World Academy of Science, Engineering and Technology
International Journal of Economics and Management Engineering
Vol:3, No:5, 2009

Lean Changeability – Evaluation and Design of Lean and Transformable Factories

Tim Klemke, and Peter Nyhuis

***Abstract*—**In today's turbulent environment, companies are faced with two principal challenges. On the one hand, it is necessary to produce ever more cost-effectively to remain competitive. On the other hand, factories need to be transformable in order to manage unpredictable changes in the corporate environment. To deal with these different challenges, companies use the philosophy of lean production in the first case, in the second case the philosophy of transformability. To a certain extent these two approaches follow different directions. This can cause conflicts when designing factories. Therefore, the Institute of Production Systems and Logistics (IFA) of the Leibniz University of Hanover has developed a procedure to allow companies to evaluate and design their factories with respect to the requirements of both philosophies.

***Keywords*—**Factory planning, lean production, transformability

I. Introduction

NOWADAYS companies are faced with a rapidly changing environment [1]. The reasons for this include changing and increasing customer demands, the decreasing predictability of sales volumes, and additional variants. This situation is called a turbulent environment [2], [3]. In this environment companies need to handle two principal challenges to remain competitive. On the one hand, they are forced to save resources because of the increasing pressure on costs in the competitive environment. On the other hand, they need to retain enough potential to react to unpredictable future changes. To accomplish these complex problems, companies in the first case use the philosophy of lean production more and more, in the second case the philosophy of transformability. To a certain extent these philosophies exhibit opposing tendencies. That can lead to conflicts between lean production and transformability. The aim of lean production is to avoid every type of waste in order to save resources and hence money. By contrast, when implementing transformability it is necessary to retain transformability reserves in order to be able to react to changes in the corporate environment. From the lean production viewpoint these reserves may sometimes be regarded as waste. On the other hand, by designing a factory according to the lean production principles, it may be more difficult to integrate additional products if this becomes necessary as a result of market changes.

To resolve this conflict of aims, a research project was implemented at the Institute of Production Systems and Logistics (IFA) of the Leibniz University of Hanover. The goal of this project was to develop a procedure that allows factories to be evaluated and designed with respect to the requirements of lean production and transformability. Only by implementing lean production as well as transformability is it possible to follow the requirements of both philosophies and hence achieve an optimum positioning of the company in the competitive environment. To develop such a procedure, it was essential to identify the lean production and transformability requirements for factories, which in turn would allow the resulting conflicts to be found. The procedure described here was developed with the help of the knowledge gained.

II. Basics: Factories, Transformability, and Lean Production

A. Factories

A factory is a place where added value takes place by manufacturing industrial goods using factors of production [4]. It is a highly complex socio-technical system that cannot be generalized [5], [6]. Nevertheless, to allow a systematic view of a factory, so called factory fields, factory levels, and factory objects are defined. Horizontally, a factory is structured into the factory fields means, organization, and space. Means, for example, are defined as means of storage, transportation, and handling, the provision of media and energy plus IT. Organization includes, for instance, the organizational structure and labor organization. Aspects like real estate or factory layout are part of the spatial view [7]. Vertically, a factory is subdivided into the levels site, factory, cell (or system), and workstation [8], [9]. The view of a factory becomes more and more detailed as we proceed from the highest level site down to the lowest level workstation. Linking the factory fields to the factory levels produces a matrix. The so-called factory objects can be defined with the aid of this matrix (Fig. 1) [10]. Each of these objects can be described and evaluated by their characteristics, so-called evaluation features [7]. Evaluation features that allow a precise evaluation and description of the factory object real estate (factory level: site; factory field: space) are, for example, the number of nonoverlapping growth directions or

Tim Klemke is research associate at the Institute of Production Systems and Logistics, Leibniz University of Hanover, Garbsen, 30823 Germany (corresponding author to provide phone: 0049-(0)511-762-18185; fax: 0049-(0)511-762-3814; e-mail: klemke@ifa.uni-hannover.de).

Prof. Peter Nyhuis is director of the Institute of Production Systems and Logistics, Leibniz University of Hanover, Garbsen, 30823 Germany (e-mail: nyhuis@ifa.uni-hannover.de).

actual obstacles on a factory site.

Factory levels \ Factory fields	Means	Organization	Space
Level I: **Site**	▸ Provision of media and energy – centralized hubs	▸ Organization structure	▸ Real estate ▸ Building development ▸ External facilities
Level II: **Factory**	▸ Provision of media and energy – distribution ▸ IT	▸ Structure ▸ Logistics concept ▸ Production concept	▸ Factory layout ▸ Girder ▸ Shell ▸ Form ▸ Impression
Level III: **System/ Cell**	▸ Means of storage ▸ Means of transpor-tation and handling	▸ Labor organization	▸ Fitting-out
Level IV: **Work-station**	▸ Production technology ▸ Production means ▸ Additional equipment	▸ Quality assurance concept	▸ Workplace design

Fig. 1 Factory fields, factory levels, factory objects

B. Transformability

Many different terms and definitions are used to describe the transformability of factories in the literature [11]. Hernández defines transformability as the potential of a factory to be able to accomplish reactively or proactively a goal-oriented reconfiguration of the factory objects on every system level with little effort by using transformability enablers intrinsic to the system and structure. The goal of transformability is to increase the efficiency of a factory [12]. To be capable of reacting to the constant changes, like an increase in production or additional products, a company can activate the integral potential rapidly and with little effort if necessary despite the lack of forecasting options [2], [13].

Therefore, the factory objects and transformability enablers play an important role. The transformability enablers allow the factory objects to perform a transformation. Five different transformation enablers have been defined: universality, mobility, scalability, modularity, compatibility [14], [15] (Fig. 2). Some factory objects are not affected by certain transformability enablers. The attribute mobility, for example, cannot be reasonably linked to the factory object real estate [12].

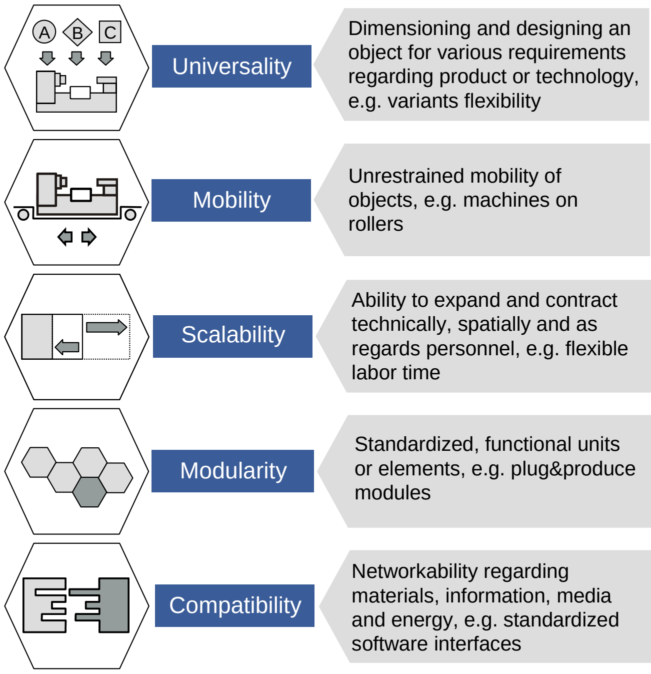

Fig. 2 Transformability enablers

The transformability of a factory takes three forms: space, organization, and means. *Spatial* transformability denotes the scope for the expansion and contraction of the factory. A characteristic known as “breathability” plays an important role with respect to floor and site areas and principally concerns the factory, the ergonomics, and the production layout. *Organizational* transformability enables the alteration and adaptation of organizational structures and processes. Transformability of the *means* refers to the configurability and reconfigurability of operational resources, processes, etc. It embraces all the technical systems in a factory [12].

C. Lean Production

The main objective of lean production is the elimination of every type of waste [16], [17]. Costs can thus be saved and production at the lowest possible prices is possible. Here, waste means everything that does not add value to a product [18]. The seven types of waste are: overproduction, waiting times, unnecessary transportation and handling, waste in the production process, useless and excess inventories, useless motions plus production of scrap and defects [19]-[21]. Lean production is predicted on the basis of the Toyota Production System, which was mainly created by the engineers Ejji Toyoda and Taiichi Ohno [22]. According to this system there are other goals in lean production beside the elimination of waste, e.g. a continuous production flow and the goal-oriented involvement of the employees in the processes [23], [24].

Lean production provides a number of methods for reaching these goals. The methods of lean production used in this paper to illustrate the developed procedure are described below.

The *Just-In-Time Principle (JIT)* means an order-oriented material supply. The goal is that the required demand in the required quantity is procured at the exact time at the correct place [25], [26].

5S represents a workplace organization that is responsible for order and cleanliness. The five S stand for sorting, straighten or set in order, sweeping or shining, standardizing, and sustaining the discipline [25]. Results include an increase in job performance and optimization of throughput times [23], [24].

The concept of *Single Minute Exchange of Die (SMED)* represents a method to decrease the setup times for new tools to the level of minutes. The activities involved in the setup process are, for example, already activated as soon as the demand is requested. For example, dies can already be prepared and transported to the proximity of the machine while the current process is still in operation [24].

Kaizen means a continuous improvement process in a company in which all the employees participate and introduce their ideas [25]. This can be accomplished in a company by a standardized improvement system, for example.

Standardization allows mistakes and abnormalities to be understood and therefore avoided. It is achieved, for example, by implementing standardized means of storage. Furthermore, standardization requires that work processes are documented in detail. They can thus be optimized and waste can be avoided [23], [25].

According to the principle of the *One-Piece-Flow*, a product is transported from the beginning of the process to the end, from one workstation to the other, without interruption [25].

Visualization and transparency imply that tools and products as well as production activities and performance indicators are clearly organized so that every person involved is able to see easily in which condition the system is arranged [24].

Only through the interaction of the lean production methods can the desired targets be reached.

III. Requirements for Factories

To develop a procedure for evaluating and designing a factory with respect to the requirements of lean production and transformability, it is necessary to know what both philosophies require. These requirements can be derived systematically from the factory levels and factory fields for all factory objects. The bases for the requirements of transformability are the transformability enablers. The goals of the different methods are essential for the requirements of lean production. Even if those mostly have the workstation level as their target, it is possible to expand them to the complete factory.

A. Requirements from the Transformability Viewpoint

If transformability is to be assured, factories need to comply with many requirements. At this point, the requirements that result from the transformability enablers on the workstation level are illustrated as an example (Fig. 3). The requirements placed on the other three levels can be derived similarly.

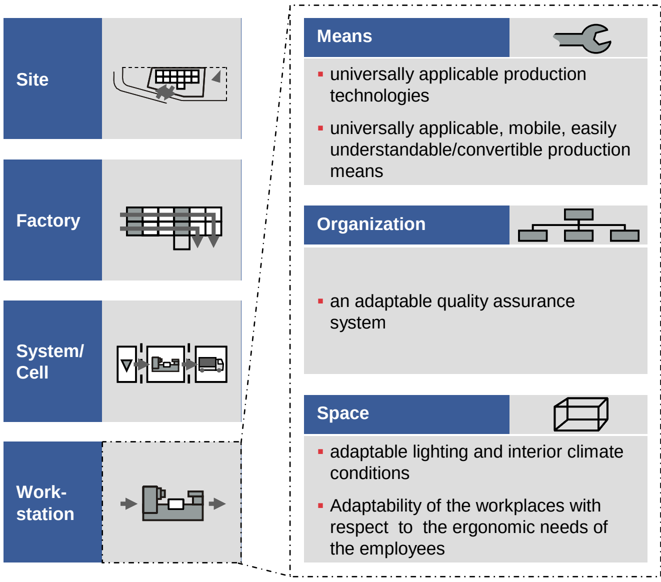

Fig. 3 Examples of transformability requirements to be fulfilled by factories on the workstation level

The transformability of a factory on the workstation level from the means viewpoint can be assisted, among others things, by universally applicable production technologies and production means. These allow the manufacture of different products with the same technology or means. Production means not requiring a permanent connection to the floor or lightweight plant can be easily transported and thus easily moved to another place when this is necessary because of changes. Hence, these production means can increase the transformability of a factory. If it is also possible to learn easily the operation of the production means, new employees can be readily integrated when there is, for example, an increase in production.

From the organizational point of view, an adaptable quality assurance system, which allows the testing of additional products after a change, can support the transformability. A readily adaptable system is necessary to cope with such changes.

In order to be able to react to spatial changes every time, it should, for instance, be possible to accomplish activities that need plenty of light throughout the entire factory. In addition, it is preferable that the climate conditions at every place in a factory building can be adapted to the requirements of certain tasks with little effort. That allows every workplace and every job to be arranged anywhere in the factory if a change is necessary. Furthermore, changing a worker between workplaces or workstations can be easily handled if each workplace is readily adaptable to the needs of workers [7], [27].

Beside the technical, spatial, and organizational aspects, the personnel of a factory play an important role in the transformation process. To utilize the potential for change that has been created and to design the transformation in a factory successfully, the personnel must participate in and support the process [28].

B. Requirements from the Lean Production Viewpoint

Like with transformability, it is possible to derive the requirements from the lean production viewpoint by using the individual method targets of lean production. The requirements will again be described using the workstation level as an example (Fig. 4).

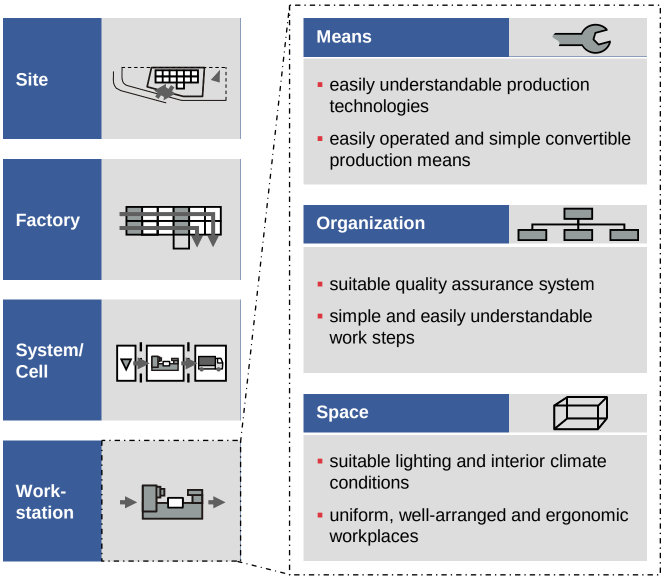

Fig. 4 Examples of lean production requirements to be fulfilled by factories on the workstation level

From the technical viewpoint, the production technologies, for example, should be easily understandable. Furthermore, it is necessary that the production means used are easily learned and operated. Both requirements are linked to the goal of avoiding mistakes. The easier the workers understand the machines and technologies used, the fewer mistakes there will be. In addition, it should be possible to retool the machines easily and rapidly in order to minimize waiting times. That is one aim of the SMED method. Hence, a lot of different variants can be produced, and the different customer demands can be satisfied at short notice. Thus, the goal of the one-piece-flow is followed.

To improve the workflow and the process organization, it is necessary that the work steps used are easily understandable, a fact that promotes production with a low reject rate. In order to reach this goal, a suitable quality assurance system is also essential.

When considering the factory field “space” from the viewpoint of lean production, standardized, well-arranged, and ergonomic workplaces need to be available or should be realizable. If not, the 5S method cannot lead to success. If there are unobjectionable workplaces, clarity in the work area can be implemented easily, jobs are eased and the reject rate of the production is reduced. The reject rate can also be reduced by ensuring suitable lighting and interior climate conditions because the work environment is harmonized with the requirements of job and worker.

Furthermore, like with the implementation of transformability, the participation of the employees plays an important role in the successful implementation of lean production in addition to the factory fields described. The know-how of the workers, their willingness to communicate, and their motivation to implement the measures needed are essential for the lean philosophy [16], [23].

IV. Synergies, Neutralities, and Conflicts between Lean Production and Transformability

The identification of the requirements, which result from the viewpoints of lean production and transformability and their comparison, show that the interdependencies can be synergetic and neutral as well as conflicting.

Synergies are due to, for example, an easy-to-understand instruction manual for every production means. Hence, on the one hand, the job training for additional staff after a change is enhanced. On the other hand, the reject rate in production is reduced. That again is a goal of lean production. Another instance of synergies is the standardization of means of storage. If the standardization level of these means is high, uniformity and clarity is supported from the viewpoint of lean production, meaning that rejects can be tracked and avoided in future. Transformability, too, is improved by a high level of standardization because the means of storage can be used without modification at every other place in the factory after a change has taken place.

An example of neutrality between the two philosophies is the type of connection between the production means and the floor. If there is a readily detachable connection with the floor, machines can be repositioned with little effort. The transformability is thus enhanced. Whether or not a machine is connected to the floor is not normally critical for lean production and its integration into a factory because a fixed, immovable machine is normally assumed in lean philosophy. However, lean production does require that production processes follow the one-piece-flow philosophy. This constraint does not apply to the concept of transformability.

It is especially the conflicts that exist between the two philosophies that can severely hamper the design of factories. A leaner design of the factory objects in this case also means a lower level of transformability. Therefore, these conflicts have to be considered very carefully when developing the desired procedure.

Clustering the conflicts across all factory objects and their evaluation features resulted in, among others, the following existing conflicts between lean production and transformability when designing a factory.

The concept of transformability requires the creation of area modules and the reservation of expansion areas. The goal is to support changes to areas and sectors within the factory. A strict implementation of the lean production concept, however, results in configuring the production according to a static load condition. This minimal configuration during the design of the processes reduces investments to a minimum but does not allow resources to be reserved for future changes, e.g.

expansion areas. The amount of space in area modules is not used efficiently in most cases either. That again means waste.

Furthermore, the integration of reserves for constructive enhancement, e.g. in terms of an upgradable provision of media and energy, supports the transformability. However, this conflicts with the design of lean factories because this sets conditions for expansion that are not necessary in the current condition. That can be seen as waste.

Small working groups can have a positive affect on transformability because this approach eases the self-organization of a group after a change. In the best case every worker can be displaced independently of the other workers. However, from the viewpoint of lean production it is an advantage if the working groups are not too small. An appropriate group size helps to enhance the learning and continuous improvement processes.

To aid factory transformability, the connections between the individual units should be minimal, or “elastic”. This allows changes within the process to be handled by establishing other connections. From the viewpoint of lean production, on the other hand, “inelastic” connections are required because standardized processes help to avoid mistakes and guarantee clarity. This inelastic interconnection of lean processes, which are not designed to allow changes, is contradictory to the requirements of transformability.

V. Procedure for the Evaluation and Design of Lean and Transformable Factories

Taking the procedure for the evaluation of transformability [7], [15], [29] as a starting point, a systematic procedure was developed at the IFA which allows companies to evaluate and design their factories with respect to the requirements of lean production and transformability. Using this procedure it is possible to evaluate the so-called lean integration (LI), which means the degree of implementation of lean production in a factory. The efficient use of resources can thus be planned and waste avoided. By designing the factory with respect to the requirements of transformability (TF), it is also possible to react to future changes. The procedure developed consists of five steps – factory analysis, quantification of the actual status of the factory objects (FO), quantification of the target status of the factory objects, identification of needs for action, and derivation of measures for action for the factory objects (Fig. 5).

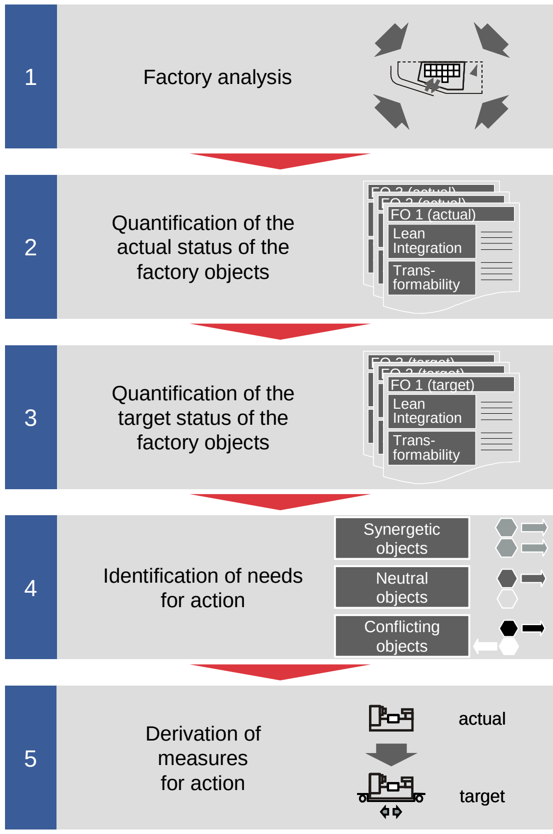

Fig. 5 Procedure for the evaluation and design of lean and transformable factories

The procedure starts with a factory analysis. The purpose is to describe the factory to be assessed and its factory objects. Furthermore, the competitive environment (e.g. competitors, customers, products) and the identifiable trends in the branch of industry of the factory are cataloged and analyzed. In addition, it is important to specify the strategic objectives, visions, and goals of the company.

Thereupon, the actual status of every factory object is cataloged with the evaluation features that characterize them. The evaluation features of all factory objects were derived from the requirements of both philosophies identified beforehand and a scale for the evaluation was developed for every feature. As some evaluation features are evaluated quantitatively and others qualitatively, all feature values are transformed into a percentage scale. It is thus possible to compare all factory objects. Therefore, the evaluation is described by means of features rateable both quantitatively and qualitatively. The case of a standardized means of storage is used as an example of the qualitative evaluation (see above). As described, the standardization of the means of storage has an influence on lean production as well as transformability. The fulfillment of this feature is essential for both philosophies. It is thus possible to evaluate the lean integration and the status of transformability of the object using this feature. The higher the level of standardization, the leaner and more transformable is the feature. The example in

Fig. 6 illustrates that in the case shown here the means of storage in the factory are all standardized and can be interchanged with each other. Looking at the transformed scale, that means both the transformability and the lean integration possess a value of 100 percent.

Scale defintion and feature evaluation

Evaluation feature**:**

Standardization of the means of storage

Example: All means of storage are standardized and can be interchanged with each other

Scale	Evaluation	TF Value	LI Value
not fulfilled		0%	0%
sporadically fullfilled		25%	25%
partial fulfilled		50%	50%
mostly fulfilled		75%	75%
fullfilled	x	100%	100%

Fig. 6 Evaluation example – standardization of the means of storage

The second example deals with a quantitatively rateable feature – the expansion areas in the layout (see above). The goal of lean production is to avoid the waste of resources. That means no expansion areas should be reserved because that ties up capital and space is not used efficiently. By contrast, transformability requires adequately sized expansion areas to enlarge fields of work if there is an increase in production or additional products need to be integrated into the production process. This feature is important to both philosophies, but there is a potential for conflicts. The leaner the feature, the less distinctive is the transformability. In the example, the percentage of expansion areas compared to the complete area of the layout is only 4.3 percent. Thus, the expansion options are not satisfactory from the viewpoint of transformability (value for transformability: 25 %). However, this means a low level of waste and good integration of lean production into the factory (value for lean integration: 75 %) (Fig. 7).

Scale defintion and feature evaluation

Evaluation feature:

Areas of expansion

Example: The percentage of areas of expansion in the factory compared to the area of the layout is 4.3 %.

Scale	Evaluation	TF Value	LI Value
[0%, 2%]		0%	100%
(2%, 5%]	x	25%	75%
(5%, 10%]		50%	50%
(10%, 20%]		75%	25%
(20%, 100%]		100%	0%

Fig. 7 Evaluation example – expansion areas

In the next step, future scenarios have to be developed for the factory in order to gather information about the future transformability and lean production needs for all factory objects [30]. Therefore, the trends in the branch of industry in which the company is active, that were identified within the factory analysis, are investigated.

After the target values for the factory objects have been detected, the next step is to identify needs for action for the factory objects of a lean und transformable factory on the basis of the actual and target values. In doing so, it is necessary to look at three different types of needs for action. The first case, as described in section IV, regards the features of a factory object that show synergies between lean production and transformability, e.g. standardized means of storage. What this means is: the leaner a feature, the more transformable it is without additional costs. In this case the maximum feature value should be derived from the target values of both philosophies.

Moreover, it is possible that a feature only affects either transformability or lean production (neutrality). Examples of this were the level of connection between the production means and the floor or the design of processes by implementing the principle of one-piece-flow (see above). Where a neutral feature is involved, the target value to adjust is the target value of the philosophy concerned.

The last and most complicated case concerns the factory objects characterized by features that exhibit conflicts between lean production and transformability. These were described in detail in section IV. The features affected in that case cannot be handled easily. Instead, it is necessary to perform an analysis of the factory object in each individual case. Therefore, a costs-benefits analysis of the different features should be carried out. The goal is to discover the best value combination for the company from the viewpoints of both philosophies.

After needs for action have been identified, the fifth and last step of the procedure is to derive measures for action and thus adjust the factory objects to the value identified so that in the optimized condition the factories are transformable as well as lean.

The target values for the design of the factory objects are the values that were identified in step 4 and represent the best combination of both philosophies.

From the viewpoint of transformability, the factory objects are reconfigured by adjusting the associated features. Therefore, measures are defined to increase or, if necessary, decrease the transformability of every single feature and thus adjust the feature to the target value. Two types of measures have to be differentiated here. On the one hand, measures that can be carried out during production. On the other hand, measures that can only be realized by interrupting production. The former type concerns, for example, the factory object fitting-out. One option for increasing the transformability of this object during production is to replace fixed markings on the floor by ones that can be easily changed if necessary, e.g. when the sizes of areas or sectors are altered after a change. A measure that can normally only be realized when there is a break in production, for example, is a modification of a production means to ease the operability [7].

The company-specific adjustment of the factory objects to the required status with respect to lean integration is realized by using the well-known methods of lean production. The lean methods that have the biggest effect on the object were defined for every factory object. Using the appropriate methods means it is possible to design the objects leaner. According to this classification, Kaizen and standardization can affect most of the factory objects. These methods are therefore effective in almost all areas of a factory when design the factory to be leaner. As for transformability, the measures can be differentiated according to the two types described above. Standardization, for example, as shown above, can increase the lean integration of the factory object means of storage. The means can be interchanged and standardized successively, which can help to reduce the reject rate. That is normally possible without interrupting production. Setup times may be able to be reduced by using the SMED method. In many cases it is necessary to interrupt production if the setup times are to be reduced because it is usually necessary to modify the production means.

VI. Summary

In the turbulent competitive environment, companies are faced with two principal challenges. On the one hand, it is necessary to reduce costs in order to be able to produce at reasonable prices. On the other hand, companies need to reserve potential in order to be able to react, for example, to an increase in production or additional products. To achieve the costs targets, companies have been using the philosophy of lean production for many years. The philosophy of factory transformability is utilized in order to be able to react to future changes. Transformability, however, entails additional costs in some cases. In several points the two philosophies exhibit opposing tendencies with respect to optimizing production.

A five-step procedure has been developed at the IFA that allows companies to evaluate and design their factories with respect to the requirements of both philosophies – lean production and transformability. Therefore, the requirements of both philosophies and the interdependencies between them were identified. Based on the requirements, features and scales were developed to evaluate the factory objects. These are the fundamentals of the procedure. On the basis of the evaluation results measures can be derived to adjust the factory objects to the identified target value of both philosophies. Thus, the procedure helps companies to use their resources efficiently and economically, but to react to changes as well.

References

[1] E. Westkämper, “Digital manufacturing in the global era,“ 3rd International CIRP Seminar Digital Enterprise Technology, Setúbal, Portugal, 2006.
[2] R. Cisek, C. Habicht and P. Neise, “Gestaltung wandlungsfähiger Produktionssysteme,“ ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb 97(9), Carl Hanser Verlag, München, Wien, 2002, pp. 441-445.
[3] J. Niemann and E. Westkämper, “Investitionskosten versus Betriebskosten,“ wt Werkstattstechnik online, 94 (3), 2004, pp. 43-47.
[4] VDI5200, “Fabrikplanung – Planungsvorgehen“, VDI, Düsseldorf, 2009.
[5] G. Ropohl, “Allgemeine Technologie – Eine Systemtheorie der Technik,“ 2nd ed., Carl Hanser Verlag, München, Wien, 1999.
[6] E. Westkämper, et al., “Ansätze zur Wandlungsfähigkeit von Produktionsunternehmen - Ein Bezugsrahmen für die Unternehmensentwicklung im turbulenten Umfeld,“ wt Werkstattstechnik online, 90 (1/2), 2000, pp. 22-26.
[7] C. Heger, “Bewertung der Wandlungsfähigkeit von Fabrikobjekten,“ dissertation at the Leibniz University of Hanover, 2007.
[8] W. Eversheim and G. Schuh, “Betriebshütte: Produktion und Management,“ 7th ed. Vol. 1 and 2, Springer Verlag, Berlin / Heidelberg, 1996.
[9] M. Schenk and S. Wirth, “Fabrikplanung und Fabrikbetrieb – Methoden für die wandlungsfähige und vernetzte Fabrik,“ Springer Verlag, Berlin / Heidelberg, 2004.
[10] P. Nyhuis, M. Kolakowski and C. L. Heger, “Evaluation of factory transformability,” 3rd International CIRP Conference on Reconfigurable Manufacturing, Ann Arbor, USA, 2005.
[11] H.-P. Wiendahl, “Wandlungsfähigkeit - Schlüsselbegriff der zukunftsfähigen Fabrik,“ wt Werkstattstechnik online, 92 (4), 2002, pp. 122-127.
[12] R. Hernández, ”Systematik der Wandlungsfähigkeit in der Fabrikplanung,“ in: VDI Fortschritt-Berichte, Düsseldorf, dissertation at the Leibniz University of Hanover, 2003.
[13] H.-P. Wiendahl, R. Hernandez and V. Grienitz, “Planung wandlungsfähiger Fabriken,“ ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, 97 (1-2), Carl Hanser Verlag, München/Wien, 2002, pp. 12-17.
[14] H. ElMaraghy and H.-P. Wiendahl, “Changeability – An introduction,” in: Changeable and Reconfigurable Manufacturing Systems, editor: H. ElMaraghy, Springer Verlag, London, 2009, pp. 3-24.
[15] H.-P. Wiendahl, et al., “Changeable manufacturing - classification, design and operation,” Annals of the CIRP, 56(2), 2007.
[16] J. K. Liker, “The Toyota Way – 14 Management Principles from the World´s Greatest Manufacturer,” McGraw-Hill, New York, et al, 2004.
[17] J. P. Womack and D. T. Jones, “Lean Thinking,” Simon & Schuster, New York, 2003.
[18] B. Carreira, “Lean Manufacturing that works,” AMACON, New York, 2005.
[19] P. Hines and N. Rich, “The seven value stream mapping tools,” International Journal of Operations and Production management, 17(1), 1997, pp. 46-64.
[20] T. Ohno, “Toyota Production System – beyond large-scale production,” Productivity Press, Portland, Oregon, 1988.

[21] D. Tapping, T. Luyster and T. Shuker, "Value Stream Management – eight steps to planning, mapping, and sustaining Lean improvements," Productivity Press, New York, 2002.
[22] J. P. Womack, D. T. Jones and D. Ross, "Die zweite Revolution in der Autoindustrie," Vol. 8, Campus Verlag, Frankfurt, 1992.
[23] J. Allen, C. Robinson and D. Stewart, "Lean Manufacturing: A plant floor guide," Society of Manufacturing Engineers, Dearborn, Michigan, 2001.
[24] M. F. Zäh and F. Aull, "Lean-Production Methoden und Interdependenzen," wt Werkstattstechnik online, 96 (9), 2006, pp. 683 - 687.
[25] M. Imai, "GEMBA KAIZEN - A commonsense, low-cost approach to management," Vol. 20, McGraw-Hill, New York, 1997.
[26] W. A. Levinson, "Beyond the Theory of Constraints," Productivity Press, New York, 2007.
[27] H. Luczak, "Arbeitswissenschaft„ Springer Verlag, Berlin, Heidelberg, 1998.
[28] T. Heinen, D. Gerst and P. Nyhuis, "Management of factory transformability on the basis of business processes," The Business Review, Cambridge, Vol. 9, No. 2, 2008, pp. 295-302.
[29] P. Nyhuis, M. Kolakowski and C. Heger, "Evaluation of factory transformability - a systematic approach," Annals of the German Acadamic Society for Production Engineering, XIII (1), 2006, pp. 147-152.
[30] J. Gausemeier, A. Fink and O. Schlake, "Scenario management: an approach to develop future potentials," Technol Forecast Soc Change 59 (2), 1998, pp. 111-130.