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Assessing changes towards lean production

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Introduction

The purpose of this article is to develop an operationalized model which can be used to assess the changes taking place in an effort to introduce lean production. In keeping with the theme of this special issue, we have limited ourselves to the factors that concern the work organization in the manufacturing part of a company. This model has been developed using available theory, and has also benefited from an empirical test and concurrent development in a longitudinal field study.

To be able to study a change process, it is important to have the anchor of an outcome, or put another way; the content of the change is important[1]. This means that if we look at lean production as constituting a determinant of performance, we need to operationalize it in detail in order to study the change processes properly. We need a way to measure progress made in an effort to become lean. The choice of the word "progress" is important, since lean can be seen as an intended direction, not as a state or as an answer to a specific problem[2].

The research into processes in firms has the potential of developing knowledge which is of value to practitioners[3]. In this vein, an operationalized model of lean production can be used by managers as a tool to follow progress in an effort to introduce lean production. It can provide answers to questions such as: are the actions taken in the direction of lean production? What progress are we making on different variables?

Methodology

In order to develop an operationalized model of lean production, we have taken the description in *The Machine that Changed the World* as a starting point[4]. With that as a basis we have developed a model which summarizes the important principles contained within lean production. These different principles have then been elaborated using available theory behind a lean production system. The purpose is to find measurable determinants of what constitutes such a system in a manufacturing company. The model developed has been tested and concurrently developed in a clinical research project[5] in what will henceforth be termed a "try-out".

The testing of the model has been performed in an international manufacturing firm producing mechanical and electronic office equipment, mostly for export. In late 1991, the company decided to restructure their operations, using lean production as the model for this endeavour. The first

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year was spent on planning and preparation, and the physical and organizational changes started in 1993. Since then, the researchers have spent two to three days per week in the company, over a period of two-and-a-half years. Our role in the change process was to introduce academic knowledge and theories about production organization into the company, mainly in the form of seminars, but also through daily interaction.

Lean production

Ever since its introduction, the concept of lean production has gained widespread attention, both in the literature and in practice. It is probably fair to say that it has become a dominant strategy for organizing production systems. A step in the development of the concept was taken when the results of the International Motor Vehicle Program were published in the book *The Machine that Changed the World*[4].

An important contribution made by this book was that it tied together many of the seemingly disparate principles that had caught the attention of researchers and practitioners alike. Lean production is not confined to the activities that take place in the manufacturing function of a company, rather it relates to activities ranging from product development, procurement and manufacturing over to distribution. The book even discusses strategies for a lean company.

In assessing changes towards lean production we feel that it is important to make a distinction between the determinants and the performance of a lean production system. The ultimate goal of implementing lean production in an operation is to increase productivity, enhance quality, shorten lead times, reduce cost etc. These are factors indicating the performance of a lean production system. The determinants of a lean production system are the actions taken, the principles implemented, and the changes made to the organization to achieve the desired performance.

The model developed in this article operationalizes the determinants of a lean production system. Implicit in this is the notion that by introducing lean production, performance can be enhanced. It is also important to repeat at this stage that we are interested in assessing the changes taking place in the determinants, not in their absolute values. What, then, are the determinants of lean production? We feel that it is advisable to start the development of our model by using the source of the concept[4]. From these findings we have based our own studies on a conceptualization of lean production as consisting of a number of principles characterizing different functional areas and the overall strategy of the lean company[6]. These functional areas and factors are summarized in the model in Figure 1. Our interpretation of the fundamental principles of lean, which go through all functions, is found at the bottom of the model.

Although the model spans over different functional areas, we are concerned here with the consequences of lean production for the work organization. These consequences are predominantly found in what is termed “lean manufacturing”

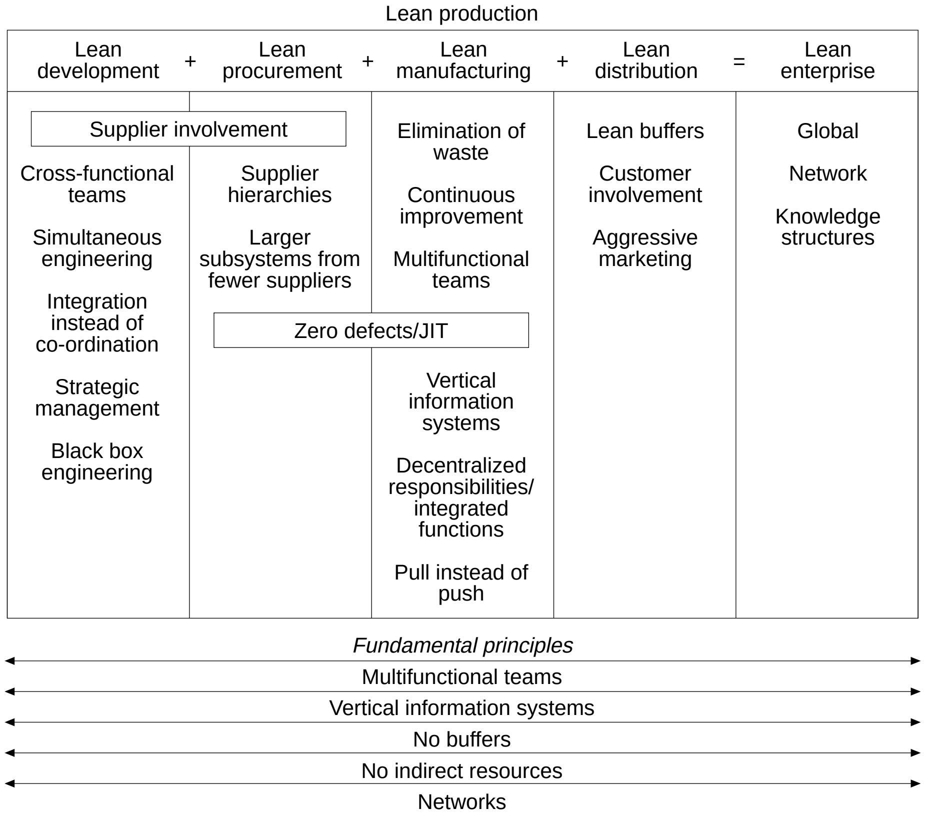

Figure 1.
Our conceptualization of lean production

in the model, and to some extent also within product development. The focus in this article will therefore be on the manufacturing function of a company.

Assessing changes towards lean production

Thus far, we have established the underpinnings of the model of lean production. We will now proceed by taking the principles of lean production, as described in the model, and developing each principle by using available theory. The purpose is to find what determines a lean practice within each principle. The important point here is to find the determinants that are able to reflect changes in an effort to become lean. These determinants are then operationalized into a measurable format.

As previously mentioned, the model has been tried-out in a clinical field study, as a result of which many of the theoretically developed measurements have had to be revised. An outline of the model is shown in Table I and the resulting measurements are displayed in Tables II-X.

The structure is that we first make the theoretical elaboration of the determinants, after which follows an explanation of the measurements that were significantly revised as a consequence of the clinical try-out. It should also be kept in mind that we had to find a balance between detail and simplicity, in order for the operationalized model to be usable (see also [3]).

Determinant	Measurement	Lean
Theoretically derived indicators lying behind the principles of lean production	Operationalized indicators, that have been found to be suitable for use in assessing changes towards lean production, in an empirical case	Indicate the desired direction of the indicator, if moving in a lean direction: ↗ = Should increase ↘ = Should decrease ↕ = Practice should change in this direction

Table I.
Outline of the model for assessing changes towards lean production

Elimination of waste

The purpose of the lean production philosophy that was developed at Toyota Motor Company following the Second World War, is to lower costs. This is done through the elimination of waste – everything that does not add value to the product[7]. Waste is something that the customer is not willing to pay for and it should therefore be eliminated (see Table II).

Determinant	Elimination of waste	Lean
Work in progress	Value of work in progress in relation to sales	↘
Lot sizes	Production run time between set-ups	↘
Set-up times	Amount of time needed for die changes	↘
Machine down time	Number of hours machines are standing due to malfunction in relation to total machine time	↘
Transportation of: Parts	• Number of times parts are transported • Total physical distance parts are transported	↘
Scrap	Value of scrap in relation to sales	↘
Rework	Value of rework in relation to sales	↘

Notes: ↘ = Should decrease

Table II.
Elimination of waste

Perhaps the most important source of waste is inventory. Keeping parts and products in stock does not add value to them, and should be eliminated. In manufacturing, inventory in the form of work in progress is especially wasteful, and should therefore be reduced. Apart from being wasteful in itself, inventory also hides other problems, preventing their solution[8]. The effects of reducing work in progress, therefore, go beyond that of reducing capital employed[9]. However, it is not advisable to eliminate inventory mindlessly. Instead, the reasons for the existence of inventory must first be removed. One important way of doing this is by minimizing down time in machines[10]. This is accomplished through preventive maintenance.

Another efficient way of keeping inventory down is through reducing lot sizes. A reduction of lot sizes also has other positive effects such as increasing flexibility, since it is possible to switch between different parts more often. However, given that lot sizes are reduced, to follow the familiar formula on economic order quantities, set-up times also have to be reduced for cost per unit to be constant. A reduction in set-up times is therefore essential. Important work in this area was done at Toyota following the Second World War. Through an ingenious method – SMED, developed by Shingo[11], set-up times in large punch presses could be reduced from several hours to under ten minutes. This had dramatic consequences on lot sizes. Thus, a reduction in set-up times is an important way of eliminating waste.

Another source of waste is the transportation of parts. Transporting parts from one location in the factory to another does not add any value to the product. It also adds to manufacturing lead time. It is therefore essential to reduce transportation in the manufacturing process. Here it is necessary to distinguish between rationalization of transportation and a removal of the need for transport[10]. Automating transport is fine, but eliminating the need for transport is far better. For instance, if machines can be grouped together in a cell-based layout, the physical connection of the flow of products renders a faster truck useless.

Lack of quality is a further source of waste. Manufacturing parts and products that are defective and therefore need to be reworked is wasteful. Perhaps even worse is the scrapping of parts. They certainly do not add any value to the customer. Therefore, eliminating scrap and rework is the last determinant of the elimination of waste. Manufacturing parts which are fault free from the beginning has profound consequences for productivity[9].

Most of the determinants and their measurement here are fairly common and easy to understand, as was confirmed in the clinical try-out. However, one measurement which was revised as a consequence of this try-out was the transportation of parts. It was found to be useful to divide the measurement into two. First, we measured the number of times parts were transported. This gave an indication of the reduction in the amount of administrative work that had to be carried out as a consequence of having physically separated processes. Second, we found it useful to measure the total physical distance of the transportation of parts. The reason for this was twofold: first of all, it was more easily accessible than length in terms of time; and, second it gives, together with reduced lot sizes, a fair approximation of the time spent in transporting parts. Together, the two measurements of transportation were found to reflect the physical coupling of production stages that is important in lean production.

Continuous improvement

If the elimination of waste is the most fundamental principle of lean production, then continuous improvement can be said to come second. The production system is being constantly improved; perfection is the only goal[8]. The constant strive for perfection even has its own word in Japanese – *kaizen* – a word that has become very well known in the West. This is due to the fact that it has been used as an overriding concept behind good management – the Japanese way[12]. However, here we have chosen to apply it in a more restricted sense. We are using the English translation with the emphasis on "ongoing improvement involving everyone"[12, p. xxix].

Involving everyone in the work of improvement is often accomplished through quality circles. These are activities where operators gather in groups to come up with suggestions on possible improvements. To this is tied an elaborate scheme for implementing suggestions, rewarding employees, and feeding back information on the status of the suggestions. This can be contrasted with the traditional suggestion scheme, where individual employees are encouraged to leave suggestions in a "suggestion-box". The benefit of the Japanese system is often measured by looking at the number of suggestions per employee and year. It is also beneficial to look at the percentage of suggestions which were implemented, as a measure of the quality of the suggestions and the interest shown by the company.

Thus, it is through the organization of the suggestion scheme that continuous improvement is accomplished. It is possible to imagine this organization as having different stages. First, there is the case where there is no explicit organization and employees might improve the system of their own accord. Second, there is the case where the company has implemented a structured approach for dealing with suggestions, based on individual participation. Formal suggestion schemes are an example of this. Finally, there is the use of quality circles. These are, in themselves, complex phenomena that have been treated extensively elsewhere (see, for example [13]). For the purpose of this article, we have contended ourselves by having quite a general definition.

Table III describes the measures developed to assess changes towards continuous improvement. In the case studied, we found that these measurements were useful in reflecting the changes taking place. The number of suggestions is a straightforward measure that is also used in the literature. The movement towards the use of quality circles as a vehicle for improving the

Determinant	Continuous improvement	Lean
Suggestions	• Number of suggestions per employee and year • Percentage of implemented suggestions	↗
Organization of improvement activities	1. Quality circles 2. Multifunctional teams, and spontaneous problem solving 3. Formal suggestion scheme 4. No explicit organization	⇑

Notes: ↗ = Should increase
⇑ = Practice should change in this direction

Table III. Continuous improvement

process was much more complicated. In making the move towards lean production, we found it useful to distinguish between two stages in the use of small group activities for problem solving. The theoretical elaboration made above considers only the use of quality circles.

Before quality circles were created at the company, the manufacturing tasks were organized in multifunctional teams (see below). When these were created, the company noted a rise in the interest among employees to work with problem solving and process improvements. The increased responsibilities and the grasp of the whole process were thought to be the cause of this rise in interest. There were, however, no formal small group activities and improvements were made more on an informal basis.

This situation changed when a more formalized way of working with continuous improvements was introduced in the form of quality circles. Through gathering employees in small groups, at pre-planned occasions, the number of suggestions and the interest in making improvements rose notably.

Zero defects

Although quality in itself is an important performance variable in lean production, it is also a prerequisite for the production system[7]. To be able to attain high productivity, it is essential that all parts and products are fault free from the very beginning. The goal is to work with products that are fault free through the continuous improvement of the manufacturing process. Thus, zero defects denote how a lean company works in order to attain quality.

In a lean production system it is important to move towards a higher degree of process control. In its most elaborate form, each process is controlled through knowledge gathered about the parameters of the process. Thus, instead of controlling the parts produced, the process is kept under control. The issue here is to prevent defects from occurring, through discovering errors that can lead to defects[14]. Herein also lies the issue of how the products are inspected. One feature in lean production is the use of autonomous defect control (*poka yoke*)[7]. These are inexpensive means of conducting inspection of all units to ensure zero defects.

Another salient feature is the lack of personnel dedicated to quality control. Quality assurance is the responsibility of everyone. This has a number of implications: first, identification of defective parts is the responsibility of workers, not the quality control department. Workers are also allowed to stop the line in the event that defective parts are found. Second, responsibility for adjusting the defective parts is also delegated to workers. In its most elaborated form, the responsibility for adjustment lies with the person who has caused the defect. As a consequence, the number of personnel working in the quality control department can be reduced. A further result of ensuring quality from the beginning is that the size of the adjustment and repair areas can be reduced[15].

Table IV describes the measures developed to assess changes towards zero defects. The work to ensure quality was an important and very time-consuming

Determinant	Zero defects	Lean
Responsibility for identification of defective parts	1. Workers identify defective parts and stop the line 2. Workers identify defective parts, but do not stop the line 3. Quality control department identify defective parts and informs production management	⇑
Responsibility for adjustment of defective parts	1. Defective parts are sent back to the worker responsible for the defect to adjust it 2. Workers take out and adjust defective parts 3. Adjustment department adjusts defective parts	⇑
Quality control department	Number of people dedicated primarily to quality control	↘
Degree of process control	1. Processes are controlled through measuring inside the process 2. Measuring is done after each process 3. Measuring is done only after product is complete	⇑
Autonomous defect control	Percentage of inspection carried out by autonomous defect control	↗
Adjustment and repair area	Size of the adjustment and repair area	↘

Notes: ↗ = Should increase

↘ = Should decrease

⇑ = Practice should change in this direction

Table IV.
Zero defects

task at the company in this study. From having devoted time largely to reactive work, they tried implementing a more proactive way of working with quality. The above measurements were altered to reflect this change. For instance, the responsibility for identifying defective parts was transferred from the quality control department to the employees. However, in the early stages of the changes, workers were not very eager to stop the line.

This was solved when manufacturing tasks were reorganized into teams. This made the employees more aware of the need to manufacture only fault free parts. An important reason for the improved awareness was that the physical contact between manufacturing stages allowed for better communication. This is also related to the responsibility for adjusting defective parts. Previously each employee in final assembly was equipped with a rubber hammer to “fit” the parts together if necessary (which it often was). Largely through the use of teams, employees found it beneficial to have the responsibility for correction resting with that part of the process where the error has been committed. These experiences led us to differentiate among three stages in a movement towards lean production, both in terms of identification and adjustment of defects.

The work to achieve control over the processes was also found to contain significant steps. This is, however, a much more complicated task than allocating responsibility. Through the use of statistical process control, with tests after each process, the company is hoping to gain better control over their processes. A movement to the highest stage is still far away. That will be to have control of the errors (the sources of defects) through the constant monitoring of the process variables.

However, it is worth noting at this point that this work required frequent tests to be made, thereby increasing the amount of paper work. This is, to some extent, contrary to the fundamental principle of eliminating waste. It is thus possible here to find a certain trade-off. All in all, the company found it useful to reflect the total effect of this new way of working with quality by using the two last measures: the number of people dedicated primarily to quality control and the size of the adjustment and repair area.

Just-in-time

Closely associated with zero defects is the principle of just-in-time, since accomplishing fault free parts is a prerequisite to achieving just-in-time deliveries. It should be noted here that we have chosen to use the term in a narrower way than is often done in the literature. The principle of just-in-time in its basic meaning implies that each process should be provided with the right part, in the right quantity at exactly the right point in time[10]. The ultimate goal is that every process should be provided with one part at a time, exactly when that part is needed (see Table V).

Determinant	Just-in-time	Lean
Lot sizes	Production run-time between set-ups	↘
Work in progress	Value of work in progress in relation to sales	↘
Order lead time	Amount of time spent processing each order	↘
Level of just-in-time	1. Sequential just-in-time possible 2. Type specific deliveries just-in-time possible 3. Lots are delivered just-in-time	↑

Notes: ↘ = Should decrease
↑ = Practice should change in this direction

Table V.
Just-in-time

To be able to achieve this, a number of factors are important. Most of these can be found under the principle of waste elimination, which is also closely related to just-in-time. We will, therefore, consider here only the determinants that are highly interrelated with just-in-time. The first and perhaps most obvious determinant is the importance of reducing lot sizes. Interrelated to this determinant is the reduction of buffer sizes. Third, to achieve just-in-time it is also necessary to reduce order lead time.

Finally, it is possible to imagine different levels of just-in-time. First, there is the case when parts are moved between different processes in lots. Second, parts are differentiated according to product variants. Third, in the most elaborate form, there is sequential just-in-time. Here parts arrive with reference to the individual products on the line. For example, car seats might arrive at the assembly line in the exact order in which they are needed, colour and type of seat taken into consideration. In general, the higher the level of just-in-time a company is able to master, the better. However, this does not mean that sequential just-in-time is always needed. It will vary depending on the nature of the products.

In trying-out the determinants of just-in-time at the company we found, as was the case with waste elimination, that most of them were fairly common and easy to understand. The last determinant, the level of just-in-time, proved to be the most difficult, both to understand and to achieve. Here it is also necessary to distinguish between different types of products. When the products are standardized and relatively inexpensive, as in this case, it might not be too important to achieve the highest level of just-in-time. After an ABC-analysis of the annual requirement value (ARV) of parts, the company started the work necessary to achieve just-in-time, from the bottom of the scale. In this work, the company found the scale useful for directing their efforts.

Pull instead of push

Closely related to the principle of just-in-time is the way in which material is scheduled, through pull instead of push. Since this principle is binary – either you have pull or you have push – it is necessary to look at the issue in a slightly different way to find determinants that can assess the change taking place. In trying to operationalize this principle, we found it useful to look at the relationship between forward scheduling and backward request. In arriving at this measure, we were considerably helped by the clinical try-out (see Table VI).

Determinant	Pull instead of push	Lean
Backward request in relation to forward scheduling	The number of stages in the material flow that uses pull (backward requests) in relation to the total number of stages in the material flow	↗
Degree of pull	Percentage of the annual requirement value that is scheduled through a pull-system	↗

Note: ↗ = Should increase

Table VI.
Pull instead of push

Before starting to implement lean production in the company, final assembly was made to customer order. All other stages of the manufacturing process were produced to a forecast. As the work with implementing lean production proceeded, the number of manufacturing stages producing against customer orders was extended. However, the early stages of the process (stamping in this case) were still producing to a forecast. Thus, somewhere in the material flow is a “point” where pull meets push. This means that behind this point, backward requests are used. Ahead of the point there is forward scheduling. This has led to difficulties in stock-outs or too large stocks at this pull-push point. This essentially boils down to the difficulty in making correct forecasts.

However, it should be observed that the point at which pull meets push existed before the work of implementing lean production began. Then it was immediately prior to final assembly. Now the point has been moved closer to the start of the material flow. This is what we see as a determinant of a change towards pull; the point at which pull meets push is moved backwards in the material flow.

Finally, an ABC-analysis of the annual requirement value of parts led the company in this study to use different types of materials control for different kinds of parts. This experience also led us to add a second measure to follow changes towards pull instead of push; the degree of pull. This is measured as the percentage of the annual requirement value that is scheduled through a pull-system.

Multifunctional teams

Perhaps the most salient feature of the work organization in lean production is the extensive use of multifunctional teams. The percentage of employees working in multifunctional teams is much higher than in traditional work organizations. A multifunctional team is a group of employees who are able to perform many different tasks. These teams are often organized along a cell-based part of the product flow. Thus, each team is given the responsibility of performing all the tasks along this part of the product flow. This means that the number of tasks in the group increases.

One consequence of the use of multifunctional teams is that the number of job classifications decreases. Instead of having different employees performing only a limited number of tasks, the aim is to have employees who are able to perform more than one task in the team. Since the tasks are rotated in the team, one important benefit is that the increased flexibility reduces the vulnerability of the production system. Each person performs many different tasks during a day. Therefore, there is not so much dependence on single persons. Achieving this multifunctionality, however, requires efforts in staff training.

The first point to note is that the number of tasks in which employees receive training increases. Training can be given in statistical process control, quality tools, computers, performing set-ups, carrying out maintenance, etc. Second, the employees are trained in a number of functional areas. Tasks previously performed by indirect departments are now the responsibility of the team. Training in such areas as materials handling and control, purchasing, maintenance, and quality control, therefore, becomes essential.

Table VII describes the measures developed to assess changes towards multifunctional teams. In assessing these changes in this study, we found the theoretically derived determinants to be useful. Most of them are also well documented in the literature. However, the clinical try-out provided a few contributions to the elaboration of the scales. The first instance concerns the different steps in the rotation of tasks. The aim of the company was that employees should be able to rotate among tasks frequently, at least a number of times per day. This was not achieved initially, due to a number of reasons. One important reason was the reluctance of employees who had performed the same tasks for years suddenly to be required to do something else.

Determinant	Multifunctional teams	Lean
Team structure	Percentage of employees working in teams	↗
Task structure	Number of tasks in product flow performed by the teams	↗
Job classification	Number of job classifications	↘
Task rotation	Employees change tasks within the team	
	1. Continuously	
	2. Every hour	
	3. Every day	
	4. Once per week	
	5. Once per month	↑
	6. Once per year	
	7. Less than once per year	
Training	• Number of different tasks which employees are trained in	
	• Number of different functional areas employees are trained in	↗
	• Amount (in hours) of training given to newly employed personnel	

Notes: ↗ = Should increase

↘ = Should decrease

↑ = Practice should change in this direction

Table VII.
Multifunctional teams

This reluctance was overcome to some extent by training, which made employees more willing to change tasks. Also, a new remuneration system proved to be important, since it rewarded flexibility[16]. However, it proved to be difficult to make the employees change tasks more than a few times per week, on average. This led us to the conclusion that it was important to reflect changes towards multifunctional teams by using a quite detailed classification scheme, since these changes were not brought about easily. Our experiences in the clinical try-out also proved useful when it came to the elaboration of the measurement "training". From the beginning of the change it was apparent that the employees needed training and this was started before the physical and organizational changes took place. Initially, our own conception was that the amount of training should suffice as a measurement. It soon became apparent that this was not enough to reflect the nuances of the training.

First, employees in the company were trained in performing different kinds of tasks in the production process. Those who had previously been in assembly were trained in parts manufacturing, and vice versa. This training took place mainly as on-the-job training, to which was added theoretical training in performing other types of tasks along the production process. Second, the employees received training in performing indirect tasks. The most important part here was leadership training, in order to be able to rotate the team leadership among employees in the team. Thus, although these two types of training are related to the amount of training, we found it necessary to distinguish between them in order to reflect more correctly the need for training that is an important part of lean production.

Decentralized responsibilities

Another important characteristic of a lean work organization is that responsibilities are decentralized onto the multifunctional teams. First, and perhaps foremost, there is no supervisory level in the hierarchy. What is meant by the term supervisor here is foreman. There might still be hierarchical levels between the team and the production manager, depending on the size of the operation. However, in a lean production system the multifunctional team is expected to perform supervisory tasks. In its most elaborate form, this is done through rotating team leadership among employees especially trained for the task. As a consequence, the number of hierarchical levels in the organization can be reduced. Second, the number of functional areas that are the responsibility of the teams increases. As has previously been mentioned, the multifunctional teams are charged with the duty of performing tasks that were previously carried out by employees in indirect departments.

Table VIII describes the measures developed to assess changes towards decentralized responsibilities. In performing the clinical try-out, we found reasons to elaborate the theoretically derived measurements. With regard to supervisory tasks, it was found to be useful to differentiate between rotating team leadership and the decentralization of supervisory tasks onto the team. The intention of the company was that team leadership should rotate among employees in the team. Initially this was not achieved, since no employees who were willing and able to accept the task could be found. Thus a gap between the old and the new organization arose, since one hierarchical level was gone. Gradually, it became possible to find employees who were willing to accept the role of team leader. This was a slow process for a number of reasons. First, employees who had previously worked under a supervisor found it difficult to accept responsibilities for these tasks. Second, it was also a question of finding

Determinant	Decentralized responsibilities	Lean
Supervisory tasks performed by the teams	1. Team leadership rotates among team members 2. Supervisory tasks performed by the team 3. Separate supervisory level in the organization	↑
Team leadership	• Percentage of employees being able to accept responsibility for team leadership • Percentage of employees having accepted responsibility for team leadership	↗
Organization hierarchy	The number of hierarchical levels in the manufacturing organization	↘
Areas of responsibility	Number of functional areas that are the responsibility of the teams	↗

Notes: ↘ = Should decrease
↑ = Practice should change in this direction

Table VIII.
Decentralized responsibilities

suitable employees for the team leadership task. Their background and competence as well as their own will to perform these tasks were found to be crucial. Finally, there was also the issue of training these employees, which also took time.

When the first group of team leaders had been trained, it was possible to bridge the gap that had arisen between the old and the new organization, as supervisory tasks could be performed by the teams. However, the tasks were still not rotated, the reason for this being twofold: first, there were not enough employees able to perform the task; second, there was still some anxiety on the part of the employees about whether they would be able to manage such a task.

As time went by, employees could see that the system of team leadership was working well and the situation changed. To start with, team leadership began to be rotated among different employees. After this, the number of employees who were willing to take on the responsibility, and who were therefore trained, increased. The development of the work organization with respect to team leadership showed us that it was helpful to have the measure consisting of three different levels. It also made us realize that the number of people who were able to perform and who had performed supervisory tasks was an important determinant of how well-functioning these teams were. The determinant reflecting the nature of the organization hierarchy also proved to be useful. At the company we studied, two layers of the hierarchy were removed as a consequence of the introduction of lean production: supervisors and preparatory workers.

Finally, although the measurement “number of functional areas the teams are responsible for” is somewhat similar to the determinants found under multifunctional teams, we found it useful to include it here, but with a different meaning. Although training was given in different functional areas, responsibility was not delegated to the same extent, at least not initially. Among the reasons for this were, for example, internal power struggles.

Integrated functions

A second important principle concerning the multifunctional team is the integration of different functions into the teams. This means that tasks previously performed by indirect departments are integrated into the team, increasing the work content of these teams. Tasks such as procurement, materials handling, planning and control, maintenance, and quality control, are performed by the team. Thus, the number of tasks performed by the team increases, and consequently the number of indirect employees can be reduced. Support functions are no longer necessary to the same extent as in traditional production systems.

Table IX describes the measures developed to assess changes towards integrated functions. Initially, we had planned to include the determinants of this principle among the determinants of decentralized responsibilities. Our try-out showed that there were sufficient reasons for keeping them separated from each other. First, even though employees were trained in and were given responsibility for performing indirect tasks, this did not mean that they were performed. A number of factors were found to intervene. The willingness of indirect employees to delegate the tasks was one. Another was the willingness of direct employees to perform different tasks. Initially, many of them were reluctant to perform new tasks. Immediately following the physical and organizational changes, employees thought they had too many new things to worry about, without also having to perform largely unknown tasks. Familiarity with the new organization eventually weakened this attitude.

Table IX.
Integrated functions

Determinant	Integrated functions	Lean
Work content in teams	The number of different indirect tasks performed by the team	↗
Support functions	The ratio of indirect employees in relation to direct employees	↘

Notes: ↗ = Should increase
↘ = Should decrease

Second, although the intention of the company was that the number of indirect personnel should be reduced through the decentralization of tasks, this proved to be a slow process. Some support functions were even increasing in size, at least initially. The physical relocation that was necessary to make the move into a cell-based layout resulted in a slight increase in the maintenance function, although some of its tasks were being taken over by the teams. The work with the new quality assurance system (largely inspired by ISO 9000, but going beyond that at the demand of a large OEM customer) meant that the number of indirect employees working with issues related to quality rose. However, over time, it is expected that there will be a decrease in both of these functions, and indeed this has already begun.

Another important reason for the number of indirect personnel was the company's no lay-off policy. This meant that people who lost their job were moved to another job, often in an indirect function. Previous supervisors were often found among this category. Jobs were also eliminated through the decentralization of tasks in, for example, planning, purchasing and materials handling. However, retirements have since made it possible to start the work of reducing the total number of indirect employees. This is still quite a slow process. For these reasons we found it useful to measure the relation of indirect to direct employees as a determinant of the move towards being lean.

Vertical information systems

The final principle is that of vertical information systems. Information is important in order for the multifunctional teams to be able to perform according to the goals of the company. The first issue here is the mode in which the information is provided to the employees. The objective is to provide timely information continuously, directly in the production flow. This information is then discussed among the employees. Second, there is the content of the information. The content can, in turn, be divided into two types:

(1) Information of a more strategic type, concerning the overall performance and intentions of the company. This is characterized by the longer time perspective that is taken. It is also possible to consider the number of areas in which employees are informed. Examples include market plans, production plans, process development plans, and financial performance.

(2) Information of a more operational type. This type contains information about the performance of the team in question. This performance is measured along several dimensions, such as quality, timeliness, productivity, lead times, etc.

Table X describes the measures developed to assess changes towards vertical information systems. Our clinical project also helped us to differentiate the determinants of this principle. This was especially the case concerning the mode of information provision. First, we found it useful to distinguish between written and oral information. Previously, written information had been predominant, mostly in the form of the company's newsletter distributed twice per year. Early on in the change process, it was decided to provide information more regularly. This information was also to be provided orally, since oral information created the opportunity for comments and clarification.

However, displaying the information directly in the teams was seen as the final goal. This was done more slowly than was initially expected by those involved. Observations indicate that this was due to issues of internal power struggles. Some managers were reluctant to share their information with the teams, since they were afraid that this might make their position redundant.

Determinant	Vertical information systems	Lean
Mode of information provision	1. Information continuously displayed in dedicated spaces, directly in the production flow. Regular meetings to discuss the information 2. Oral and written information provided regularly 3. Written information provided regularly 4. No information to employees	⇑
Strategic content in information	• Number of areas contained in the information given to employees • Time perspective in the information	↗
Operational content in information	Number of different measures used to assess the performance of the teams	↗
Information frequency	The frequency with which information is given to employees (differentiated by the content of the information)	↗

Notes: ↗ = Should increase
⇑ = Practice should change in this direction

Table X.
Vertical information systems

Thus, we found it useful to differentiate among the four different modes of information provision. These experiences also made us realize that the frequency with which the information was given was important as a determinant. Here there might be a need to differentiate between the different types of information. Operational information is probably more frequent than strategic. However, here as elsewhere, the importance lies in assessing the changes taking place. With regard to the content of the information, we found that as time passed, the amount of information grew, both on strategic and operational measures. At the operational side this was, to a certain degree, a consequence of the change in remuneration to include different performance measures. The employees were therefore very much helped by this type of information, and demanded it.

Synthesis

The purpose of this article has been to develop a model that operationalizes the different principles in lean production, with a focus on those that concern the work organization in the manufacturing part of a company. The basic rationale behind doing this is our interest in studying change processes when introducing lean production. In order to conduct such studies properly, an operationalized model of lean production is necessary. The uncertainty surrounding the lean concept and the lack of a precise definition of what lean production is, also lies behind the need for an operationalized model. This uncertainty leads, among other things, to practical problems when trying to assess whether changes made in a company really takes it in the direction pointed out by lean production.

Development of the model started with the description of lean production made in the book, *The Machine that Changed the World* [4]. With that as a basis, we developed a model that summarized the important principles contained within lean production. These principles were then elaborated by the use of available theory. It was important to find determinants that were able to reflect changes in an effort to become lean. These determinants were then operationalized into a measurable format. Finally, the resulting model was tried-out in a clinical field study.

This field study took place in a company which was in the process of implementing lean production. Through the use of the model, changes in the direction of lean production could be assessed. The try-out also provided us with valuable feedback that was used to alter the tool developed. Through the high degree of penetration and involvement in the organization, we were able to gain access to a richness of data that allowed us to trace through the connections between phenomena. As a result of this many of the theoretically developed measurements were revised.

The final model has implications both for research and practice. For research, it can be used as a model for operationalizing lean production in order to be able to study change processes properly. In practice, the model can be used as a tool to assess the development taking place in an effort to become lean. Finally, it can be used as a checklist for what to aim at when trying to implement lean production. The important point to note, however, is that lean should be seen as a direction, rather than as a state to be reached after a certain time. Therefore, the focus lies on the changes in the determinants, not on their actual values. It should also be noted that all the determinants might not point in the right direction all the time. There could be instances where they can send mixed signals. However, keeping this in mind, the model is a helpful tool for companies to check that they are not deceiving themselves.

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