

# Development of a Model for the Redesign of Plant Structures

L. Richter, J. Lübke, P. Nyhuis

**Abstract**—In order to remain competitive in what is a turbulent environment; businesses must be able to react rapidly to change. The past response to volatile market conditions was to introduce an element of flexibility to production. Nowadays, what is often required is a redesign of factory structures in order to cope with the state of constant flux. The Institute of Production Systems and Logistics is currently developing a descriptive and causal model for the redesign of plant structures as part of an ongoing research project. This article presents the first research findings attained in devising this model.

**Keywords**—Causal model, change driven factory redesign, factory planning, plant structure.

## I. INTRODUCTION

**B**OTH increasing globalisation of the competition and the transformation of the suppliers' market into a buyers' market are reflected by constant changes in market conditions. This transformation is accompanied by an upsurge in the individualisation of customer requirements along with increasing market saturation, one result of which is that product and variant diversity continue to expand. Market internationalisation also leads to situations of severe competition, reflected by shorter product lifetimes, the necessity of just-in-time- and just-in-sequence deliveries, and a reduction in manufacturing costs, among other factors. The challenge that this presents to businesses is to remain competitive despite the volatile market conditions and to adapt in accordance with the changes occurring in their environment [1], [2]. Many companies in the 1990s achieved success by making their assembly and production processes more flexible. However, now and in the future, continued success in a turbulent environment not only requires flexibility but also the ability for businesses to undergo structural change [3].

As part of the 'Model-based Redesign of Factories (ReFa)' research project funded by the German Research Foundation (DFG), a descriptive and causal model is being developed at the Institute of Production Systems and Logistics (IFA) which aims to reproduce the impacts that a factory's structural elements have on each other and the direct and indirect

Lukas Richter and Jens Lübke are with the Institute of Production Systems and Logistics, 30823 Garbsen, Germany (phone: +49-511-762-19810; fax: +49-511-762-3814; e-mail: richter@ifa.uni-hannover.de, luebke@ifa.uni-hannover.de).

Prof. Peter Nyhuis is the director of the Institute of Production Systems and Logistics, 30823 Garbsen, Germany (phone: +49-511-762-2440; fax: +49-511-762-3814; e-mail: nyhuis@ifa.uni-hannover.de).

This research was made possible through the generous funding by the German Research Foundation (DFG) in the context of the project 'Model-based Redesign of Factories (ReFa)', which is funded under the sign NY 4/56-1

impacts of internal and external change drivers on these structural elements. The model aims to anticipate modifications that are necessary to a factory's structure and to express them systematically in terms of modification measures.

The first part of this article presents the fundamentals of factory planning, plant structure and factory changeability. The next section discusses the necessity of a model for the change driven redesign of factory structures. Finally, the results of an analysis of relevant change drivers are presented together with their direct impact on structural elements within the factory. The article concludes with a summary and an outlook of further activities to be performed in the research project.

## II. BASICS OF FACTORY PLANNING, PLANT STRUCTURE AND CHANGEABILITY

### A. Factory Planning

A factory is a 'place where value is created by the manufacture of industrial goods based on division of labour while utilising production factors' [4]. Factories are complex systems and vary immensely in terms of their function, dimension, structure, design, productivity and team ability [5].

Factory planning comprises a methodical, goal-oriented, structured process undertaken in successive, sequential phases. The process can be divided into the following phases: setting of objectives, establishment of the product basis, concept planning, detailed planning, preparation of realisation, monitoring of realisation and ramp-up-support. The ensuing tasks are characterised by their uniqueness; they are performed by a team in the form of projects and controlled using the methods of project management. Factory planning projects can be triggered by changes in factory requirements that can be factory-internal (e.g. wear and tear to existing company equipment), company-internal (e.g. changes in corporate strategy) or company-external (e.g. changes in market conditions). A distinction is drawn between various planning cases: development planning (building a factory on a greenfield site), replanning (remodelling planning, expansion planning), clearance (factory shut down, demolition) and revitalisation (industrial reutilisation of wasteland site) [4].

### B. Plant Structure

According to Harms, a plant structure consists of a factory's elements and the relations between them (based on system theory). An example of an element in the context of a factory structure is a resource or an employee. A combination of these forms a structural unit. Structural units in the factory can be aggregated in terms of their levels of detail [6].

The success of factory planning is measured in terms of the degree to which the goals defined at the start of the project are reached. In the course of structural planning, factory objects are reproduced in a relational structure that satisfies the defined requirements. This must have the ability to endure for as long as possible both from a processual and a spatial point of view, whilst also allowing modifications in the event of any changes to the limiting conditions. As a rule, it is not possible to pinpoint a consistent structural principle for an entire factory. It is therefore advisable to segmentise the factory's structure into various levels of detail (e.g. factory, department, or system) in accordance with appropriate structural characteristics (e.g. customer, technology, product group) [7]. The various ways in which structural elements can be combined lead to different planning options. These are then evaluated and compared, with the aid of criteria defined in the set objectives. A summary of factory planning objectives and criteria can be found in [8].

### C. Change Drivers

Both technical and social elements in a factory may be affected by changes. It is because of these change drivers that a factory's processes and structure need to be modified in increasingly short intervals. To ensure that appropriate modifications are able to satisfy their objectives, they need to be planned in advance. Changes can be triggered either by external change drivers, such as changes in market prices, or internal change drivers, such as strategic changes [9]. Such triggered changes can have an impact on different levels and parts of a factory, they can be one-off or they may be continual, and they can vary in their scope [10]. A comprehensive list of internal and external change drivers is available from Klemke [9].

### D. Flexibility & Changeability

Change forces manufacturing companies to constantly rethink their production structures and to modify them in order to remain competitive [11]. In the context of change, such terms as flexibility and changeability are therefore of central significance [7], [12].

A factory's flexibility is understood to be its ability to react to anticipated changes in production factors within a defined area. Changeability, on the other hand, describes a factory's ability to implement changes beyond this area (see Fig. 1) [13]. In contrast to flexibility, changeability is not immediately available for use and must first be activated in the desired form. For example, changeability exists when strong fluctuations in demand cannot only be absorbed within a particular quantity corridor, but these corridors can themselves be modified flexibly to current prevailing demand [14].

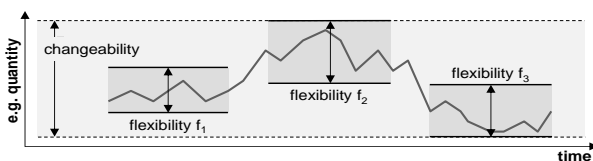


Fig. 1 Difference between changeability and flexibility [13]

## III. NEED FOR A MODEL-BASED REDESIGN OF PLANT STRUCTURES

If change drivers have such a strong form or they are able for some other reason to impact so strongly on a factory's structure that requirements cannot or can only partially be fulfilled by changes within the framework of the factory's changeability, it will be necessary to undertake comprehensive changes to operational interrelations and processes. These are summarised under the heading of Restructuring [15]. If individual structural elements are influenced by a change within the factory or in its immediate environment, this influence can also affect numerous other structural elements (see Fig. 2).

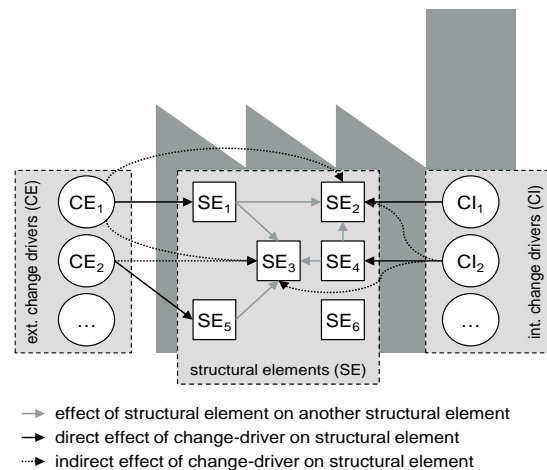


Fig. 2 Effects between change drivers and structural elements

Existing approaches to describing and planning factory structures point towards two essential deficits. The first consists of an insufficient depth of detail with regard to the relations between the factory's structural elements: a factory structure is seen as an abstract arrangement of business units and their interrelations; these relations themselves are generally viewed merely as a general aggregation of material and information flows. However, there are further relations that exist between structural elements in addition to material and information flows, such as communication, personnel and energy flows [6], [16]. The second deficit is the inability to predict the impact that changes will have on other structural elements. The questions of the effects that a change in environment will have on a factory's structure and what restructuring measures these changes will necessitate remain so far largely unaddressed.

## IV. IDENTIFICATION OF RELEVANT CHANGE DRIVERS

The aim of developing a descriptive and causal model of factory redesign is to be able to discern a change driven need for modification to a factory's structure at an early stage and to use it to derive suitable restructuring measures. The research findings presented in the following are intended to contribute to the development of a factory redesign model. It first of all addresses the following questions:

- What are the changes that are relevant to a factory's structure?
- What change drivers have a direct influence on a factory's structural elements?

Change drivers that are of relevance to a factory's structure are to be incorporated in a causal factory redesign model. The following distinguishing criteria have been defined to identify these change drivers:

**Criterion 1** serves to distinguish change drivers whose impact can be reacted to by changeability from change drivers whose impact may require a redesign of the factory:

*If a change driver exerts an impact such that modifications to a factory's structure are required that are fully addressed by changeability in the context of the modifications and therefore do not require the planning of a new factory structure, the criterion is deemed unsatisfied.*

**Criterion 2** serves to distinguish change drivers that exert an impact on structural elements solely through changes in resources, methods and conditions from change drivers that have a direct impact on a factory's structural elements:

*If a change driver exerts an impact on one or more structural elements solely by way of changes in resources, methods and conditions and hence does not directly affect one or more of the factory's structural elements, the criterion is deemed unsatisfied.*

**Criterion 3** serves to distinguish impacts of change drivers that represent external costs and are exclusively compensated for by changes in input and output factors from impacts of change drivers that can be responded to with restructuring measures:

*If the impacts of a change driver are exclusively in the form of external costs which can be compensated for solely by a reduction in input and output factors (e.g. energy, water, raw materials, or waste) and not by restructuring, the criterion is deemed unsatisfied.*

**Criterion 4** serves to exclude change drivers that exert an impact on structural elements but whose impacts cannot or can only insufficiently be countered by restructuring:

*If a change driver has an impact on structural elements that cannot or can only insufficiently be compensated for in terms of structural planning, the criterion is deemed unsatisfied.*

Fig. 3 shows an extract from the study findings following application of the defined distinguishing criteria on the 39 change drivers after Klemke [9] for change drivers in the group 'Suppliers'.

group	change driver	criterion			
		1	2	3	4
suppliers	changed delivery times			x	
	changed delivery reliability			x	
	changed parts attributes	x	x	x	x
	changed parts quality	x	x	x	x
	changed material cost			x	
	changed order quantities	x	x	x	x
	long-term supply shortages / failures			x	
	changes in energy costs	x			
	changes in water costs				

Fig. 3 Identification of change drivers relevant to the study

An 'x' denotes that a criterion is fulfilled by a change driver. In this example, the change drivers 'changed parts attributes', 'changed parts quality' and 'changed order quantities' satisfy all four distinguishing criteria. In this way, a total of 17 change drivers from the groups 'legislators & organisations', 'customers & market', 'suppliers', 'company & network', 'technology' and 'employees' were identified as relevant for integration in a causal model for the redesign of factories.

#### V. EFFECTS OF CHANGE DRIVERS ON STRUCTURAL ELEMENTS

The effects of the identified change drivers on the factory's structural elements were investigated by researching the literature and compiling findings from previous factory planning projects. Fig. 4 contains an extract of a relational matrix showing qualitative descriptions relating to change drivers in the group 'suppliers' and the structural elements 'production', 'assembly', 'maintenance' and 'warehousing'.

group	change driver	structural element			
		production	assembly	maintenance	warehousing
suppliers	changed parts attributes	x	x	x	
	changed parts quality	x	x	x	
	changed order quantities				x
	change in corporate vision, mission, strategy,	x			

<b>change driver:</b> changed parts quality	<b>structural element:</b> production
<b>definition:</b> Parts quality refers to the degree to which the requirements of part features are met.	<b>definition:</b> Production refers to all organizational and technical activities required to change materials or products.
<b>effect-description:</b> Parts from suppliers that do not meet the given requirements and are not sorted out before entering the production area can cause redundant work or waste in the manufacturing process. Influences on production by parts from suppliers that exceed the given requirements are not recognizable.	

Fig. 4 Direct impacts of change drivers on structural elements

In addition to definitions of change drivers and their impact elements, the relational matrix also contains descriptions of the possible impacts of change drivers on structural elements. The present example describes the impact of the change driver 'changed parts quality' on the structural element 'production'. This impact can be responded to by changes in structure, for example by subjecting incoming parts to a quality inspection before they enter the production area.

#### VI. SUMMARY AND OUTLOOK

In the course of the research project 'Model-based Redesign of Factories (ReFa)', change drivers were identified that exert an impact on a factory's structural elements and which can be responded to by implementing a redesign. The impacts of these change drivers on a factory's structural elements were subjected to a qualitative investigation and presented in a relational matrix, to which definitions and descriptions were appended. The results of the impact analysis were presented in extract form. The present report constitutes interim findings.

The impacts determined must now be quantified by means of expert interviews and amended where appropriate.

In the further course of the research project, the dependencies between a factory's structural elements should be investigated. This would generate a basis for a causal model that would reproduce both the direct and indirect relations between change drivers and structural elements. These causal relations should as far as possible be quantified and operationalised by means of detailed descriptions.

Furthermore, to allow successful application of the causal model, an approach should be developed that will allow a redesign of factory structures under application of the model. The procedure and the model should be validated under realistic conditions. The final result of the research project will be a practicable procedure for the model-based redesign of factories.

#### REFERENCES

- [1] B. Lotter and H.-P. Wiendahl, "Montage in der industriellen Produktion. Ein Handbuch für die Praxis," Montage in der industriellen Produktion, 2012.
- [2] H.-P. Wiendahl, Variantenbeherrschung in der Montage. Konzept und Praxis der flexiblen Produktionsendstufe. Berlin. Springer, 2004.
- [3] E. Westkämper and E. Zahn, Wandlungsfähige Produktionsunternehmen. Das Stuttgarter Unternehmensmodell. Berlin. Springer, 2009.
- [4] VDI, Factory planning - Planning procedures, vol. 03.100.99, 2011.
- [5] S. Wirth, M. Schenk, and E. Müller, "Fabrikarten, Fabriktypen und ihre Entwicklungsetappen," ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, vol. 106, pp. 799–802, 2011.
- [6] T. Harms, Agentenbasierte Fabrikstrukturplanung. Garbsen. PZH Produktionstechnisches Zentrum, 2004.
- [7] H.-P. Wiendahl, J. Reichardt, and P. Nyhuis, Eds., Handbuch Fabrikplanung. Konzept, Gestaltung und Umsetzung wandlungsfähiger Produktionsstätten. München. Hanser, 2009.
- [8] M. Brieke, Erweiterte Wirtschaftlichkeitsrechnung in der Fabrikplanung. Garbsen. PZH Produktionstechnisches Zentrum, 2009.
- [9] T. Klemke, Planung der systematischen Wandlungsfähigkeit von Fabriken. Garbsen. TEWISS, 2014.
- [10] J. C. Aurich, M. Rößing, and R. Jaime, "Änderungsmanagement in der Produktion. Am Beispiel der Einführung einer Maschinen- und Betriebsdatenerfassung," ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, vol. 99, pp. 381–384, 2004.
- [11] R. Hernández Morales, Systematik der Wandlungsfähigkeit in der Fabrikplanung. Düsseldorf. VDI-Verlag, 2003.
- [12] P. Nyhuis and C. L. Heger, "Adequate Factory Transformability at Low Costs," International Conference on Competitive Manufacturing, pp. 469–474, 2004.
- [13] G. Reinhart, 1st International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV 2005). München. Utz, 2005.
- [14] P. Nyhuis, G. Reinhart, and E. Abele, Eds., Wandlungsfähige Produktionssysteme. Heute die Industrie von morgen gestalten. Garbsen. PZH Produktionstechnisches Zentrum, 2008.
- [15] H. Becker, Produktivität und Menschlichkeit. Organisationsentwicklung und ihre Anwendung in der Praxis. Stuttgart. Lucius & Lucius, 2002.
- [16] M. Schenk, S. Wirth, and E. Müller, Factory planning manual. Situation-driven production facility planning. Heidelberg, New York. Springer, 2010.