

Chapter 5

Summary and Outlook

The requirements for production systems are constantly changing as a result of changing competitive conditions and the associated performance targets regarding time, quality, cost and innovation. The ever-increasing planning uncertainties as to type (product/variant mix) and extent (amount) of products to be manufactured pose a difficult task for production companies and lead to a growing demand for flexibility. In this context, flexibility assessment methods of production systems play a significant role in allowing meaningful conclusions to be made regarding existing technical and organizational scope of action, which allows the creation of an optimized level of flexibility. Although manufacturing companies have offered a number of opportunities through this and multiple research activities in this area were, and continue to be, made, there is still no visible acceptance of such assessment tools in an industrial environment. The main reasons for this lie in the difficulty to conform to the multidimensional nature of the flexibility and to simultaneously allow consistent, focused appraisals for the different areas of a production system. But it is precisely the lack of established methods for flexibility assessment in corporate practice, despite the digital factory planning tools used, that leads to the building of sub-optimal production infrastructure over and over again. The results are often considerable flexibility deficits that can endanger the cost-effective manufacture of the products during “turbulent” times, which are amplified by the current financial crisis.

5.1 Summary

This book presents a significant contribution to solving the above-mentioned problem for flexibility assessment of production systems. The core elements are the three evaluation methods for the assessment of Volume-, Mix- and Expansion flexibility, the object-oriented production system model as well as the ecoFLEX implementation. The starting point for their development is the **guiding research question** formulated in Sect. 1.3, which narrow the field of observation and lead to the cognition process in this book. The important results of this process have been summarized below.

Several meanings, influencing factors and -objects for production systems can be extracted from the literature. An *analysis* of the evaluation method focused on the objective of the book brought the following findings to light:

- Production systems are goal-related summaries of the resources: equipment, supplies, personnel and material and characterize themselves through organizational, technical and economic characteristics.
- Their functions include not only the technical production process but also the planning, controlling and maintenance of the production process.
- Depending on the demand for explanation of the production system, their detailing can be done on different observation levels, each representing a specific set of system objects which have basic, common and level-specific characteristics. For a useful distinction between these levels, the hierarchical sub-divisions called factory, segment, line, and workplace are used.
- The various objects in a production system are controlled by multiple links, whose spatial-temporal allocation and hierarchical classification describe the system structure. The structure involves certain degrees of freedom which vary in their distinction for individual system objects, depending on external and internal changes.
- All processes running in a production system are either directly or indirectly related to the actual services rendered, whose results are material goods, called the product.

Based on these characteristics of production systems, the term “Production system” can be defined as follows:

A production system is an allocation, aligned with physical value-creation, of the resources equipment, personnel and material that are grouped together at various system levels for specific objects. These so-called system objects have the appropriate degrees of freedom, from which emerges a specific system dynamic for the response to external and internal changes.

The analysis for detecting the importance of flexibility in production systems showed that many opinions exist among experts as a result of the numerous inconsistent terminologies. As a consequence, there is a lack of common understanding of the scope and limitations of flexibility in the related concepts such as versatility, agility and adaptability. In principle however, the existing freedom of action or freedom of decision in production systems, which act upon the change, are denoted as flexibility. The following three dimensions are characteristic of their description:

- Variety
- Cost
- Time

The fundamental understanding of manufacturing flexibility developed by the author in the course of his research can be summarized in the following definition:

The flexibility of a production system describes its technical and organizational freedom of action to react to environmental uncertainties arising from economically justifiable

adjustments or changes to the system structure and resources; so that the estimated production targets are met. The concrete Flexibility measure of a system can be determined by the dimensions variety, cost and time.

In addition to this general approach, the application context in which the production systems have to respond flexibly must also be included. The corresponding literature distinguishes between different types of flexibility, which vary however, as a consequence of the diverse classification possibilities as well as differing terminologies. Taking into account the identified, current developments and challenges in industrial practice (see Sect. 1.2) the range of flexibility types is limited for this book to *Volume- Mix- and Expansion flexibility*. Their impact and definitions have been clarified in Sect. 2.2.3. Based on the overall findings for the flexibility of production systems, the following criteria for a practical flexibility recording are derived:

- Evaluation ability at the observation levels factory, segment, line, and workplace
- Consideration of the dimensions time, cost and variety
- Cross-industry applicability, as well as comparable and objectively determinable evaluation results
- Evaluation of flexibility in terms of responsiveness to volume fluctuations, to changes in the Product-/Variant mix and on expanding capacity

Extensive literature searches show that none of the existing flexibility assessment methods can meet these demands to a satisfactory degree. Hence the corresponding need for research. This is subject to certain **requirements** (see Sect. 2.5), which are essential for the development of a flexibility evaluation methodology which conforms to the target requirements. Due to the similar importance of these requirements, they can be categorized into *basic usability, flexibility metrics, production system model and software implementation*.

The requirement definition made in this book sets out the principal direction towards the **development of evaluation methods**. The basic idea touches on quantifiable dimensions used to make Volume-, Mix- and Expansion flexibility, including their subsystems, measurable. The individual flexibility types are assigned the following *quantifiable dimensions*:

- **Volume flexibility:** Break-even point, cost-efficient maximum capacity
- **Mix flexibility:** system optimal profit, product-specific profit deviation
- **Expansion flexibility:** alternative-specific break-even point, target capacity

All calculations in this context to determine flexibility indices will be combined under the concepts of flexibility evaluation method or flexibility metrics. Since the different dimensions to be quantified often exhibit varying temporal as well as cost- and product related restrictions, their boundary values (minima or maxima) are to be determined. These can be traced back to optimal, restriction conforming production plans. Such a plan describes the best possible utilisation of a system's resources regarding their type and complexity for specified period and number of products. The calculation of these production plans lead to so-called optimization problems that in principle can be considered to be linear. In order to solve these

problems, the simplex algorithm is used. The prerequisite for this is the setting up of a mathematical model, which provides a distinction between three types of calculation parameters:

- Non cost-related calculation parameters (see Table 3.2)
- Cost-calculation parameters (see Table 3.3)
- User-dependent calculated parameters (see Table 3.4)

Because these parameters are counted as variable elements that are assigned different values depending on the operational systems in production, it needs to be clearly defined which criteria are to be used in the approach. This especially concerns the cost-related calculation parameters whose value assignments are closely related to the operational cost and performance and which have a direct impact on the quality of flexibility calculation results. It is therefore in the interests of a uniform, complete cost accounting (one which is based on the observation levels of production systems) to orientate towards a *cost calculation reference* approach that is modelled on part costing procedures with differentiated cost treatment (see Table 3.18).

In order for flexibilities for selected objects in a production system to be quickly calculated and to also remain easy to understand for the user, both the calculation parameters and the flexibility evaluation model are linked to the yet to be tested, real-world analysis object/production system via a so-called production system model. This model is seen to be an abstract representation of evaluation-relevant system objects in a neutral notation, so that their flexibility-related dependencies are identified and flexibility deficits easily assigned to the responsible positions. It follows the paradigm of object orientation and thereby allows easy, dynamic model configurations of the structure of the production system to be evaluated.

The practicality of the evaluation methodology developed in this book can be confirmed through a comprehensive *verification* in industrial application. This is done based on the production system of a series producer of infotainment systems, where the application experiences made with the involvement of expert opinions with the requirements of Sect. 2.5 were evaluated. The basis of verification is a specially developed software tool called ecoFLEX, which implements the mechanisms of the evaluation methodology. Through this it shows the requirement-conforming applicability through which allows the quantification of flexibility of the production systems and the assignment of individual system objects. The analysis possibilities applied in practice, such as the quick and easy identification of flexibility-related vulnerabilities and comparability of solution alternatives, highlight the user benefits of an ecoFLEX supported flexibility investigation and demonstrate the successful implementation of the evaluation methodology.

This can be further demonstrated by practical experience with ecoFLEX not included within this book, gained in other large companies outside of the infotainment industry and also in various medium sized production companies. There too, both unexpected and remarkable deficits in the production and change management came to light. The potential from the multiple applications for ecoFLEX are clarified by the following examples [Roga-10]:

- **Shortening of the decision making in investment projects:** the selection decision for the purchase of a new automated workplace at the production site of a medium sized producer of stamping and assembly technology with about 140 employees, called for an average cumulative input of six person-months (PM), which incur an average cost of approximately €54,000. Through the ecoFLEX solution, due to a significantly improved transparency of the causal dependencies in the production, this expense could be reduced by up to 70%, which corresponds to a cost saving of €37,800 for each procured automated workplace. Due to regular product changes at the site, an average of four new job positions a year are currently required. This gives the ecoFLEX solution a total saving of €75,600 per year.
- **Reduction of follow-up costs through significantly improved selection decisions:** based on uniform, objective evaluation fundamentals, a consistent and transparent flexibility analysis was attained that easily identified flexibility deficiencies in production systems easily and correctly assigned and eliminated them. As a result, the follow-up costs can be reduced when purchasing new equipment, since the increasing the predictability is improved. In this way it was possible for the aforementioned medium sized company to reduce the likelihood of avoidable follow-up costs from 33.3% to 10% by reaching a sub-optimal investment decision. This results in average savings of €15,000 with each newly acquired workplace, giving a total saving of €30,000 a year.
- **Risk minimization for factory planning:** Regardless of the digital factory planning tools used by different user companies, weaknesses were found in the design and dimensioning of the production equipment, based primarily on their economic effects. The utilisation of ecoFLEX allowed a significantly improved factory planning that is tested for cost-effectiveness and which provides the right degree of flexibility. This allows the representation of economically viable alternative configurations of different production systems, which minimize its dependence on certain products or product variants, which ensures both an improved medium-term and long-term protection of cost-effective production.
- **Improved planning of personnel and the production program:** In addition to a pure flexibility analysis, additional parameters such as break-even levels or time- and cost-optimal production programs are determinable through the use of ecoFLEX. This also enables the evaluation of, for example, ad-hoc contracts in a current production program, so that they take into account cost and set-up configurations as well as allowing lead and holding times to be processed efficiently. In addition, the most cost efficient staff utilization for the processing of pending production orders can be determined, to which the most profitable work time is allocated. These are functions that are not covered by existing PPS and ERP-Systems. For the user companies, the use of ecoFLEX resulted in valuable cost savings in terms of a short to medium term safeguarding of their economical production.

As a result of such applications of ecoFLEX, it is particularly possible for small and medium enterprises to keep up with their competitors (including those from

low-wage countries), despite the ever-increasing competition with tight cost and time budgets and an increase in complex production relationships. This is due to, on the one hand, improved on-time delivery and the resulting customer retention, which ensures a steady demand and promises future sales. On the other hand, the unique evaluation capabilities of the developed methodology, cause a targeted and dynamic approach to the production resources personnel, material and equipment. This avoids unnecessary additional costs for the inefficient use of resources or ineffective adjustments to the production infrastructure, such as construction and decommissioning of production equipment and creates funding for future investments [Roga-10]. Thus, secure existing jobs and creating more, for example, under the particular conditions of the economic and financial crisis by the acquisition or the establishment of additional production equipment that are integrated into the existing network and thus strengthening the company's personnel. The financial security and gains resulting from this benefit not only employers and employees in the production area, but also the national economy. Through stable or rising profits and wages the consumer economy is also strengthened, which has a positive effect on downstream businesses and industries. The resulting additional income taxes allow a strengthening of social security systems.

5.2 Outlook

As a result of the existing planning uncertainty in terms of capacitive demand fluctuations, changes in the product-/variant mix and capacitive expansion requirements, frequent adjustments and changes to the current production needs are inevitable. For this reason, companies increasingly find themselves confronted with the problem of a suitable recording of economic freedom of their production systems. The experience made in this area with the software ecoFLEX in the practical field of application, is testament to the usefulness of the developed evaluation methodology. As shown in Sect. 4.2, flexibility deficits can be identified using ecoFLEX by the quantification of flexibility margins within production systems and can be subsequently resolved. As a consequence, planning security and response time in recognizing and implementing flexibility-increasing measures are improved. In addition, costs attributed to flexibility weaknesses are avoided. Overall, the methodology supports a short, medium and long term protection of economic production. Linked to this, with the goal of compliant user benefits (see Sect. 1.3), is a crucial precondition. It refers to continuous and consistent data in each user company because the quality of the evaluation results and the associated success always depends on the quality of input data.

Nevertheless, the efficiency of the presented method of evaluation continues to grow. One approach would be the expansion of a special algorithm that recognizes the flexibility deficits in the production system and based on that offers *automatically generated alternative solutions* that allow the optimal configuration of volume, mix and Expansion flexibility. This could only be done based on the known system objects,

Flexibility Measurement in Production Systems
Handling Uncertainties in Industrial Production

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2011, XI, 186 p., Hardcover

ISBN: 978-3-642-18116-0