sigma projects.

Even with easier tools, many obstacles need to be overcome before their true potential can be unleashed. Reasons for this, can in some cases, depend on which person that is leading the improvement change. Another reason can be resistance of groups, which can be hard to overcome.
As stated, there is an extensive number of change and improvement methods described in many different research fields. However, many methods of improvement are of a general character and do not provide sufficient information on what to improve in operations. While the OD model gives a good picture of a typical organisation, it does not provide help on what to improve. Some of the methods prescribe where to start, such as TOC, which tells us to start with a bottleneck in production. However, this is not always the correct way to start improvements since TOC focuses on increased output. A company can have difficulties without any need to increase its output as it could create overproduction of unwanted customer products.

One of the problems described in Chapter 1 Introduction was that the tools and concepts give too little support on where to start improvement work. This can leave more inexperienced practitioner in the dark regarding where to start (Grünberg, 2004). Further, this may be a result of consultancy dependence, due to complicated improvement tools, that require specialist competence. This is mainly caused by many methods having pre-described problem areas such as TPM with machine utilisation. Tools and concepts in general, usually present lists of possible measurements to make in operations. In the BPR method for instance, a process model is presented to use for process mapping. Process mapping can include measurement but does not include lead-times in the models, which is important to use for improvement purposes.

In conclusion, all improvement approaches are specialist dependent in some way as they impose a change. After time, this dependency is reduced. However, at what level and how long this could take, differs from approach to approach and how specialist dependent they are. When forming a new method, that should overcome this, a new method must be simple to understand and use.

Which approach to use is also dependent on so-called improvement maturity, described by Bessant and Francis (1999). In the evaluation made in this Chapter, this is referred to as specialist dependence, i.e. if a method is easy to use for an improvement immature organisation. Then it has a high specialist independence degree.

The extensive approaches should only be used if proper resources are used and the organisation has a high improvement maturity, otherwise it is best to use one of the less extensive approaches. It is also so that the less extensive approaches are more specialist independent.

It is also clear that all methods but Six Sigma, do not have any type of competence scheme connected to the method. This imposes problems in the form of difficulties to communicate change. Furthermore, for the people using the methods it can be difficult to get results, without proper training.


<table>
<thead>
<tr>
<th>Criteria/Method</th>
<th>5S</th>
<th>TPM</th>
<th>Six Sigma</th>
<th>CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>No or small structural changes</td>
<td>Strong</td>
<td>Strong</td>
<td>Medium</td>
<td>Weak</td>
</tr>
<tr>
<td>Easy to understand</td>
<td>Strong</td>
<td>Medium</td>
<td>Weak</td>
<td>Medium</td>
</tr>
<tr>
<td>Usable directly in daily work</td>
<td>Strong</td>
<td>Medium</td>
<td>Weak</td>
<td>Weak</td>
</tr>
<tr>
<td>Fast results</td>
<td>Strong</td>
<td>Medium</td>
<td>Weak</td>
<td>Weak</td>
</tr>
<tr>
<td>Possibility to evaluate economic benefits</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Medium</td>
</tr>
<tr>
<td>Involve all personnel</td>
<td>Medium</td>
<td>Medium</td>
<td>Weak</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Figure 33: Ljungström’s evaluation of some improvement methods.

5.4.2. Evaluation of the Improvement Methods

A note on the definition of low support is that the method does not have strong support of the criterion, i.e. it does not mean that it is a bad method regarding that criterion. An example is that even if Lean production scores weak support, on many criteria, it does not mean that Lean production is a bad choice of method. It means that it is a more difficult method to use, as there is less support on the criteria.

About organisational support, none of the methods has strong support, but the less extensive methods tend to meet less resistance. All these methods imply some sort of change, and of course, the more extensive methods would bring larger change. However, in, for example, Six Sigma and BPI the organisation of the change teams supports this criterion. Further, if a new method has a means of adapting to the company’s way of working, it should greatly increase the chances of success.
The evaluation results are made in four categories. Furthermore, this evaluation is made in relation of the improvement methods described in this thesis:

- **1 = Weak or low support**
  
  If a method does not include sufficient, unambiguous described support for a specific criterion, it renders this classification. The meaning of sufficient unambiguous described support is when the method has a module or part describing how to fulfil the criteria, such as the TPM OEE measurement for measurement base, while TOC as a method does not have defined measurement. Another example is that TPM clearly implies improvement of machine utilisation while TQM has a wide scope, which is ambiguous on implication of what to improve.

- **2 = Partly supportive**
  
  This category is used to describe criteria support that is either unambiguous or has a sufficient criteria support, such as the implementation support of BPR/BPI that describes an implementation organisation, but the method is highly specialist dependant which makes implementation difficult any way.

- **3 = High support**
  
  This is the opposite of weak support, if a method has sufficient unambiguous support of a criterion, which is not overshadowed with another criterion such as a specialist dependency flaw.

- **N/A = Not Applicable**

<table>
<thead>
<tr>
<th>Method</th>
<th>Specialist Supportive</th>
<th>Competence Supportive</th>
<th>Implementation Supportive</th>
<th>Measurement Based</th>
<th>Object Supportive</th>
<th>Organisational Supportive</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
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<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
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<td>3</td>
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<td>1</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
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<td>1</td>
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<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>RPA</td>
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<td>2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
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<td>N/A</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
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<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
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<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Five S</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>CI</td>
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<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Decision</td>
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<td>1</td>
<td>N/A</td>
<td>2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Figure 34: Evaluation of the methods described in this thesis.
Some methods’ support regarding which improvement objects to start with is weak. TPM, TOC and SMED are very clear on what to improve and change, while in the other methods this remains an open issue. Naturally, help with what object to change, acts supportive in the improvement work.

Implementation support, varies among the methods. For example, TPM has an implementation guide in seven or more steps, 5S has five steps for the implementation of Continuous Improvement.

Finally, about measurement support, there are some methods, which have strong support of this criterion, while others have weak support. An example of strong support is TPM with the OEE measurement base. An example of weak support is Lean Production and SCM; there are statements in the concepts that show the importance, but the actual method does not support measurement work.

When studying the methods from the viewpoint of the criteria, there is no method, which has strong support in all criteria. A new method should have support in all criteria to increase the chances of success.

The Improvement Method described in Chapter 6. The Performance Improvement Method, includes some parts from each of these methods, which are supported by the criteria. The specific parts are presented together with the method. One of the most important things is that a performance improvement method should be usable in many business settings. This can be done using performance factors and a pre-study phase.

To discuss the evaluation in Chapter 8 Conclusion and Critical Review, we summarise Figure 34’s Columns and Rows:

<table>
<thead>
<tr>
<th>Specialist Independent</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competence Supportive</td>
<td>18</td>
</tr>
<tr>
<td>Implementation Supportive</td>
<td>24</td>
</tr>
<tr>
<td>Measurement Based</td>
<td>31</td>
</tr>
<tr>
<td>Object Supportive</td>
<td>21</td>
</tr>
<tr>
<td>Organisational Supportive</td>
<td>22</td>
</tr>
</tbody>
</table>

If we compare the criteria to each other, we see that the measurement criterion has stronger support than the other criteria.

<table>
<thead>
<tr>
<th>TPM</th>
<th>JIT</th>
<th>TQM</th>
<th>Lean</th>
<th>BPR</th>
<th>BPI</th>
<th>Sigma</th>
<th>DFT</th>
<th>SCM</th>
<th>TOC</th>
<th>RPA</th>
<th>DES</th>
<th>Mapping</th>
<th>SMED</th>
<th>5S</th>
<th>CI</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>7</td>
<td>11</td>
<td>6</td>
<td>10</td>
<td>6</td>
<td>11</td>
<td>4</td>
<td>7</td>
<td>8</td>
<td>13</td>
<td>10</td>
<td>9</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The above table shows a comparison between the methods and it shows that some methods have stronger overall support than other methods do. These values are later used to compare The Performance Improvement Method developed in this thesis.
6. THE PERFORMANCE IMPROVEMENT METHOD

This Chapter presents the new Performance Improvement Method.
6.1. Overview Of The Method

The method described in this Chapter will be referred to as the PIM, the Performance Improvement Method. The PIM is a synthesis from several analysed sources:

- The pilot cases, see the next Chapter 7.3 Pre-Case Studies of the PIM
- The analysis of improvement methods described in Chapter 5 Performance Improvement
- The problem description in Chapter 1 Introduction

Physically the method is in a ring binder with pages of pictures and explanations. See 10.2 Appendix and Figure 36. In addition to the ring binder there are templates made in Excel with tools and forms, including:

- Planning forms and tools
- Pre-study forms
- Process mapping tools
- Measurement forms and tools
- Improvement suggestion list

The Suggestion list template offers possibilities to sort and search among the suggestions. The PIM, as it was presented to the case participants, is included in the 10.2 Appendix.

In short, the method is divided into three phases with seven steps in total. The steps in turn include activities, see Figure 35. Each phase should be repeated until it is finished before a new phase is begun. The first phase includes pre-steps such as planning and pre-studies. The second phase deals with measurements and observations. The third phase is about analysis of results and implementation.

Step 1. Planning includes the activities Processes and Planning. Processes is an activity for dividing a complete site or larger processes into smaller more manageable sub-processes. The activity Time is to plan when in time all pre-studies and measurements should be performed.

Step 2. Pre-study describes how the pre-visits should be conducted. Furthermore, Pre-study includes the activities of Factors, Interviews and Control. There should be one pre-study conducted per defined sub-process from the previous step of Planning. Factors is an activity to make an evaluation of the performance factors to see which factors have improvement potential. The Interviews should generate more information about the sub-processes’ factors. This activity helps with the retrieval of information about factors, which are difficult to observe, such as motivation. Further, the Interviews can give a good picture of the improvement potential. The activity of Control is about defining control figures, which monitor outcomes that are found to be important from an improvement point of view. All
these activities have results, which are used in later steps; e.g. the data retrieved in the step of Pre-study are processed in the Analysis step. See Figure 35.

Step 3. Process mapping is the making of process maps of all the sub-processes defined in the first step.

Step 4. Process Measurement is the measurement of all the sub-processes according to the PIM’s instructions, updating the process maps with the new data. See Figure 35.

![Figure 35: The improvement method with Phases and the seven steps, each step includes activities under the step name.](image-url)
Step 5. **Analyse** is the analysis of measurement data and process maps to retrieve more improvement suggestions. Furthermore, there is selection and prioritisation of suggestions in this step. This step has many inputs from earlier steps, see Figure 35.

Step 6. **Implementation** is about implementing improvements. The input for this step comes from the step of Analyse.

Step 7. **Evaluation** is to evaluate improvement progress, and then restart the complete work. The step of evaluation and the Pre-study step could be performed as a common step in a repeated run. This step also includes the writing of a report.

---

Figure 36: Pictures of the ring binder with the PIM and a screenshot of the Excel document with same content.
The intended group size for use of this method is 5 to 6 participants with good knowledge of the area in need of improvement. The group should consist of:

- At least two operators with extensive insight of details related to production.
- 1 - 2 support people who work with operation engineering
- 1 - 2 people from middle management level, for increased support

The members of the group must be interested in this type of work and feel that it is rewarding for them. One way is to let the members recruit themselves, i.e. if they want to participate after they have seen the method’s approach.

All the results should be documented in the forms provided in the Excel file of forms and tools included in the ring binder. The data documented should later be used in a report written by the group.

6.1.1. **Step 1 Processes**

This step consists of one activity and it is about dividing large processes into smaller, more manageable parts. A complete plant is often too large to handle as one process, so it should be divided into smaller parts. This may already have been done in some way. Plants have departments and other natural dividers, which can be used for this activity.

To be able to perform all measurements and mappings, each defined sub-process must be of an adequate size. What an adequate size is can be difficult to determine. If no one in the improvement group can make this decision, a measurement study must be done before the group plans the rest of the studies.

An important task is to plan the time allocated for this work. After the sub-processes have been defined, it can be seen how many measurement studies that are required to cover the intended improvement areas. It is important to remember that if several shifts are used, all shifts must be studied. The Excel template includes a timetable to help plan the time.

The result from this activity should be defined sub-processes. Further, this activity is synthesised from the BPI work method of processes and pre-cases, described later.

Further, this activity should be visualised with the aid of the Excel templates. All the results from the activities should be documented in the forms. These are later put together in the form of a report, which is intended to help communicate the results from the improvement work.

6.1.2. **Step 2 Pre-study**

This step includes three activities: Evaluation of factors, Interviews and Control. The purpose of these activities is to gather information regarding improvement areas in an early stage of the improvement project. Interviews are used to gather
more information about improvement areas, which may be difficult to observe; examples of this can be routines and insufficient leadership. The control figures are another source for improvement areas. The pre-studies also get people’s attention and focus which is helpful when performing improvement work.

There are two main approaches when identifying a problem area. First, the problem can be identified with input from the pre-study. Second, the problem can be defined from the client who has ordered the improvement work. However, no matter how the problem is defined, it is important to set clear goals for the improvement work.

The factors are evaluated and documented in forms. The evaluation is documented into two categories: red or green. First, if there is no improvement work and inferior results are connected to the factor, this renders a red factor and means that it is a potential improvement area. Factors that show good results should be marked green and should not be addressed any further. This evaluation should be done at the factor’s location, e.g. on the production floor. Further, the factors which are difficult to evaluate through observation must be complemented with interview questions; for example, what is the supplier’s quality of material like, can you show me scheduling data, etc. The PIM includes explanations of each factor and directions on how it can be evaluated.

The interviews should be done with people who work in the processes that are visited. This should generate input regarding improvement areas. One positive side-effect of interviews is that the PIM practitioners have the chance to explain what they are doing, which should increase support. One must not forget to interview leaders on what they perceive as being important regarding improvement work.

All companies have some monitoring of performance. This should be used to align the PIM work with the company goals. By choosing five well-defined (by the company) control figures to work with, additional focus can be directed towards the improvement work. Another advantage is that this can increase support among the leaders, as parts of the improvement work are focused on problems shared by the leaders, i.e. the leaders also want improvements in these areas.

Expected results are a preliminary conception of what the main problem areas are; however, this is not yet supported by measurements.

The identified problems must be well accepted by both the company leaders and the employees. If not, they must be well supported by measurements. If a practitioner defines a problem, which is not well accepted and difficult to prove with measurement data, a good result can be difficult to obtain in the implementation step. Further, if the practitioner’s view differs from an accepted view, the practitioner should reconsider pursuing the actual problem before making it acceptable to others, as it is very easy to switch focus from improvement work to fruitless discussions.
6.1.3. **STEP 3 PROCESS MAPPING**

This step of the PIM involves in-depth investigations using of the steps 3. Process mapping and 4. Process measurement. For practitioners of improvement work, process mapping is a useful tool to use to get a visualisation of sub-processes, which should be investigated. Process mapping provides better understanding regarding how the production processes are organised and in which order products are made. This information can be used to identify unnecessary steps and actions performed in the processes.

The symbols used for process mapping according to the PIM:

- Inflow, where material enters the process
- Decision, when material can follow different paths
- Inventory/Buffers, where material is stored
- Information, info about the material
- Operation, where material is processed
- Transport, where material is in transit
- Outflow, where material leaves the process

There is a template appended to the PIM in the form of an Excel file, which should be used. The symbols represent different states that the material or services pass through within a process. The symbols should be arranged in the same order as the process. Further, the symbols should be connected with arrows so flows can easily be followed.

The result of this activity is process maps of the sub-processes, defined earlier. This step is synthesised from the analysis in Chapter 5.3.3 Process Mapping. This activity should support the competence enhancing criteria as process mapping increases knowledge of the studied processes. The next section describes how to make process measurements and it is connected to the process mapping, since all process maps should be measured.
6.1.4. **STEP 4 PROCESS MEASUREMENT**

The measurements are supposed to create facts for practitioners to find improvement suggestions. Together with the process maps and the study of factors, this should form a basis on which to build improvement suggestions. All measurements should be documented in the forms appended in the Excel file. Further, the facts gathered from process mapping and measurements should help the practitioners to communicate why, where and how improvement is supposed to take place. This step forces the practitioners to be involved in the processes for a long time and gives them in-depth understanding of the processes and the production system. Further, these measurements are derived from the findings in Chapter 4 Performance Factors and Process Measurement.

The measurements, which should be conducted according to the PIM, are:

- Lead-time, from the start of sub-processes to the end of sub processes, measured in minutes
- All transport distances and lead-times should be documented
- Queue, all queues are measured in units every 15 minutes
- Lead-time in inventories are documented and measured in minutes
- Capacity, what the resources can produce, measured in units
- Tact, the demand for units from the next process, stated in units per hour
- Downtime, the time, in minutes, when machines are non-functional
- Staffing, how many people are working in the process, measured in number of persons
- Scrap, material thrown away because of defects, measured in units
- Rework, material in need of adjustment to be functional, measured in units
- Reset-time, time to change machines set-up to produce different parts, measured in minutes
- Inflow, the accumulated material entering the process, measured every 15 minutes in units
- Outflow, the accumulated material leaving the process, measured every 15 minutes in units

The result from this activity is data, which should be documented in the process map. The tool used for this is called bubbles and is found in the Excel file. The data should be entered in the bubble as shown in Figure 37. Further, the results from this activity should be analysed further to find additional improvement suggestions; the PIM includes recommendations on how to do this, see the next step.
6.1.5. **STEP 5 ANALYSE**

The work carried out here should give results in the form of improvement suggestions. As these suggestions can be many, there must also be support for selection of these suggestions. The previous steps have provided data from measurements and improvement suggestions from earlier observations. This step includes activities of analysing data from earlier steps. Further, one should connect identified improvement factors with defined control figures and prioritise among the improvement suggestions.

The method, gives aid for the analysis of data, through a set of recommendations, see the Appendix:

*Elimination of unnecessary process steps*

Analyse the process maps, find process steps, which can be removed, moved or simplified for an improved flow.

*In and out flow*

Flows should be levelled and adapted to demand. If not, this is grounds for queues and longer lead times with more losses. Analyse the measurements of flow to find peaks and dips, which can be levelled.

*Queues*

Queues should if possible first be eliminated. If this is not possible, they should be reduced. Analyse the forms of queues and find improvement suggestions.

*Lead-times*

Analyse the measured lead times, find long or lead times with high variation; create improvement suggestions to shorten and stabilise lead times.

*Inventory*

Inventories increase lead-time, and should be shortened or eliminated.
Transport

Transport indicates process steps, which can be integrated or eliminated. Use the process maps for analysis of transport. Suggest how the process steps can be changed to minimise transport.

Operations

Use the operations form and analyse the values to find improvement suggestions. Indicators to look for here could be: is the capacity sufficient, is the actual output paced to tact, is downtime too high, could scrap and rework be decreased, etc.

When the measurement data has been analysed, it is time to decide in which order the improvement suggestions should be done. This selection should be made in several ways. First, the control figures generated in Phase one should be used to connect improvement suggestions with the control figures they might affect. The suggestions tied to the control figures should be prioritised which generates a number of focus areas, e.g. the factors that were identified as improvement areas. Second, in each focus area, the suggestions should be prioritised with the tools described in Chapter 5.3.7 Decision Support. Furthermore, the suggestions should be documented in the Excel form, which has pre-made categories; each suggestion should be sorted according to:

- Suggestion, a name of the suggestion and an explanation
- Category, which Category from Figure 20, the factor model, that suggestions are linked to
- Factor, which Factor from Figure 20, the factor model that suggestions link to
- Benefit, what benefit the suggestion is supposed to give
- Focus Area, built on the control area from Phase one
- Responsible, indicates who is responsible for implementation of the suggestion
- End date, when implementation should be finished
- Reason for rejecting a suggestion; if the suggestion is rejected, leaders must explain why

The purpose of this activity is to bring order and structure to the suggestions. This order is then used to formulate an implementation plan. The expected result is an implementation plan, which clearly states deadlines and who is responsible people for implementation activities.

6.1.6. Step 6 Implementation

This step includes the activity the actual improvement of the suggestion derived from the previous steps. This method only gives some general guidelines on how to organise an implementation project. How this should be done must be adapted
from time to time, depending on where the performance improvement takes place.
The implementation project must be based on the leaders’ initiative; in addition, the implementation plan must be agreed to by all involved. Some of the people who participated in the earlier phases must continue to work with the actual implementation. The expected results are implemented suggestions.

6.1.7. Step 7 Evaluation
The pre-study, which was done in Step 2, should be done again to track change. This activity is very much the same as in Phase 1, and can be coordinated as both a follow-up and the start of a new performance improvement project. Improvement work should be an ongoing process and not just a project. However if an improvement project is conducted as suggested it could be called continuous improvement. Between the start of improvement work there should be time for reflection and documentation of the lessons learnt.

6.2. The PIM´s Intended Criteria Support
The steps of the PIM are supposed to fulfil the criteria described in Chapter 1 Introduction, here described for each criterion.

C1 Usable by non-specialists. For a method to be usable for non-specialists, it must be easy to understand, easy to use, supportive regarding communication of goals and results. The Methods, which partly fulfil this criterion, are Process mapping, SMED, Five S, CI and decision support.
The specialist dependency is alleviated by the instructions on how to start the improvement work. Further, it is alleviated by the method of finding relevant problems in the pre-study step. The evaluation of factors should give a good basis on which to start the improvement work. Further, the factor model is used to make the PIM more understandable, see Chapter 4.1 Performance Factors.
In addition, to be easy to use, some basic conceptions from production engineering are used, such as queues, staffing, material flows, lead-times, transports, resource wastes as downtime, and time in inventory, which also is found in the factor model.
The PIM starts with a feasibility study to find out what to start to analyse in more depth, this also helps to start the improvement work. This is important, as this generally should help practitioners to start improvement work. A Pre-study step is omitted in most methods described in Chapter 5 Performance Improvement. Connected to this, there is an activity to find important measurement figures to base the improvement work on. This should assist with communication of goals
and results with the improvement work, support for this is found in Chapter 3 Defining Performance Measurement. The PIM provides detailed instructions on how to conduct each step sound in the PIM.

C2 Competence enhancing. For a method to be competence enhancing, there must be strong support on how to perform steps and actions. This can either be made with education, as in the case of Six Sigma, or with a thoroughly described action plan. The PIM is supposed to be a thoroughly described method for the performance of improvement work. It is believed that if the practitioners perform the improvement work themselves, they will learn better.

The feasibility phase should also be competence enhancing, as time must be spent considering the factors and dividing the operations into sub-processes. When the cases, described in Chapter 7 Case Studies were performed, the time spent using the method was up to 8 weeks, depending on the size of plant. The time spent measuring the production system should give good knowledge of the production site. The measurements should also give a good understanding of the basics of production engineering knowledge. The choice of measurements should also support the criterion of non-specialist support, as this is hold at a basic level in the PIM.

C3 Implementation supportive. For a method to be implementation supportive, it is important that the suggested improvement has support amongst personnel and leaders; this should be accounted for, as it is personnel from their own organisation who perform the improvement work. Support from the leaders should come with actions of finding control figures and goals, which is found in phase 1 of the PIM.

However, the implementation step in the PIM is not well formalised well; the reason for this was the design of the evaluation cases. Where the PIM should be evaluated up to the implementation phase, this due to the time for a full implementation. However, some results regarding implementation were derived and are found in Chapter 7.4 Evaluation Cases. Furthermore, there are some further recommendations for improvement of PIM in Chapter 7.4.

C4 Based on performance measurements. For a method to be based on facts, measurements must be used; however, these measurements must not be too complicated. The list of performance measurement models below should be of use when studying operations, see Chapter 4.3 Process Measurement:

- Queues
- Staffing
- Material flows
- Lead-times
- Transport
- Time in inventory
- Resource wastes: as downtime, capacity, tact, staffing, rework and scrap

To increase the support when making these measurements, the PIM has pre-made forms and instructions, which can be used. Further, these activities also act as a competence enhancer, since measuring the studied production system gives greater understanding when observing the system.

C5 Supportive regarding choice of improvement object. To be able to decide what to start to improve, the PIM has a feasibility phase; where users are supposed to evaluate all performance factors listed in a form, see the Appendix. After this evaluation, a number of factors should form a basis for further studies.

C6 Not act against organisational resistance. To form a method, which does not act against company culture, support needs to be built among staff and leaders. This is done here with participation from the organisation in the improvement project, and a step from the method’s feasibility phase is to pick five control figures. In addition, the documentation formed by the project participants should also be used to communicate plans and results. Furthermore, the documentation is also invaluable when doing follow-ups. This activity is synthesised from material in Chapter 5.2.5 Business Process Reengineering and 5.2.6 Six Sigma.
7. **Case Studies**

This chapter is a presentation of the case studies that have been conducted for the research presented in this thesis.
7.1. The Case Studies

Two types of case studies were performed in this research, namely pre-study cases and evaluation case studies. In total there has been eight cases conducted. The pre-study case studies were conducted as exploratory case studies and were conducted before the PIM was finally formalised. The purpose of the pre-study cases was to get empirical knowledge on how an improvement method should be designed to meet the criteria described in Chapter 1 Introduction. The evaluation cases were made to assess how the developed PIM meets the derived criteria and objective of this research. Further, the evaluation should also answer if the PIM could deliver improvement suggestions as anticipated.

7.2. Posten Context

Most of the cases have been conducted at Posten. For this reason, a short description of Posten’s operations is made here for context purposes. The flow of postal material varies, partly depending on which time and what kind of letters we are looking at. The processes are divided in two main processes first and second-class letters. First class letters must be delivered over-night and second-class letters are to be delivered within 3 days. Further, these processes are divided into two parts, collection and distribution sorting. The products handled in these processes are letters, flats, bulky letters and flimsy letters.

In the collection process, mail is collected from mailboxes, distribution centres and customers and transported to a sorting centre. Most of the mail is handled by machines in several processes. The rest of the mail is handled manually because of odd shapes, flimsiness and the inability for the machines to read addresses. The
order of processes is that the unordered mail is culled and faced during the collection process. Further, mail directly from customers and large distribution centres can be pre-sorted, pre-culled, and pre-faced. This mail comes to the sorting centre in mail carriers, which contain from 50 – 250 mail pieces, depending on what kind of mail it is. The ordered mail is transported directly to the sorting resources. See Figure 38 for a schematic process map of the flows.

At the spread process, mail is collected from other sorting centres. This mail is then sorted for the distribution centres. This is done at night. See Figure 39. Both machine and manually operations are used in this process.

Second class letters are handled in the same way as first class letters, but this is done during daytime.

This is a list of production resources used at sorting centres:

- Robots and conveyors
  
  All sorted and pre-processed mail are placed in mail carriers which in turn are placed on conveyors that transport the carriers to robots which sort the carriers to the right sorting centre or distribution centres.

  Incoming mail, both from other sorting centres and large customers, are placed in carriers, which are sorted internally by robots.

- Culling machines
  
  These machines handle mail that arrives from mailboxes. The mail is transported to sorting centres in sacks. To make it possible to run the mail in machines, the mail must be ordered and faced properly. This is done with culling machines.
• Sorting Machines
In this process the machines read addresses, print a barcode on letters, and sort them accordingly. These machines have a typical capacity of 30,000 units per hour, approximately 8 letters per second.
The addresses which cannot be read by the machines are video coded, i.e. a picture of the letter is taken and sent to a centre where people read the address and type the correct code.
Machines are used for all products except for flimsy items which require manual work all through the process.

• Manual sorting
Mail, which for different reasons cannot be handled by the machines, must be manually sorted. Around 30% of the mail is handled manually.

All mechanised resources are monitored with OEE measurements, except for conveyors and the robots connected to the conveyors. The processes are monitored with measurements that are built on the weight of the mail and the number of processed items in the machines. For the leadership process, measurements such as balanced scorecard and quality monitoring are used. In 2000, Posten Production won the Swedish Quality Award for large organisations.
The differences, from an improvement point of view, between a Postal production and a manufacturing site are the use of warehouses, storage of components and finished articles, which manufacturing sites have but Posten does not. Further, there is no need for a MPS and MRP system as all received mail should be delivered just a couple of hours after it has been received. Otherwise, Posten and other companies share the same problems regarding performance improvement, i.e. losses in the processes.

7.3. Pre-case Studies Of The PIM
7.3.1. ABB Robotics AB
The PhD students within the Productivity Project, see Chapter 2.1 Research Context, performed this case study. The case study was conducted at ABB Robotics in Västerås. ABB Robotics is one of the world’s leading robot manufacturers, and has since 1974 sold and installed more than 90,000 robots around the world. ABB Robotics had at this time about 650 employees and a turnover of around 300,000,000 dollars per year. ABB Robotics actively works with development and improvement of its production system to be able to improve the service to their customers.
The complete report of this case is published as:


**Objectives**

The first objective was to investigate how ABB Robotics works with their productivity development in order to identify potential areas for productivity improvements.

The second objective was to formulate a theoretical base for the improvement of productivity in manufacturing companies; which in the future could be developed into a general method.

The third objective was that ABB Robotics could use the results from this case study for productivity improvement.

**Method**

This case study was conducted as an exploratory case study with a diagnosis action approach in the following way. An investigation of ABB Robotics was performed through reading internal documents related to performance outcomes. Twenty-seven interviews were conducted, from top-management to bottom-line-operators. Further, the production site was also investigated to identify improvement areas.

A literature survey was done concerning measurement definition, key factors driving productivity and improvement work practicalities. From this survey, a theoretical base of how to improve and define productivity was developed.

A comparison between the developed theoretical base and the findings at the company’s site was done to find improvement areas. The comparison resulted in several identified improvement areas. An additional literature survey, concerning the identified improvement areas, was conducted before the final recommended improvement areas were presented. The case study was performed in a two-day period in the year of 2001.

**Industrial Results**

A number of improvement suggestions were derived during this case study. The utilisation of assembly stations was relatively low; the researchers believed that this was mainly caused by lack of input material for the assembly. The reason for the lack of input material was simply a lack of parts, but also defect parts entering assembly.
Monitoring waiting times was found to be important as many losses were generated from waiting time in the production process. To keep track of waiting times, a measurement system was suggested. By using the suggested productivity measures shown in Figure 40, it would be possible to clarify losses tied to the waiting time. The improvement areas, measurements and interrelations are described in Figure 40.

Some improvement suggestions concerned the distribution of information throughout the supply chain. The information should include forecasts and quality feedback to suppliers. This could also help ABB Robotics to keep track of which suppliers have a short delivery lead-time and a low delivery of defect parts. Further, in-house machining of key components could reduce vulnerability in assembly; making use of standardised components for all robot families and each product family.

**Academic Results**

A theoretical frame of reference was formed, which has been used in this thesis. The frame covers productivity definitions and practical improvement work such as the factors model and the importance of interviews.

The factor model, see, Chapter 4.1 Performance Factors, was first tested during this case and proved useful both as an analysis tool and as a tool for finding improvement areas. The interviews were an important input to find improvement areas such as lack of material. Further, the interviews were found to be important and should be included in a future improvement method.
A general need for a structured improvement method was identified as there were many improvement attempts, but they were not sufficiently coordinated and communicated. However, ABB Robotics had plans to make a mechanised line, and start to use DFT, to cover this need.

For improvement practitioners, the tool of process mapping should be used as this gives a good picture of the manufacturing within a short time span. The importance of measurements connected to improvement work was detected here; the researchers were dependant on secondary sources such as interview material, which could not be thoroughly verified by the researchers. Without this base of verified facts, found issues could easily be disputed. The case gave important input when forming the first Sub Objective and to find the relevance of this research project.

7.3.2. Posten AB, Study at The Gothenburg Sorting Centre

The Mail Sorting Centre in Gothenburg employed around 900 people at the time of the case study. For a further description of the production site, see Chapter 7.2 Posten Context.

The complete report of this case was published as:
Grönberg T., Postterminalen i Göteborg har bittat sin flaskhals, Bättre produktivitet med PLAN Nytt, nr 5, 2002.

Objectives

The case study was initiated as a project to solve problems regarding the capacity of the mail centre. There was, however, no clear picture of what the problems really were, so the first task of the project was to identify these problems.

The scientific objective was to explore how improvement work could be conducted.

Method

The project group was composed of participants from both production and support staff. The author of this thesis acted as a full partnership action researcher within that group. Further, the case was an exploratory case.

The members were selected from different parts of the organisation. The purpose of this was to get insights from different areas, such as engineering and leadership.

In the beginning, the movie The Goal was seen by the project participants, to get all participants of the project on the same track. The philosophy of OPT is more

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2 The Goal is a film version of the book with the same name, that describes OPT, see Chapter 5.2.9 Theory Of Constraints.
easily conveyed to larger groups through the movie, rather than having everyone read the book.

A brainstorming process was carried out to create a list of potential bottlenecks at the production site. A discussion could later on reduce that list to the minimum. However, further investigations were needed to conclude which of the potential bottlenecks that really was a bottleneck. The improvement project was conducted according to the principles of TOC, see Chapter 5.2.9 Theory of Constraints.

**Industrial Results**

As a first result, it was identified that there was little knowledge about bottlenecks amongst the production personnel, which were solved with everyone watching the movie *The Goal*. The second task was to identify the bottlenecks.

Tied to the five steps of TOC, see Chapter 5.2.9 Theory of Constraints, numerous measurements were conducted, in order to find the bottlenecks.

The results are listed as some of the steps of TOC.

- **Identification**
  
  Firstly, measurements of the queues in front of the resources identified from the brainstorming were conducted. Two of the resources were distinguished by the fact that queues were identified in front of them.
  
  To really decide which of the resources that was a bottleneck, further measurements were conducted see Figure 41. The measurements revealed that one of the resources was a bottleneck, since the demands on the resource at certain times was greater than the capacity of the resource.

- **Exploitation**
  
  Exploitation should be that more capacity could be gained by using manual labour as a complement to the machining resources to alleviate the bottleneck.

- **Elevation**
  
  The actual implementation of the manual labour to increase capacity was easily done, since it consisted of manual labour. The work with the flow was more difficult because of the complexity of the deliveries to the mail centre. If volumes are moved from the time when full capacity is reached to an earlier time, capacity is freed.
An unexpected result was that after a couple of days with queue measurements, queues seemed to vanish. The reason for this was that focus was set on reducing queues, and at non-bottlenecks, the queues disappeared.

**Academic Results**

The main result was a first structure to conduct improvement work. For a thorough improvement method, there is need for measurements; this case study showed that without measurements the bottleneck would be hard to detect. Further, the method of TOC does not handle measurements support, which proved to be important for finding bottlenecks. This was important, as there were queues at non-bottlenecks as well.

The conclusion regarding the project was that this structure of improvement work was an effective work method, shown by an increase in capacity. Results from this work were insights concerning how an improvement work could be conducted. The idea of a pre-study was born here.

**7.3.3. POSTEN AB, EVALUATION OF A PROCESS MAPPING MODEL**

The case study was carried out at the Swedish Postal Mail Sorting Centre in Gothenburg. Gothenburg Mail Sorting Centre employs around 900 people. For a further description of the production site, see Chapter 7.2 Posten Context.

The process mapping objects were two mail-sorting machines, with an automatic unloading feature and a conveyor system.
The complete report of this case is published as:


**Objectives**
The main objective was to evaluate the usefulness of the proposed model to describe a process. The other objective was to see if the suggested measurements were relevant both for process mapping and for improvement work.

**Method**
A process-mapping model was theoretically generated by Anders Karlsson and the author. The model was later evaluated in an explanatory case study.

The process studied included an Alcatel machine, which sorts C4 letters, letters with A4 content, called flats. The outlet of the machine is fully automated with an automated conveyor transporting boxes with sorted letters. The capacity and the lead-times of the machine were mapped. Losses such as downtime, waiting time, and defective goods were also mapped. Furthermore, the personnel’s working time and the capital tied up in investments were also studied during this case. The total length of the case was two days and the actual mapping took one day. The remainder of the time consisted of process selection and information gathering etc.

**Industrial Results**
The model is described in detail in Chapter 4.3. Process Measurement. The use of performance factors and the generalised process model in combination with performance measurement is a powerful tool to use when identifying potential areas of improvement. The case study revealed a number of improvement areas such as:

- Bottlenecks
- Down-times
- Utilisation-losses
- Dead lock in the automatic conveyor system

**Academic Results**
As a conclusion, the model supported process-mapping work with consideration given to lead-times and losses. Furthermore, the model proved to be practical and
should be of use to non-specialists. With the aid of the model and the factors, the practitioners could effectively trace losses in the production system and identify potential improvement areas.

Further, it was empirically concluded that the activities of process mapping should be added to an improvement method, as it generated improvement suggestions.

**7.3.4. Posten AB, Study At The Malmö Sorting Centre**

This case study took place at the Mail Sorting Centre in Malmö. The sorting centre is about the same size as Gothenburg with around 900 employees.

The case is documented as:


**Objectives**

The problem was an upcoming change in the structure of time and volume of incoming mail, which would result in larger volumes and smaller periods to finish the production. The first processes at the mail-sorting centre were at the time already overloaded. The objective of the sorting centre was to find a means to increase the capacity of this process. The research objective was to explore an improvement approach, with the components listed in the above method section.

**Method**

Three of the Productivity Project members, see Chapter 2 Research Context, executed this diagnosis action research and descriptive case study during a one week period; with a one-day pre-study done three weeks before the actual case. The pre-study consisted of a site visit and a number of interviews.

The activities conducted by the researchers were:

- Interviews
- Material flow mapping
- Measurement of volumes and flow
- The use of the factor model
- Process mapping with queue, lead-time and staffing measurement
- Analysis of production data, such as machine utilisation
- Simulation of proposals
- Generation of improvement suggestions

All measurements data were analysed with the purpose of finding improvement suggestions.
Industrial Results

The Malmö site was given a plan for how they should work with improvements to alleviate the process. The improvement areas found in this case were:

- Machine utilisation improvements
- A stop of a machine that took 20 minutes to empty, manually it could be emptied in 2 minutes, to finish earlier
- Flow control of mail between resources to avoid bottlenecks
- Visualisation of machine utilisation for operators
- Change of mail inflow
- Production control by queue and inflow
- Tracking of early incoming mail volumes

A discrete event simulation model was used to verify the project outcomes. The simulation model was also helpful when visualising the results for the receivers of the results of this case.

Academic Results

This case showed that the structured improvement approach generated results in the form of improvement suggestions. The case further showed that these results could be obtained quickly.

A number of activities were verified as being important for improvement work:

- Pre-study
- Interviews
- Process mapping
- Measurement of volumes, lead-times, machine utilisation
- Proper documentation

The pre-study was very useful to identify the problem areas. At the time, the Read a plant fast approach was used.

One difficulty was to interpret production data as the data primarily was used for financial purposes. To monitor the financial consequences of production flows, data changes were made to suit the financial model which gave incorrect data for production analysis. Real production data were accessible through the machine systems and this could be used to validate used data. The implication is that wrong data can be used for production decisions.
7.4. Evaluation Cases Of The PIM

Four evaluation cases have been conducted at Posten. For the context see Chapter 7.2. Posten Context

Objectives

The first of three objectives of these cases studies was to evaluate how the PIM in practice supported the criteria, which are described in Chapter 1 Introduction. The second objective was to evaluate if the PIM worked, i.e. if the Method delivered improvement suggestions and supported performance improvement. For the sorting centres, this was seen as an opportunity to improve their operations. Further, this was seen as a way to offer education to their employees. The time was considered limited so there was no intention to evaluate the two last steps, Implementation and Evaluation. A handover was planned with the line organisation taking over the project results. However, the end of this research project was delayed, so some results regarding the implementation have been observed.

Method

The PIM was fully evaluated at four sites during a total of 7 months. It was conducted as four different projects, separated in time, by four different sets of people. In total, 18 people were involved.

In the first case, the participants were left alone as much as possible to see how well the method worked without specialist support, i.e. if the group could perform aided only by the PIM. The group was fully aware of this approach. In the other cases one of the participants from an earlier project participated in the new project to see if the method is supportive for this type of handover.

For all four projects, a group of five people was handpicked using the following criteria:

- Being able to work in a group
- Having good knowledge of the production
- Being accepted by management
- Being accepted by management

Interviews were constantly conducted with the groups; at least one interview per week. Further, personal interviews were added to verify what was concluded from the entire group. These interviews were conducted to keep track of progress and see if the groups got along with each other. Furthermore, they were also used to see how the group interpreted the instructions from the PIM. An important task was to see how the groups perceived the support criteria in the PIM.
In the third project, the author fully participated during the first 2 and the last two weeks. The purpose of this was to ensure that the dialogue between the project group and management was active during the project. The last project was performed with a member who had been participating twice before.

Three weeks after the projects were finished all participants were invited to answer a questionnaire, see below. The purpose of the waiting time was to give the participants some distance to their work. The questionnaire included 15 questions each with seven answer option.

The form included the following questions:

1. How much have you learned about the production site?
2. How much have you learned about production engineering?
3. How do you rate the results from the PIM?
4. How has the PIM group been accepted amongst the other?
5. How has the cooperation in the group worked?
6. How has the management interest been during the PIM?
7. How has management acceptance been after the PIM?
8. What do you think the effects of the suggestions have been?
9. Have you worked with similar methods before?
10. If yes to the previous question, how do you perceive the PIM?
11. Did the PIM support you during the work?
12. Do you think that the project leader supported the work enough?
13. Was the use of the PIM a good way to work?
14. Has this work been of personal benefit to you?
15. Will this work be of personal benefit to you in the future?

All leaders were also interviewed to get their input and perception on the projects and the support criteria of the PIM. These cases were descriptive with participant action research.

These projects were descriptive case studies made with full partnership action research.

Industrial Results

All groups were very engaged in their work, the effort they put into these projects was significant. One result was that the project participants valued their learning concerning both knowledge of the production sites and knowledge of production engineering.

The four cases generated more than 700 documented and fact based improvement suggestions. However, the number of improvement suggestions created difficulties for management when it came to handling them. This was caused by a lack of resources, which is an important finding as the number of suggestions demanded much from the leaders. This was also verified by interviews. Further,
there were comments that management felt the suggestions were spread over all areas, and that the suggestions differed in scope. This also made the suggestions more difficult to handle.

Figure 42: A diagram of staffing at three machines and the queue of mail to the machines showing that the inflow and staffing are unlevelled which creates waste.

Figure 43: Diagram of throughput of mail per hour, showing that utilisation between machines is uneven, but mostly it shows waste as the capacity of machines, about 32,000 units per hour.
The suggestions dealt with the following exemplified areas:

- Leadership
- Feedback to personnel
- Resource utilisation
- Staffing and rotation
- Shift handover routines
- Inflow structure of mail
- Work methods

The diagrams in Figure 42 and 43 show examples of collected data from the measurements performed. These measurements gave a number of improvement suggestions, see list above.

**Academic Results**

The first objective was to evaluate how the PIM supported the criteria derived in Chapter 1 Introduction.

**C1. Usable By Non-specialists.**

The method was self-sustaining from a project leader point of view, which was shown during the cases and the little effort by the author had to put into detailed explanations of activities regarding the PIM. This attribute of the PIM supports the criteria of being specialist independent. However, one should never neglect experience, which was shown in the following PIM projects, which had great support from earlier participants. Furthermore, the PIM held instructions on how to perform all measurements, which showed to be sufficiently supportive for the participants. This is important, as the criterion of specialist independence is the most important criterion.

**C2. Competence Enhancing**

Regarding the criteria of competence, the PIM is supportive. All participants felt that they had gained new knowledge about basic production engineering but also about the production site. It should be noted that the participants were people who already had good knowledge of the sites. The participants found the work very rewarding which was shown during the interviews and in answers given in the questionnaires, after the projects. As one of the participants stated:

“Before this project I honestly did not know what lead-times and OEE really meant and, when I got back to my ordinary work, all the others wondered what my talk about lead-times and OEE was all about”
C3. Implementation Supportive

The group participants felt that management engagement was weaker after the PIM had been conducted, see the answers from the form below. The main reason for this was the difficulties of implementing the huge number of improvement suggestions. This implies that the PIM has weaker support for implementation, and a direct result of this is a new activity suggested for the PIM. The new activity is that a coach from the project group should be working with the implementation and coaching the management. The black belt concept from Six Sigma could be useful to support implementation of the PIM suggestions. If the implementation criteria could be fulfilled with the new suggested activity, this would in turn increase the groups’ perception regarding management involvement.

C4. Based on Performance Measurements

Both project participants and leaders found the PIM supportive of the criterion of measurement, as it is a fact based approach. Further, the PIM was supportive when choosing improvement objects and to provide facts regarding problem areas. All other steps were found to be useful in improvement work.

C5. Supportive Regarding Choice Of Improvement Object

The factor model was found difficult to use by the project participants. They found it rather unnecessary, as they were already familiar with the production. However, they believed it could be useful when dealing with an unknown production facility. This lowers the factor models criterion support, but it cannot be rejected as unsupportive. This gives the PIM lower support on the criterion of choice of improvement object. However, the PIM's instructions on how to start the improvement project support this criterion.

C6. Not Act Against Organisational Resistance

The PIM proved to be supportive regarding the organisation resistance criterion. There were two main reasons for this. First, the group came from their own organisation, so this relation supports the work amongst their co-workers. Secondly, there is a PIM component of management involvement, which also supports this criterion.

The second objective was to evaluate if the PIM delivered improvement suggestions. There were over 700 improvement suggestions generated from the project groups. However, the organisations had difficulties managing this number of improvement suggestions delivered at one time. This was caused by a lack of resources, which is an important finding as it took long time to process the suggestions that resulted from the PIM. To be successful with improvements there should be sufficient resources allocated either in-house or in the form of consultants; preferably in-house as of the learning for in-house staff. The PIM should be updated with activities to solve these question marks. In the section of
industrial findings, there is a list of improvement suggestion areas. These suggestions have a higher quality compared to the suggestions normally derived in the day-to-day work; this was also verified by management interviews. These cases were documented by the groups as four separate internal documents.

The answers to the interview forms were used to verify the answers retrieved by the interviews. The answer values have been grouped into three categories:

1 – 2 Low, 3 – 5 Middle, 6 – 7 High

The reason for this categorisation is that the meaning of the answers is easier to analyse if they are categorised this way. The categorisation should not distort the results, the variation in answers within each category is difficult to distinguish from each other because of interpretations by the participants answering.

1. How much have you learned about the production site?
   Middle
2. How much have you learned about production engineering?
   High
3. How do you rate the results from the PIM?
   High
4. How has the PIM group been accepted amongst the other?
   High
5. How has the cooperation in the group worked?
   High
6. How has the management interest been during the PIM?
   High, on all except from one site were the rating was low
7. How has management acceptance been after the PIM?
   Middle, all except from one site were the rating was low
8. What do you think the effects of the suggestions has been?
   High
9. Have you worked with similar methods before?
   40% Yes 60% No
10. If yes to the previous question, how do you perceive the PIM?
    High
11. Did the PIM support you during the work?
    High
12. Do you think that the project leader supported the work enough?
    Middle, this was high from the last site were more time were spent
13. Was the use of the PIM a good way to work?
    High
14. Has this work been of personal benefit to you?
    High
15. Will this work be of personal benefit to you in the future?
    High
The case studies, the interviews and the questionnaires formed the evaluation of the PIM's criteria support, i.e. both an empirical and theoretical evaluation. This evaluation is connected to the summary of the problem description in Chapter 1.3.4 Problem Description and the PIM's intended criteria support described in Chapter 6.2 The PIM’s Intended Criteria Support. The PIM practitioner groups’ perception regarding the criteria support correlated with the theoretical evaluation described in Chapter 5.4 Review of the Performance Improvement Methods, and the author's empirical evaluation of the PIM. The PIM criteria support is, as described above:

- C1: It should be usable for non-specialists 3
- C2: It should be competence-enhancing 3
- C3: It should be implementation supportive 1
- C4: It should be based on measurements 3
- C5: It should be supportive regarding choice of improvement object 2
- C6: It should not act against organisation resistance 3

This result is higher than other methods gained in the review in Chapter 5.4 Review of the Performance Improvement Methods, which show that PIM support performance improvement.

1. = Weak or low support
2. = Partly supportive
3. = Strong support

For definitions of these evaluation categories, see Chapter 5.4 Review of the Performance Improvement Methods.

Management were satisfied with the projects, despite the implementation problems. Many leaders had seen similar improvement methods and rated PIM higher as a whole, compared to other similar methods. This is believed to be an effect from the specialist independency.
8. Conclusion And Critical Review

This Chapter discusses how the Objective and Sub objectives have been fulfilled. Further, a discussion on the quality of the research is provided. Suggestions for future research are presented as well.
8.1. Conclusion

This research has generated a number of results, they are both theoretically and empirically derived, they are listed below. The theoretical results are synthesised mainly from literature analysis, but also through discussions within the research community and industry. The empirical results are synthesised from the case studies.

In summary, the important theoretical results are:

- The problem description of Performance Improvement, described in Chapter 1.3.4 Problem Description
- The criteria of Improvement Methods, described in Chapter 1.3.4 Problem Description
- The Factor Model, described in Chapter 4.1 Performance Factors
- The Process Measurement Model, described in Chapter 4.3 Process Measurement
- The review of Improvement Methods, described in Chapter 5.4 Review of the Performance Improvement Methods
- The PIM (this was both theoretically and empirical derived), described in Chapter 6 The Performance Improvement Method and the 10.2 Appendix.

The empirical results derived from the case studies are:

- The PIM (this was both theoretically and empirical derived), described in Chapter 6 The Performance Improvement Method and 10.2 Appendix.
- Case results, described in Chapter 7 Case Studies
- The evaluation of the PIM's criteria support, described in Chapter 7.4 Evaluation of the PIM

The result from the comparison of the PIM's criteria support and the improvement methods criteria support is shown in Figure 44. The Figure shows that the PIM has a higher total support compared to the other methods, i.e. if the scores are added. The support is high on all criteria, except the implementation and choice of object criteria. The Choice of Object criterion is partly supported. The reason for this was difficulties to use the Performance Factor Model, which is described in Chapter 7.4 Evaluation of the PIM and. The implementation criterion has weak support and the reason for this is described in the same Chapter and was because of too many improvement suggestions.

The PIM had strong support in the criterion of specialist independency. This criterion proved to be the most important issue to overcome. See Figure 44 for the criteria support. The reason for this support is mainly the easy to use tools and instructions in the PIM.
1 = Weak or low support, 2 = partly supportive, 3 = Strong support
N/A = Not Applicable

<table>
<thead>
<tr>
<th></th>
<th>Specialist Supportive</th>
<th>Competence Supportive</th>
<th>Implementation Supportive</th>
<th>Measurement Based</th>
<th>Object Supportive</th>
<th>Organisational Supportive</th>
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<td>3</td>
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<td>2</td>
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</tr>
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<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
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<td>1</td>
<td>1</td>
<td>1</td>
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<td>1</td>
</tr>
<tr>
<td>BPR, BPI</td>
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<td>1</td>
<td>2</td>
<td>3</td>
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<td>2</td>
</tr>
<tr>
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<td>The PIM</td>
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<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 44: The improvement methods compared to the PIM.

The PIM scores 15 points on the overall support, a comparison to the other methods in the table below, and shows that the PIM has a stronger overall support.

<table>
<thead>
<tr>
<th>TPM</th>
<th>JIT</th>
<th>TQM</th>
<th>Lean</th>
<th>BPR</th>
<th>BPI</th>
<th>6 Sigma</th>
<th>DFT</th>
<th>SCM</th>
<th>TOC</th>
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<td>13</td>
<td>10</td>
<td>9</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
8.2. Critical Review

First, the discussion will centre on whether the objective and sub-objectives have been met or not. Secondly, how well has the PIM met the criteria? This is done as a quantitative evaluation. After that, we discuss how well this research has been done, the qualitative evaluation. Next, do the results of this research have any relevance, see 8.2.5 Academic and 8.2.6 Industrial Relevance.

8.2.1. Has The Objective Been Met?

The objective of this research project has been to:

*Develop and evaluate a method, which supports performance improvement in industrial operations.*

A method for performance improvement has been empirically and theoretically developed and described in Chapter 6 The Performance Improvement Method and 10.2 Appendix. Results used for the development of the PIM originate from the literature reviews and the four pre-cases. The evaluation of PIM has later been carried out through the four evaluation cases, which showed that the PIM supported Performance Improvement as it scored high support compared to other improvement methods. This is presented in Chapter 7.4. Evaluation of the PIM The context in the evaluation cases shows that the PIM has been evaluated in an industrial operations environment.

Therefore, the objective should have been reached. How well this has been done can be discussed, as there are many ways to support improvement work, such as consultancy aid. However, the problem description shows, which problems that is associated with performance improvement and this has been used throughout this research. Further, this research has not evaluated different approaches of doing this. Nevertheless, it is concluded that the use of the PIM gives improvement support, which meets the objective.

Another limitation is that the results of a method are constrained by the users. However, it is believed that a method with clearly described steps decreases this influence, but it is difficult to remove this effect completely, but the PIM was evaluated in four case studies and showed no such tendencies.

8.2.2. Have The Sub-Objectives Been Met?

*SO1: Define a research problem addressing Performance Improvement*

Chapter 1 Introduction describes problems associated with performance improvement and is synthesised into the criteria described in the same chapter. SO 1 is met by these criteria in Chapter 1.3.4 Problem Description and the description in Chapter 1 Introduction. Criticism towards the criteria used that can be raised is: are the criteria correctly chosen to describe the ability of performance improvement methods, to show results? Probably other criteria could also be
used to describe the ability to show results. However, the criteria used here should be sufficient as they are formulated from the presented problems with Performance Improvement.

**SO 2: Define measurements of Performance, which fit PI**

Chapter 3. Defining Performance Measurement and Chapter 4. Performance Factors and Process Measurement deal with this Sub-objective and should be met by the Factor model in Chapter 4.1 Evaluation of Factors and the Process Measurement Model in Chapter 4.3 Process Measurement. The criticism against the factor model is that there are many factors, which are not considered. However, for the model to be practical the number of factors must be restricted and the restriction is done with empirical considerations showed by the pre-cases.

**SO 3: Describe and evaluate existing Performance Improvement methods with respect to the criteria**

In Chapter 5.4 Review of the Performance Improvement Methods, there is a review of performance improvement methods and a table of how they meet the criteria is presented in the same chapter. There are most likely methods not reviewed here which have good criteria support. Nevertheless, the literature reviews and research community did not reveal such methods and this implies that these methods have not been scientifically evaluated and made public. However, the scope of the PIM is somewhat different as it is designed to be used by non-specialists and other methods usually are specialist methods. The evaluation of the methods could be criticised as arbitrary and is an effect from lack of definitions of the methods reviewed. However, the evaluation is verified with literature reviews, cases, and discussions with industry and academia, which should be sufficient for this research to support the results both theoretically and empirically derived, see PIM:s intended criteria support, Chapter 6.2 The PIM's Intended Criteria Support.

**SO 4: Design a Performance Improvement Method that meets the criteria**

Chapter 6 The Performance Improvement Method describes how a Performance Improvement Method could be designed to meet the criteria. This SO also raises criticism as arbitrary, but this was one of the main issues to be evaluated by this research, i.e. how the PIM meets the criteria and there are several sources of evaluation.
SO 5: How well does the developed method meet the criteria

Chapter 7.4 Evaluation of the PIM provides answers on how the PIM meets the criteria and Chapter 8.1 Conclusion, gives a comparison of the PIM compared to the other methods evaluated. The arguments against this research approach used are: were the right methods chosen and are the results correct? As this research follows a scientific method and has several sources for its answers, it is believed they are.

8.2.3. HAVE THE CRITERIA BEEN MET?

The criteria founded on the problem description in Chapter 1 Introduction.

- C1: It should be usable for non-specialists
- C2: It should be competence-enhancing
- C3: It should be implementation supportive
- C4: It should be based on measurements
- C5: It should be supportive regarding choice of improvement object
- C6: It should not act against organisation resistance

Not all criteria have been fulfilled with strong support. However, the PIM should be considered to meet the objective, since it has been shown to be performance improvement supportive. The most important criterion to fulfil for the PIM to be supportive is that it can be conducted by non-specialists. With further development of the PIM, the criteria support of implementation and choice of improvement object could be increased. See Chapter 8.3 Further Research.

The implementation criteria have low support, which is explained in Chapter 7.4 Evaluation of the PIM. The choice of improvement support does not have strong support, however the criterion is partly supported and this is explained in Chapter 7.4 Evaluation of the PIM. The remainder of the criteria have strong support also described in Chapter 7.4 Evaluation of the PIM, especially the important criterion, of being specialist independent. However, many improvement issues are complicated and there must be specialists involved in some of these issues, such as materials technology or environmental issues. The PIM is not aimed to reduce specialist dependency on such matters; it is aimed to be supportive on basic production engineering improvements.

8.2.4. QUALITY OF THE RESEARCH

The results have been validated with three different approaches: the academic paper, with discussions and case studies. According to Stuart et. al, (2002) several sources for validation should be used, to make research results plausible. This validation is done in four areas, also described below:

- The problem description
- The PIM development
- The PIM criteria support
- The research approach

The problem description has been published in journal papers, conference papers and industrial magazines; see list of publications page III. The conference and journal papers have been subjected to review before being published. Further, all results have been discussed thoroughly with colleagues, research fellows, and supervisors. The case’s findings also support the findings of the problem description. These three sources of evidence form a validation procedure for these results.

The PIM was developed with input from four different exploratory cases and input from literature reviews. Furthermore, a proposal of the PIM has been published in a journal. Validation is done from three different sources, which makes the validation plausible according to Chapter 2.3.7 Validity and Reliability. Furthermore, all cases of validation showed the same results, which imply plausible and reliable results. The pre-cases and literature review resulted in an improvement method. A problem up to this point was that the PIM had only been conducted by specialists. The method had to be formalised so it could be tested by non-specialists, which is showed in Chapter 6 The Performance Improvement Method and 10.2 Appendix.

The PIM’s criteria support was evaluated in four cases studies. Interviews were conducted with both participants and management to evaluate the PIM support. The evaluation cases had the same results each time they were conducted, which implies plausible results. Furthermore, the author has theoretically evaluated the PIM’s criteria support. This evaluation, together with the two types of interviews, gives three sources for validation.

This research builds on eight documented cases studies, which should be considered as a good basis for validation; all the cases showed the same results, which imply plausible results.

In line with the definition of Science in Chapter 2.3 Scientific Methodology Applied in This Research:

*Science is organised knowledge, as an activity it is a methodological retrieval, documentation and validation of knowledge within a specific area.*

The knowledge has been retrieved both empirically and theoretically in a systematic and methodical way. The systematic and methodological way is by literature reviews, interviews, discussions and planned cases. Documentation has so far been done in articles and a Licentiate thesis. Validation has been done through several sources both theoretically and empirically. The fulfilment of these steps, should make this research to a scientific research, that has followed the scientific method described in Chapter 2.3.1 The Operation Research Approach; this, in turn, is also validation of the research. This is further confirmed by the
traditional operations research described in Chapter 2.3.1 The Operation Research Approach. This research follows the described steps, only that the use of a hypothesis is changed to an objective, which also shows that a scientific method has been used.

The criteria used were retrieved from literature research and by the pre-cases conducted. Further, interviews also implicated that these criteria were adequate for evaluation purposes. These three sources imply that the chosen criteria were, for the purpose of this thesis, sufficient ones to use.

8.2.5. Academic Relevance

This work contributes to the academic area of performance improvement as there is new knowledge provided in the form of the models of factors and process measurement. This work has also given a foundation based on problems associated with performance improvement to evaluate the improvement methods. The derived criteria are a contribution in themselves as they describe requirements for improvement methods. New knowledge has been derived through the comparison of improvement methods from different academic fields, e.g. the competence part of Six Sigma. This cannot be found in other improvement methods reviewed here and that would have been missed if this wide approach had not been used. Some of the research project results have been published in several conference articles, journal and industrial magazines.

8.2.6. Industrial Relevance

The industrial contribution should be a scientifically evaluated improvement method. The method should be suitable for any company who wants to improve performance. The method has been proven to generate improvement suggestions and an increased improvement competence, which should be a contribution for industry. The criteria described in Chapter 1 Introduction are based on industrial problems and as the PIM should support work on performance improvement, this also makes an industrial contribution.

8.3. Future Research

Many of the improvement approaches and tools are concepts taken from successful companies and repackaged for implementation in other companies, e.g. TPS from Toyota and Six Sigma from Motorola. This can however be troublesome as this is done without regard to which approaches and tools the companies were already using.

Future research should be about developing a structured method for finding improvement method components, which are lacking in companies. These components could be evaluated with the criteria used in this research project. Furthermore, the method should be developed to recommend components for
production systems. A good basis for this work has already been done by Herron and Braiden (2006), however their approach is to find applicable Lean methods for correspondent improvement needs and do not aim to build a TPS equivalent. A development of their method and this work could form a relevant future research area.

8.4. Final Remark

It is concluded that the Objectives and Sub Objectives were met. Further, it is concluded that the development and evaluation of the PIM have been scientifically executed.

The PIM proved to have weak support in the implementation. To improve the PIM, there should be a coach from the project group after the improvement project is done. The coach should assist the management group in decision-making and practical implementation issues. The advantage of this approach would be that a so-called problem owner is used as support for the implementation.

The PIM proved to meet more criteria than the other methods reviewed in this research, especially the important criterion of specialist independency.
9. REFERENCES

The references used in this thesis.


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Y

10. **APPENDIX**

The appended PIM and a list of courses taken.
## 10.1. Courses Taken

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<thead>
<tr>
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<tr>
<td>4F5701</td>
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10.2. The Performance Improvement Method

Performance Improvement

A method to support performance improvement in industrial operations

Thomas Grünberg
Posten AB
The method in your hands is the result of a research project which aims to improve performance of industrial operations. The procedure in short builds on observations and measurements.

Two main differences between this method and other approaches are the estimation of factors which act as suggestions for improvement, and the focus on measurement. The measurements create facts to deal with instead of assumptions that in the worst case are wrong. Furthermore, measures are easy to communicate.

The target user group for this method is a group of 5 to 6 participants with good knowledge of the production to be studied. Further, the group should consist of:
- Two Operators with extensive insight of the production detail.
- 1-2 support personnel who work with operational management in some way.
- 1-2 People at middle management level.

Of course, the members of the group must be interested in this type of work and feel that it is rewarding. One way is to let the members recruit themselves, i.e. if they want to participate.

Desired results are of course increases of performance but also that the group feels that the work has been educational and inspires to further work to find improvement areas.
The Method consists of three phases which, consist of a number of activities. All activities in one phase should be finished before a new phase is started. In the different phases, some activities must be repeated e.g. complementary work.

Phase I is divided into two steps. One step where sub-processes and time are defined and one step where a pre-study and interviews take place and also control figures are chosen.

Phase II is divided into two steps: Process mapping and process measurement.

Phase III is divided into three steps: selection, implementation and evaluation.
### LIST OF ACTIVITIES

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<th>Phase</th>
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<th>Finish</th>
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</thead>
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<td>DEFINE SUB-PROCESSES</td>
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</tr>
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<td>PRESTUDY, INTERVIEWS &amp; CONTROL F.</td>
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<tr>
<td>Phase II</td>
<td>PROCESS MAPPING</td>
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<td>PROCESS MEASUREMENT</td>
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<td>Phase III</td>
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<td></td>
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<tr>
<td></td>
<td>EVALUATION</td>
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Attached to this work, are some Excel templates which should be used. Descriptions to how to use them are provided in this document. The forms are filled in by hand when the studies are performed and the templates are filled in afterwards on a computer to create charts and documentation.

This work is extensive, however it will give many issues to continue to work with for a long time.
<table>
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<th>PHASE I</th>
<th>PRE-STUDY</th>
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<tr>
<td><strong>Activity</strong></td>
<td>Define sub-processes and plan when they should be studied</td>
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<tr>
<td><strong>Purpose</strong></td>
<td>To divide operations into sub-processes will give manageable parts to continue the work with.</td>
</tr>
<tr>
<td><strong>Result</strong></td>
<td>Operations divided into sub-processes and documented with the aid of Template 1.</td>
</tr>
</tbody>
</table>
Define Sub-processes

The purpose of this activity is to divide the work into more manageable parts.

Documentation is created with the help of Template 1.

Make the division using existing natural interfaces.

Natural interfaces consist of departments, storage areas, functional areas, truck or conveyor transport systems.

Plan when all pre-studies and measurements should take place. Document this in the Excel Template in the appended Excel file.
In this example, one follows the flow of products and lets the natural interfaces define the sub-processes.
This example shows sub-processes of an hospital where the flows are not as evident as in the production example.

The sub-processes reflect the departments.
These are the two parts which form the description of sub-processes.

Use template 1 and create your sub-processes.
PHASE I PRE-STUDY

Purpose
The reason for these activities is to create a basis for the improvement areas which will later be identified.

Activities
Do the pre-study and interviews
Obtain control figures and targets

Result
Factors analysed and documented. A number of critical control figures identified.
STEP II  Pre study, interviews & control

**Conduct interviews**

Factors which cannot easily be observed should be questioned. This should be performed in connection with the pre-study.

Talk to leaders and personnel regarding improvements and ask why things are done the way they are.

**Find control figures and targets.**

For a proactive approach, the five figures that support the overall strategy the most should be chosen. A help is the figure on the right that gives five targets. Choose one and define 5 measures that support the chosen one. Fill the form factors with control figure and targets.

5 control figures or targets that have an undesired trend or outcome. The 5 most desirable to improve should be chosen.

**Do pre-study**

All sub-processes should be visited. In connection with pre-studies the form of factors should be completed, with the help of interviews and observations. Furthermore, the factors should be commented in the form. Problems and suggestions should be documented here.
EXPLANATION OF FACTORS

These are factors which are used to affect the total performance in industrial operations. They are divided into four categories: Process, Resource, Product and control.

An explanation is provided to help with the evaluation of factors.
Process Factors

Late deliveries
Is there a backlog of deliveries to customers? If so it is essential to cut the backlog. This often depends on several other factors, see below. Try to identify the three most important factors of due deliveries that cause late deliveries.

Cleanliness
How is the order of the plant? Are places marked, is it clean, how would someone that is not familiar with the production understand the production?

Lead-times
This is the time when materials or information pass between two arbitrary points in the flow. Lead time is usually long when there is much waste, further if the lead-times fluctuating, there could be a problem with instable processes. Is there any work with lead-time reductions and stabilisation? Are there any measurements of lead-time?

Bottlenecks
These are constraints in production. The easiest way to discover them is their tendency to build queues. This factor is linked with lead-time as queues add more time. Is there any work with bottlenecks, are the bottlenecks defined and are there any work to alleviate bottlenecks. Further is there any problems with bottlenecks.

Flow
This is the way material or information move in the real layout. Is the flow easy to comprehend, if not there could be a lack of visualisation. Is there any work to improving the flow.

Volume
This is the quantity of material and products. Are there any fluctuations? Is there any work on prognosis? Are there any problems with variation?

Inventory
Are there large inventories? Is there work with concepts such as JIT, ABC analysis, throughout, and removal frequency?

Integration
Are the processes separated from each other and are there long transports?

Layout
How are the resources placed? Does there placing give high throughput of flow? Is the flow transparent? Are there any work with layouts?

Transport
Are there many transports between resources and is there work to reduce these?

Tact time
How much do the resources’ capacity differ, how many queues are there, is there any work to balancing the flow.
Resource Factors

Organisation
This factor includes many things, but the main attribute to look for is if the organisation is flow focused.

Utilisation
Is the resource utilisation low, is there monitoring and improvement on utilisation?

Efficiency
Are there activities to improve both manual and machinery resource efficiency?

Maintenance
Is there any preventive maintenance? Is there any operator maintenance? Are the resources stable and reliable?

Scheduling
Is there any production planning, when and in which order is production done? Does it work?

Set-up time
Are the set-up times long, is there any work reducing these?

Work methods
Is there any work with improvements of work methods? Are these standardised?

Absenteeism
Is absenteeism high and is there work to reduce this?

Capacity
Is capacity adopted to volumes and tact and is there work to improve capacity.

Ergonomics
Are there many heavy work tasks, is aid provided for this?

Motivation
What are the motivation levels, is there any work with improvement suggestions?

Competence
Is there continuous competence development and is it used? Are any competence matrixes used?

Satisfaction
Are the staff satisfied, how is this measured?

Accidents
Has there been any accidents and is there work to reduce these?

Rework and scrap
Is there high levels of rework and scrap, is there work on reducing this?
Control Factors

Development
Is there any production engineering?

Visualisation
Is the production transparent, is it easy for anyone to understand how the production works?

Cost
Is there knowledge regarding the costs and is this supportive of production?

Routines
Are the administrative routines supportive for the production?

Overproduction
Is there a customer linked production?

Suppliers
Is there developed cooperation with suppliers, are there problems with delays and quality?

Measurement
Are there continuous measurements of resource utilisation, capacity and efficiency?

Customers
Is there developed cooperation with customers?

Prognosis
Are there problems with the prognosis, how accurate are they?

Right sourcing
Is there work on which components that should be made in-house and those that should be outsourced?

Strategy
Is there a production strategy and is followed?

Planning
Do staffing plans work and is price differentiation used?
Product Factors

Assembly
Is the product adapted for production and easy to assemble?

Modularisation
Are product platforms used, how late in the process is the product customer adapted?

Product variants
Is there unnecessary variants of products that is not demanded?

Standardisation
Are the same components used in many products?
This form should be completed with observations and results from the interviews during the site visits. See the explanations of factors for help on how to do this.

Use Form 2 and colour the factors, see below.

Fill in the controls below.

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<th>FORM OF FACTORS</th>
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**FORM OF COMMENTS**

Coment the factors found. Improvements found should also be documented here.

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PHASE II  PROCESS MEASUREMENT

Activity
Process mapping

PURPOSE
Process mapping creates a clear picture of the flows studied. Process maps can reveal unnecessary actions.

Result
Process maps of all sub-processes.
Make a process map

Use the symbols from Template 2 to map the processes.

General process

A general process consists of an in-flow and out-flow of material or services. There is a transformation in the process, but there are losses in the process. Further, the process binds Capital, demands work and consumes energy. Information is tied to the process, such as prognosis and materials systems.
This process has two in-flows with transportation to a storehouse. From the storehouse material is ordered and placed in a queue in front of a resource that shall refine the material. After the refinement there is a quality check with a decision on whether delivery can be made or it is scrap or rework. Final transport is to customer.
This process has one inflow with patients in a queue for examination. At the examination there is a diagnosis made. The decision here is whether the patient can be treated here or a referral must be made. If the patient can be treated the patient enters a new queue for treatment. The last step is treatment and afterwards the patient can leave.
Description of process items
Use Template 3 to make the process maps

**Inflow**
Describes a flow into a process; a process can have several inflows.

**Decision**
A flow can take different paths depending on the decision making. For example, if a product is defective, a decision is made either to rework it or scrap it.

**Inventory/Buffer**
Products waiting for next production stage can either be stored or placed in queues in front of the next process machine.

**Information**
Information connected to the next process stage can be in the form of a prognosis manufacturing order or a product description.

**Operation**
Processing of material and products using manual or mechanised resources.

**Transport**
Movement of material or products between processing stages.

**Outflow**
Outflow of materials or products from the process.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Make process measurements</th>
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<tbody>
<tr>
<td>Purpose</td>
<td>By measuring the process and its attributes there is a creation of a basis for further improvement suggestions and fact based-decisions.</td>
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<tr>
<td>Result</td>
<td>Process maps complete with measurements.</td>
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</table>
A general process with measurements

A general process can be measured in several ways. The intention here is to measure inflow, outflow, parts per time unit, queues, lead-times and resource attributes such as downtimes.

The measurements shall be documented in the forms for measurements.

Use Template 3 to complete process maps with measure bubbles, see the tools for bubbles.

Make Process measurements

The measures from tools should be used. It is important to make the measurements your selves to increase understanding of the processes, and to be able to verify them.
EXAMPLE IV Process measurement: Manufacturing

Inflow
Distance: Leadtime:
Transport
Buffer
Time Inventory: Leadtime:
Queue
Number in queue: Leadtime:
Capacity: Takt; Downtimes; Starting; Scrap; Leadtime:
Operation
Distance: Leadtime:
Scrap
Transport
Outflow
Distance: Leadtime:
Inventory:
Leadtime:
Distance:
Leadtime:
Distance:
Leadtime:
Buffer
Queue
EXAMPLE V Process Measurement: Hospital
DESCRIPTION OF FORMS

**Inflow**
Inflow of material or products over time. A suitable interval of measurement is 15 minutes. Note the items passed in the form of Inflow, these forms are used later to make diagrams.

**Outflow**
Outflow of material or products over time. A suitable interval of measurement is 15 minutes. Note the items passed in the form of Inflow, these forms are used later to make diagrams.

**Lead time**
The lead time should be measured in each sub-process and be documented in the form of lead time. All lead times for each process step should be measured. This should be done five times during a shift and a mean value should be calculated for the process bubbles.

**Queues**
The queues in the sub-processes should be measured every 15th minute and be documented in the form for queues. Transfer these values to the bubbles.

**Inventories**
The time material is stored should be documented in the form for inventories and later be transferred to the bubbles.

**Transport**
All transport should be measured and be documented in the form for transport. Later transfer these values to the bubbles to complete the process maps.
Operation
Measure and document the operations capacity, tact, downtimes, staffing, scrap, and rework.

*Capacity* is what the operations can produce and is given as number per hour.

*Tact* is what an operation should produce per hour.

*Down time* is time when the operation cannot produce due to faults and is given in % of total run time.

*Reset time* is time when resources cannot produce due to resets and is given % of total run time.

*Staffing* is given in numbers.

*Scrap* is material that is discarded due to defects and is measured in % of total produced material.

*Rework* is material that is reworked due to defects and is measured in % of total produced material.

These values are then transferred to the process bubbles to complete the process maps.
## INFLOW FORM

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AVERAGE AVERAGE AVERAGE
The lead time should be measured in each sub-process and be documented in this form. All lead times for each process step should be measured. This should be done five times during a shift and a mean value should be calculated for the process bubbles.
<table>
<thead>
<tr>
<th>TRANSPORT</th>
<th>DISTANCE</th>
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</table>
**TIME IN INVENTORY FORM**

Time spent in inventory by material should be documented in this form.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>TIME IN INVENTORY</th>
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</table>
Operational attributes should be recorded in this form.

**Capacity** is what the operations can produce and is given as number per hour.

**Tact** is what an operation should produce per hour.

**Downtime** is time when the operation cannot produce due to faults and is given in % of total run time.

**Reset time** is time when resource cannot produce due to resets and is given % of total run time.

**Staffing** is given in numbers.

**Scrap** is material that is discarded due to defects and is measured in % of total produced material.

**Rework** is material that are reworked due to defects and is measured in % of total produced material.

<table>
<thead>
<tr>
<th>CAPACITY</th>
<th>TACT</th>
<th>DOWNTIME</th>
<th>RESET TIME</th>
<th>STAFFING</th>
<th>SCRAP</th>
<th>REWORK</th>
</tr>
</thead>
</table>
Description of Bubbles
Use this template to complete the process maps.

Lead time
This is found in all bubbles.

Transport
Write the distance from the transport form.

Queue
Mean queue from the queue form.

Inventory
Only mean lead time from the inventory form.

Operation
Take these figures from the operation form.
PHASE III  ANALYSE

Purpose
By prioritising improvement suggestions towards control figures and targets the number of improvement suggestions can be reduced. Further the analysis of measurement data should create more improvement suggestions.

Activities
Link Factors and Control
Analyse measurement data
Selection of improvement suggestions

Result
A number of improvement suggestions to work with.
Link the red marked factors from the form of factors and connect these to controls and targets in the same form. The assessment is made by finding the most critical factors for the controls and targets. As an aid for this assessment the decision tools should be used. Note the improvement suggestions connected to the controls and targets.

<table>
<thead>
<tr>
<th>CONTROLS AND TARGETS</th>
<th>FACTOR</th>
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STEP V ANALYSE

ELIMINATION OF UNNECESSARY PROCESS STEPS
Analyse the process maps, find process steps which can be removed, moved or simplified for an improved flow. Write these suggestions in the form of improvement suggestions.

IN - AND OUT-FLOW
Flows should be levelled and adapted to demand. If not this will lead to queues and longer lead times with more losses. Analyse the measurements of flow to find peaks and troughs that can be levelled. Document suggestions for this in the form of improvement suggestions.

QUEUES
Queues should at first be eliminated, if this is not possible they should be reduced. Analyse the forms of queues and find improvement suggestions and document them in the form of improvement suggestions.

LEAD TIMES
Analyse the measured lead times, find long or highly varied lead times, create improvement suggestions to shorten and stabilise lead times and document in the form of improvement suggestions.
STEP V ANALYSE

INVENTORY
Inventories increase lead time and therefore it should be shortened or eliminated. Document the improvement suggestions.

TRANSPORT
Transport indicates process steps that can be integrated or eliminated. Use the process maps for analysis of transport. Suggest how the process steps can be changed to minimise transport. Document this in the form for improvement suggestions.

OPERATIONS
Use the form of operations and analyse the values to find improvement suggestions, document this in the form for improvement suggestions. Things to look for here: is capacity enough, is actual output paced to tact, are the down times too high, could scrap and rework be decreased, etc.
<table>
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<tr>
<th>RESPONSIBLE</th>
<th>GOAL</th>
<th>END</th>
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TOOL SELECTION

FOUR FIELDS
A factor is evaluated here by the impact of the factor and the effort the implementation is believed to require.

PARETO ANALYSIS
Here is an evaluation of different factors effect on one outcome. Choose the factors with highest impact.
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<tbody>
<tr>
<td><strong>Activity</strong></td>
<td>Implement</td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
<td>To implement the improvement suggestions</td>
</tr>
<tr>
<td><strong>Result</strong></td>
<td>Implemented improvements</td>
</tr>
</tbody>
</table>
STEP VI IMPLEMENTING

Organise an implementation project with responsible personnel to implement the suggested improvements.
An Excel file is used to keep track of all improvement suggestions.
PHASE III EVALUATION

Activities
Make an evaluation

PURPOSE
This is an important step to be able to show which effects the improvement work has given.

Result
A documented follow-up.
A document should be written on the improvement project. Problems encountered on the way should be documented. Suggestions on how to avoid them in the future may be written. All material derived during the project should be recorded.

After a time, the effects of the improvement work should be examined; this should be done with the pre-study step. An advantage of this is that the pre-study then can be combined with the next round of the Performance Improvement Method.