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*plant developments,*
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# A MODEL OF PLANT DEVELOPMENTS UNDER CHANGEABILITY ASPECTS

High flexibility and strategic adaptability are two of the major challenges for manufacturing companies, who have to survive in a turbulent environment. They have to recognise the need for change and innovation on all company levels at an early stage in order to be in the position to implement necessary changes of production structures in a timely manner. In order to make necessary investments in a timely manner, producing companies have to adjust direct and indirect object, structures and processes of the system of performance according to the wishes of customers. Early planning calls for a detailed understanding of the existing processes, structures of resources and the experiences which led to their development. An analysis of the past developments is the necessary foundation for a long term planning of future plant developments. In this paper, a method is proposed for a systematic analysis of past developments of the production structures that consider the specific needs of a plant. The method is the foundation for strategic planning of manufacturing structures and provides the architecture to consider future changes of markets, products and technologies within forecasts and scenarios.

## 1. INTRODUCTION

The increasing demand of customized and multi-variant orders leads to a higher complexity of planning, while the available time for planning is decreasing [8]. Planning loses the project character and transforms into a continuous planning process. In 1997 Westkämper et al. forecasted an increasing planning frequency and a simultaneous decreasing planning time which is already reality today [3]. Flexibility and changeability of manufacturing structures are key enablers for meeting the challenges coming from the global market [10]. To deduct necessary measures for adaption of technology and capacity structures in a timely manner, permanently ongoing planning as well as early or long-term planning ahead is required.

Faced with these changing circumstances, the potential of the classic methods of factory and production planning have been largely exhausted [1],[3],[7].

The model of plant development presented here is based on the approach that a permanently ongoing planning of future developments must be built upon the individual past developments of technology and capacity structures and the specific skills of a plant. Due to the long life span of the existing structures, there has to be an orientation of the

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planning on the existing resources and specific skills. Besides building up a qualitative comprehension of the actual stand of the plant to derive measures for the future, retrospective developments of the plant performance have to be quantified in hours per year in order to project them into the future, and to calculate the impacts of planned measures on the resources and cost structures. The model of plant developments is a scalable approach, which is an important precondition for stable, efficient and capable work under the influence of different parameters, including kind of problems to be addressed as well as the number and heterogeneity of the involved systems [9]. The model of plant development is divided into the following three main parts, as presented in Fig. 1.

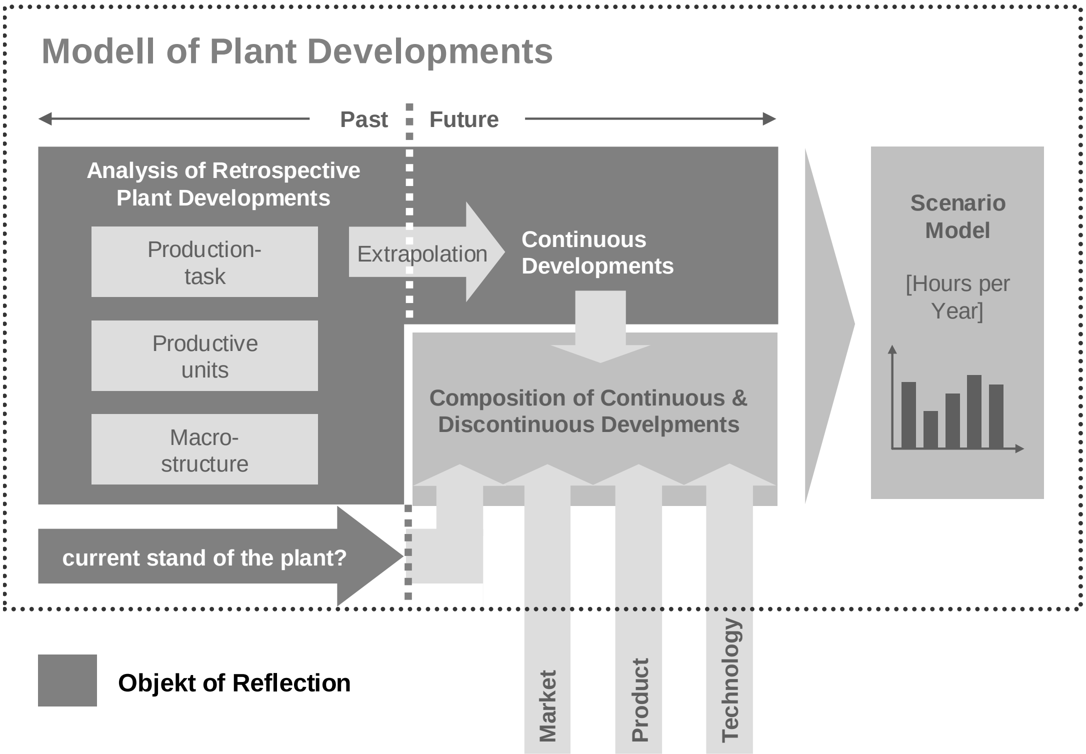


Fig. 1. Model of plant developments

*Analyses and quantification of retrospective plant developments*. These analyses are necessary to ascertain the development status of the plant and to extrapolate continuous developments in the production from the past into the future. Continuous developments are increasing steadily the performance by reducing impacts of disturbance. These impacts, among many others include the technological machining and waiting times or the lack of quality and organization. These kinds of changes can be achieved by methods such as classical industrial engineering, quality management, kaizen or six sigma [4].

*Anticipating of future plant developments*. Planning can be done through the extrapolation of past developments and the design of discontinuous developments. Discontinuous developments refer to discrete events, which influence production massively

[2]. These kinds of discontinuities are caused by disruptive technologies which cut into the continuous path of development and improvement and cover completely new dimensions of performance [5]. Discontinuous changes in a production lead to an increasing need for planning, implementation, investments and larger willingness to take risks [2].

*Design of various future scenarios*. These are constructed in dependence on market forecasts, product launches and technology developments, as well as the quantification of corresponding performance developments.

The purpose of the work presented here is to show the steps to quantify retrospective plant developments as well as their extrapolation from the past into the future, as shown in Fig. 2. The planning of discontinuous developments in the future as well as the design of scenarios is not part of this paper. There will be a short introduction to the objects of plant developments and the way they are continuing to develop. After development is described, the steps to quantifiably to describe these developments will be presented. In the conclusion the resulting future steps are outlined.

## 2. OBJECTIVES OF PLANT DEVELOPMENT

The objects of the analysis and the shaping of the past and future plant developments are in a long term field of vision for the following areas [12].

1. Changes in the production task.
2. Changes of the production units.
3. Structural change in the relations of the production units (macrostructure).

Zaepfle also states a fourth point concerning the microstructure for controlling of labors and orders in a limited scope of actions [12]. The target of the model of plant developments is to design these limited scopes of actions. Therefore, the microstructure is not part of the objectives of the model.

| Plant Developments | | Continuous developments | | Discontinuous developments |
|---|---|---|---|---|
| | | **Number** (quantity) | **Technique** (way) | **Technology** (kind) |
| Objectives | **Development of production tasks** | Number of production tasks of the same kind | Technical product modification | Completely new products (technologies) |
| | **Development of productive units** | Number of productive units of the same kind | Technical and personnel learning effects | Completely new production technologies |
| | **Development of macrostrucure** | Number of material and information flows of the same kind | Technique of material and information flows | Completely new material and information flows technologies |

Fig. 2. Objectives of plant developments

The relevant objects of plant developments shown in Fig. 2, are subject to continuous and discontinuous changes. Changes of number and technique are continuous; technological changes are discontinuous. In the long term forecast of the production development, there must be a quantification of both continuous and discontinuous developments of production.

The change in the production task is divided into technical product modification (technique), quantity (number) and new product technologies (kind). Changes in regard to productive units are technical and personnel learning (technique), the number of production units (number), and completely new production technologies (kind). The macrostructure is changing in form of quantity (number), technique and structures (technique) of material- and information flows (technique, number), and new material- and information flow technologies (kind).

In contrast to the development of the objectives production tasks and productive units, the macrostructure is focused on the design of future plant developments. Retrospective developments are ascertained by the development of the plant-specific key data, such as lead time, lean index, stock range, number of information flows, or EPEI (every part every interval) which describes the processes in between the production units. The developments of the key data enable conclusion of the impacts of past measures.

The design of the macrostructure is an essential part of planning future developments. An integrated planning-ahead of production technologies in combination with the macrostructure enables a holistic consideration of technology impacts through the whole value chain, and in accordance with specific investment behavior. Therefore, the macrostructure is not considered in this paper.

## 3. RETROSPECTIVE PLANT DEVELOPMENTS

In the following sections the relevant steps to analyze the retrospective developments of the objectives production tasks and productive units, as shown in Fig. 2 will be described.

### 3.1. RETROSPECTIVE DEVELOPMENT OF THE PRODUCTION TASK

The retrospective development of the production tasks in the form of numbers and technologies is captured by changes of the past product ranges. The analyses of the incremental development of the product modifications will be described in point 3.3.

In order to track the past developments of the production tasks, a representative product range has to be built. The representative product range must be able to represent the value adding effort, in dependence on the product variation as close to reality as possible. As shown in Fig. 3, the structure of the representative product range is equivalent to the structure of the cost center and the system levels of the production scales of the plant. Production tasks and productive units can be assigned to each other and allocated appropriately according to the input involved.

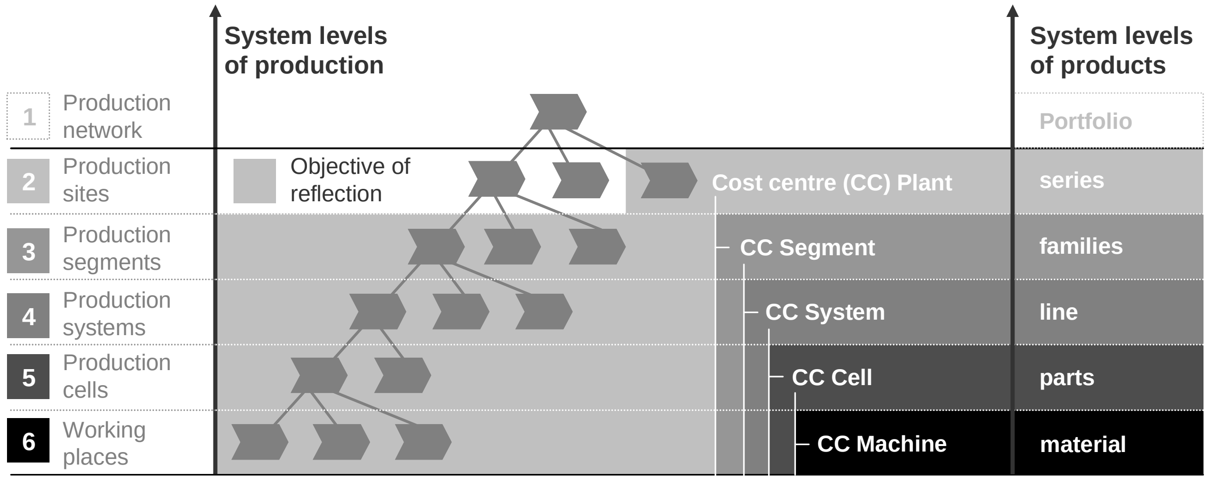


Fig. 3. Model of production tasks [6, 9]

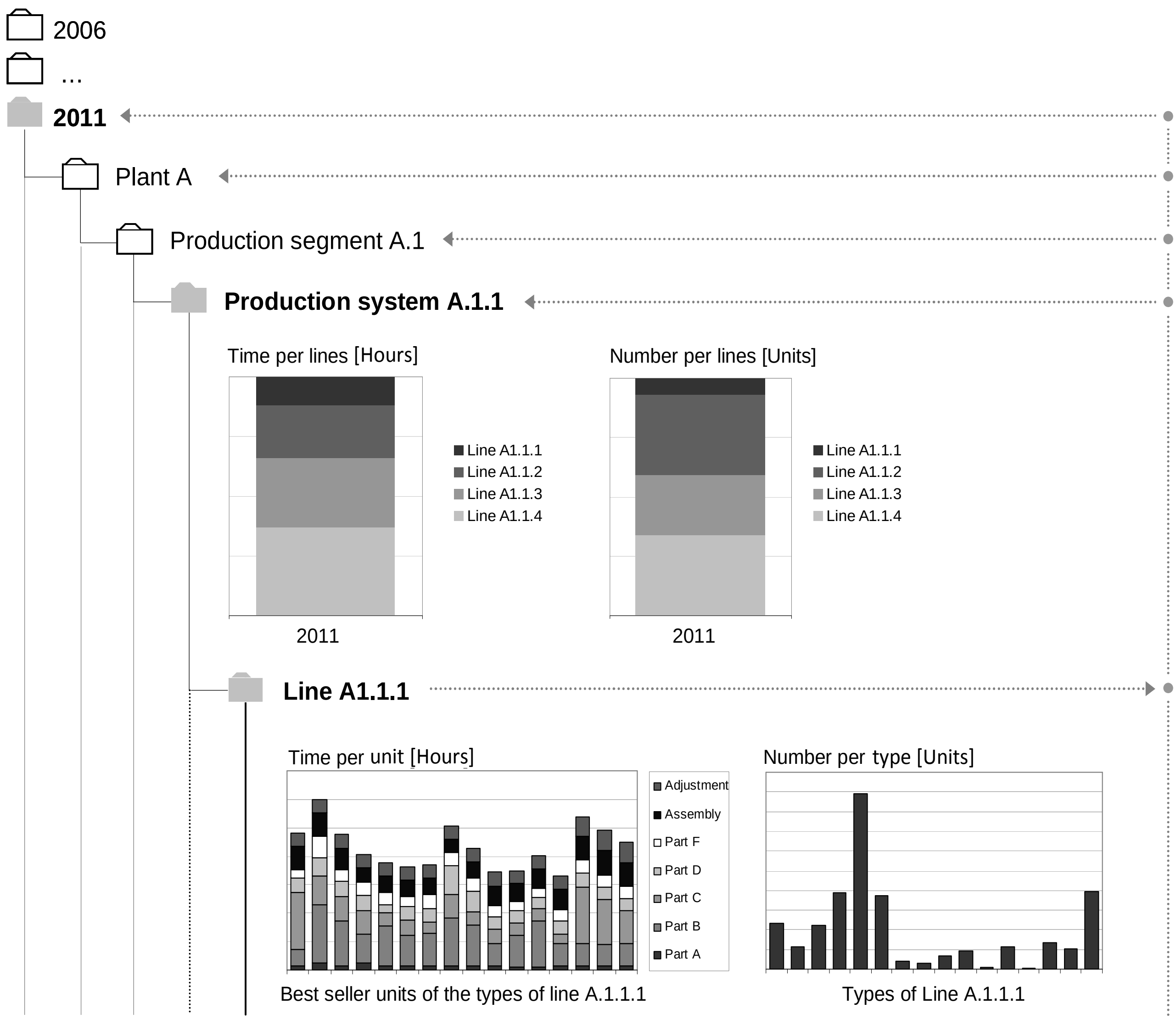


Fig. 4. Scalable model of the production task using the example of a machine manufacturer

The cluster of the lowest system level includes the parts of the best-sellers. The best-sellers are ascertained by an ABC analysis. They are representative of all the units of the cluster, as well as their quantity. On the basis of best seller target times, and the corresponding quantity, scalable efforts of a certain planning period, for a certain area, in a certain system level that has been achieved can be ascertained. This is illustrated in Fig. 4, which uses the example of a machine manufacturer. For a strategic planning of up to ten years in the future, the data of the representative range of products must be captured retrospectively for at least five years.

The further the given period is extended into the past, the more exact learning effects can be calculated and extrapolated into the future.

### 3.2. RETROSPECTIVE DEVELOPMENT OF PRODUCTIVE UNITS

Productive units are grouped according to planning-relevant manufacturing resources plus direct and indirect production-related employees. The planning-relevant machines have to be classified into categories such as, manufacturing technology, special machines, or standard machines to reduce the diversity of manufacturing resources. These categories must be assigned according to the expected age, which is based on the experiences of maintenance, manufacturing coordination or work preparation. As shown in the following Fig. 5, the development of technical capacity can be described by the procurement date and the expected age. As previously stated, the arrangements follow the structure of the cost center.

The machinery application calendar enables a transparent and early time identification of needs for actions. The development of the technical capacity extends from the past beyond the present and decreases in the future, because of the increasing age of the machinery. Future developments of capacities are dependent on past investment behaviour.

The data of the machinery application calendar enables the calculation of the development of the maximal and normal capacity. The theoretical, maximal available capacity per planning period of one year enables a comparable development and is calculated as follows:

$$C_{max} = ds_{max} \cdot hs_{max} \cdot N$$

$C_{max}$ … theoretical, maximal available capacity
$ds_{max}$… theoretical, maximal available days per year (365)
$ds_{max}$… theoretical, maximal available hours per day (24)
N… number of parallel stations

To calculate the normal capacity close to reality, reductions and increases have to be considered:

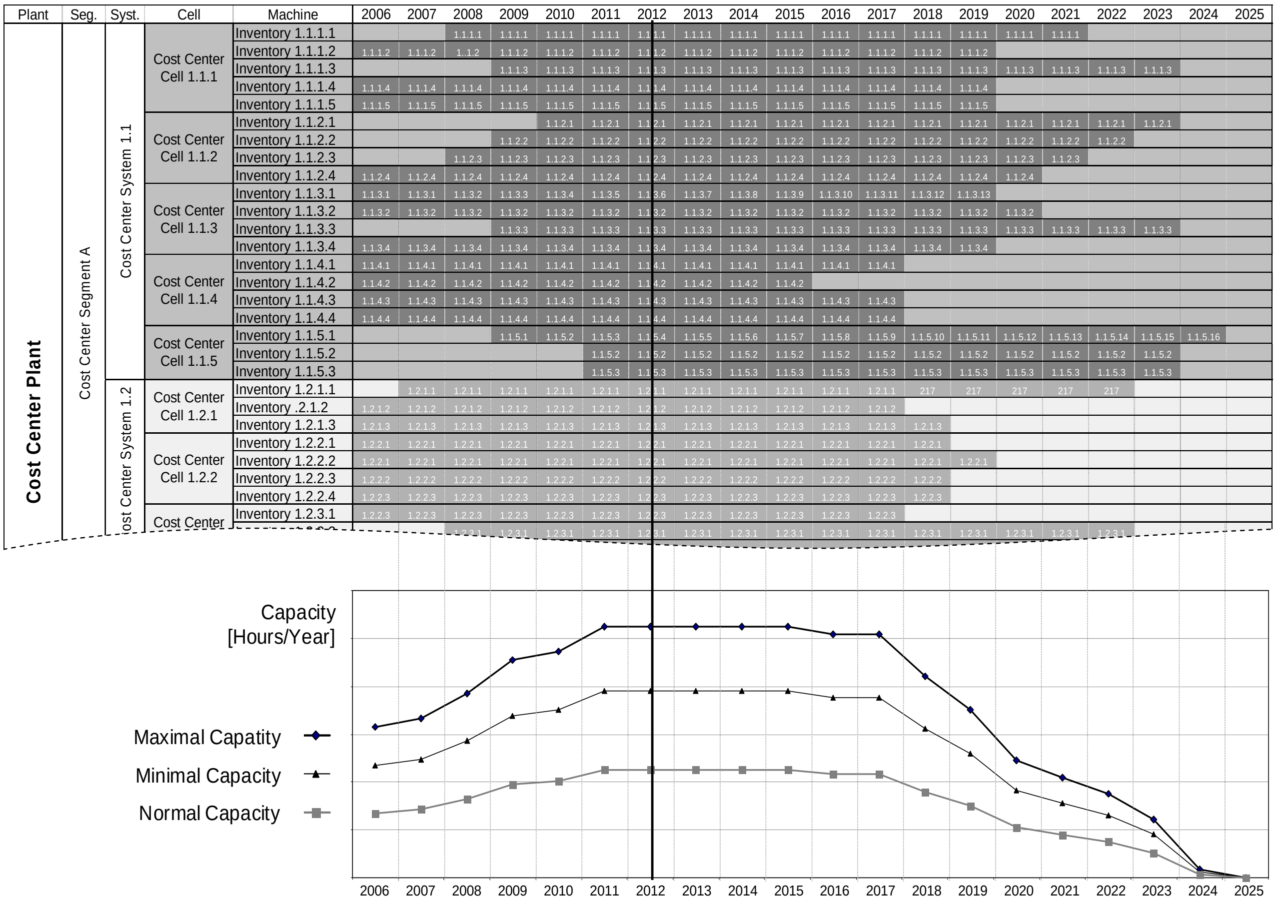


Fig. 5. Machinery application calendar using the example of a machine manufacturer

$$C_{norm} = ds_{norm} \cdot S \cdot hs_{norm} \cdot N$$

$ds_{norm}$ … workdays per year
S… number of shifts per workday
$hs_{norm}$ … hours per shift (including reductions as breaks and increases as overtime)
N… number of parallel stations

### 3.3. LEARNING EFFECTS OF RPODUCIVE UNITS AN PRODUCTION TASKS

On the basis of the learning curve theory, the continuous reduction of the net process time can be quantified. The development of the net process time, as shown in Fig. 6, is caused by personnel learning effects and incremental product and production modifications. The foundation for the calculation of the learning curves are the retrospective target times of the representative product range. According to the learning curve theory, the net process time of a product is reduced by a certain percentage by doubling the cumulated number of produced units [11]:

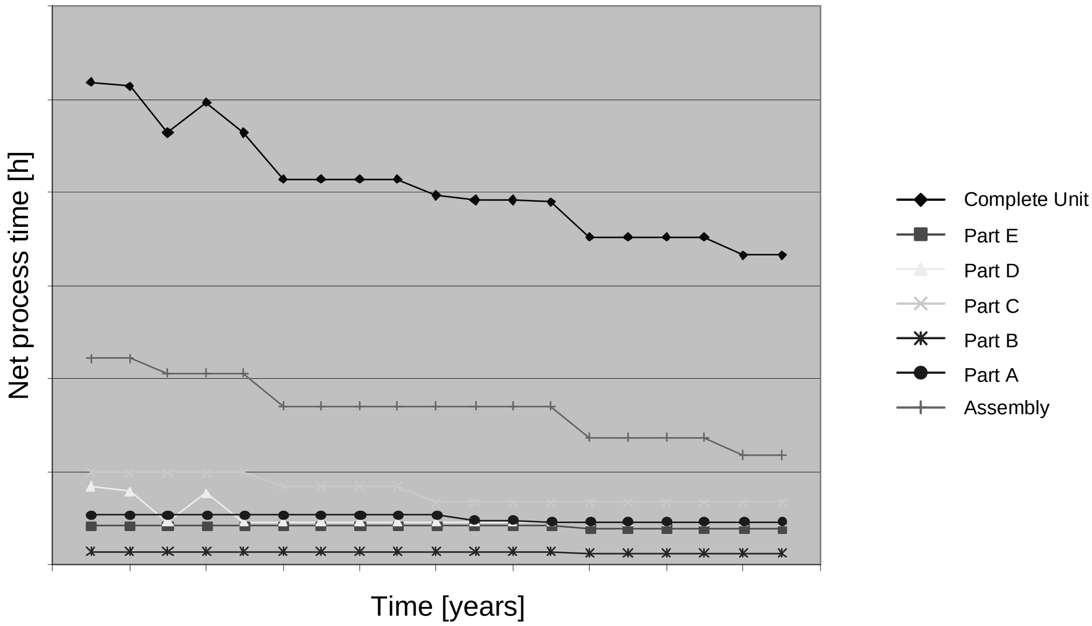


Fig. 6. Development of the net process time of a unit using the example of a machine manufacturer

$$y = a \cdot x^{-b}$$

y… process time dependent on the cumulated quantity
x… cumulated quantity
a… process time by x = 1
b… degression factor

For the calculation of the learning curve, discontinuous developments of the past, which are caused by the introduction of new technologies, must be identified and taken into account. Compared to continuous developments in the end of a technology lifecycle, the introduction of new technologies enables a higher level of developments that are achievable in a shorter period of time, as shown in Fig. 7.

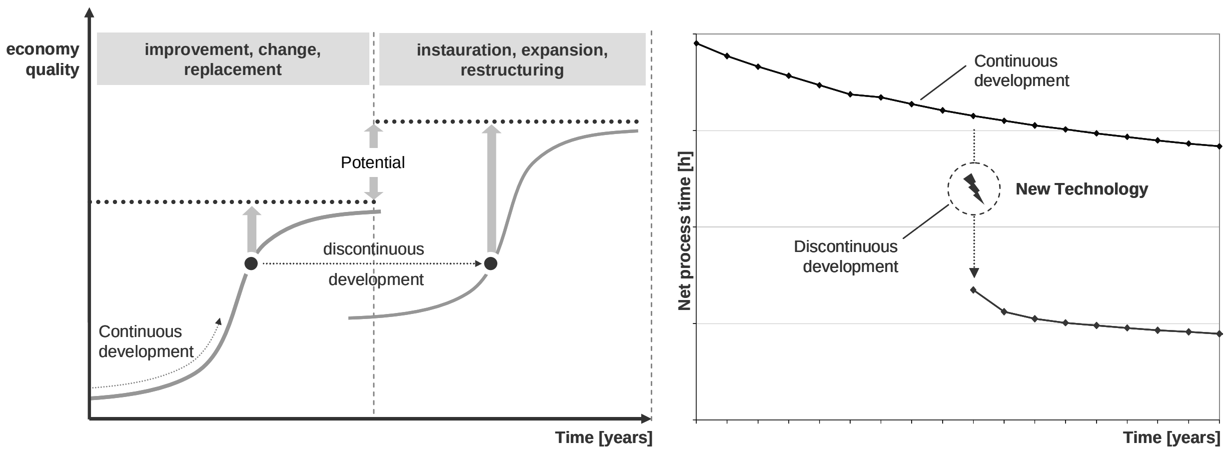


Fig. 7. Discontinuous developments using the example of a machine manufacturer

On the basis of the planned process times of entire units, the learning curves of the best-sellers of the representative product range have to be calculated. By building the weighted average of the degression factors, the learning curves of product families and series can be calculated. Thus, the continuous improvements are scalable as well.

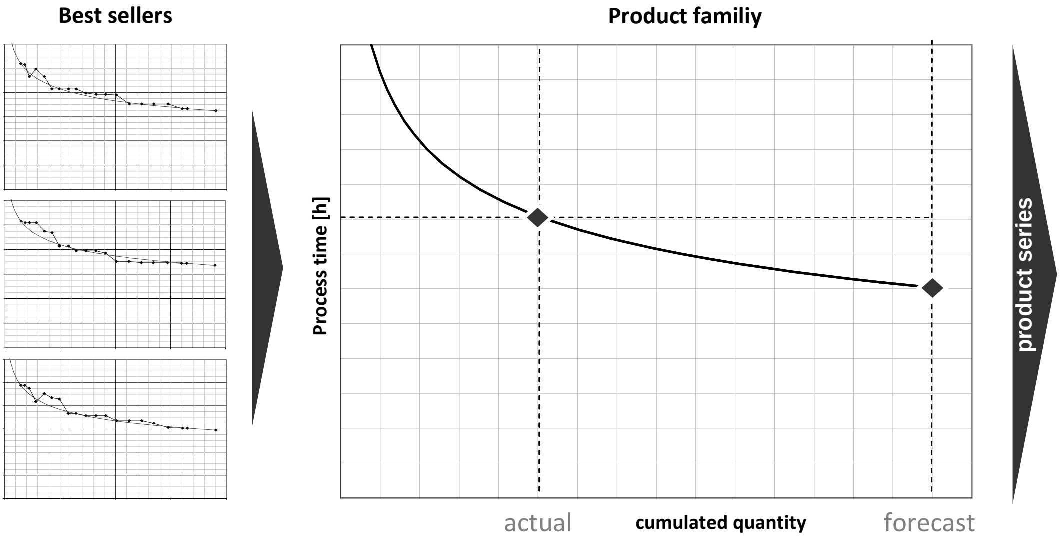


Fig. 8. Scalable learning curves using the example of a machine manufacturer

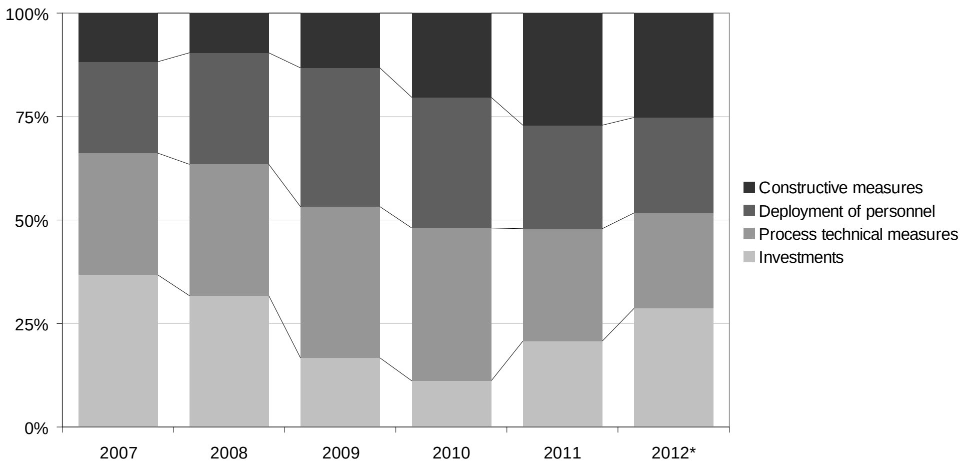


Fig. 9. Development of measures using the example of a machine manufacturer

For the specific controlling of resources for continuous improvements and identification of untapped potentials, it is necessary to ascertain retrospective measures reducing the net process time. Due to target agreements of departments, in general, rationalization measurements are controlled for specific departments. To achieve transparency, these extensive measures have to be assigned to corporate categories. The categories correspond to the objectives of plant developments, technique of production tasks and productive units. They are classified in *constructive measures*, for a production optimized product design, *deployment of personnel* such as line balancing, workplace organization or time studies, and *process technical measures* such as equipment and devices simulations, as well as *investments* in machines.

The described way of structuring the measures illustrates factory cycles such as investment waves, and allows the identification of adjusting levers. It is a simple way to project continuous developments through the different work sectors of a plant.

## 4. SUMMARY OF THE EFFECTS

The retrospective developments in the form of the representative product range (point 3.1.), the machinery application calendar (point 3.2.), and the ascertained learning curves (point 3.3.) have been described. The combination of these developments makes it possible to continue to follow the development of available capacity and requirement structures from the past into the future. The annual production performance consists of cumulative plan times corresponding to the respective years of the past and the representative product range planned for the future. Retrospective plan times are derived from the target times of the respective year, while the future target times are calculated by the ascertained learning curves. The machinery application calendar provides the development of the available maximal and normal capacity. The combination of these effects is shown in Fig. 10:

The described steps to analyze retrospective plant developments enable the scalability of the production performance as shown in Fig. 11. The scalability makes possible the analyses and planning of changes for the specific areas and corresponding impacts within a plant. Beyond the system levels of a plant, the scalability is extendable up to the level of the whole production network.

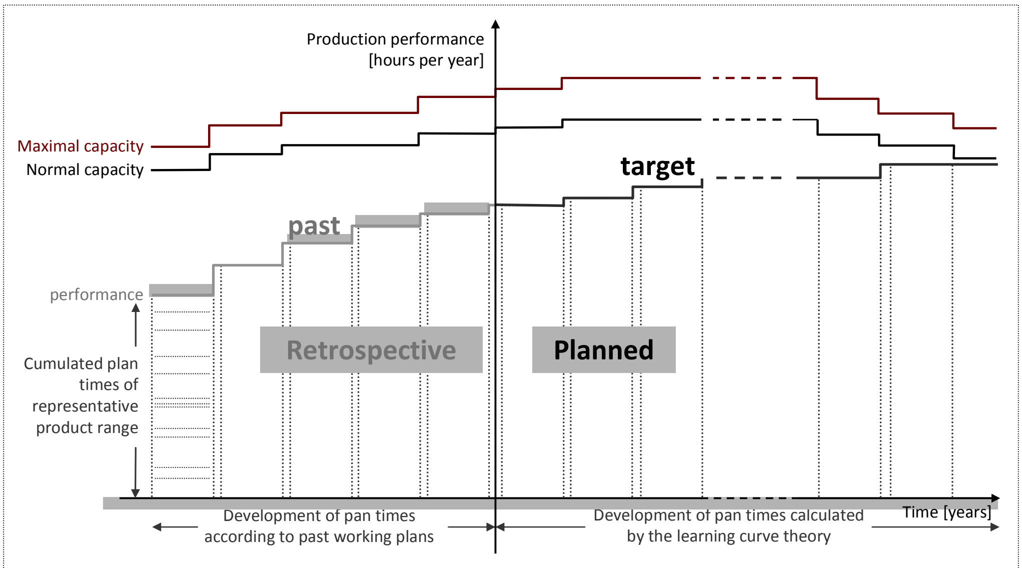


Fig. 10. Development of the capacity and requirements

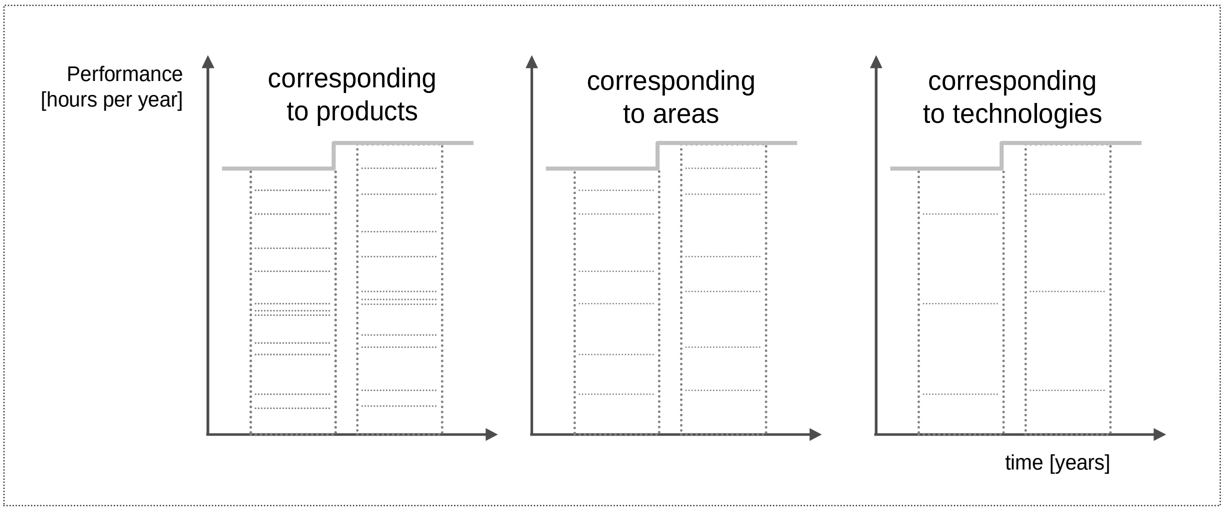


Fig. 11. Scalability of the performance

The scalability of the production performance makes possible the screening of the production structure. The effort in sectors of the components, products, producing areas, system levels and technologies can be quantified. The knowledge gained is an essential foundation for developing future capability und technology structures.

## 5. SUMMARY AND FUTURE WORK

For a permanently ongoing adaption across the system levels of a factory, a scalable analysis of retrospective developments of capacities and technology structures is the essential foundation for long-term planning of future developments. Therefore, the specific needs and circumstances of a plant must be considered. Due to the increasing complexity and frequency of planning tasks, and a simultaneous decrease in available planning time, steps presented to analyze past developments are necessary to simplify the essential information for a continuous planning ahead. The analysis make possible an understanding of the existing processes, structures of resources, and the experiences which led to their development as well as their extrapolation, which is the basis for the design of future developments.

Future work will be done in studies of the variations of impacting driving forces. Based on forecasts and possible scenarios of changing markets, products and technologies, discontinuous developments will be designed for a structured optimization and adaption. In a continuously ongoing process, plant developments beginning in the past have to be adapted to the knowledge of present operations, forecasts and possible scenarios. This model of plant developments allows for changeability, which is necessary for competitiveness in the turbulent environment of manufacturing enterprises.

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