

Chapter 4

Practical Experience in the New Methodology

With the goal of verification of the evaluation methodology, a software tool called ecoFLEX was developed, which makes use of the mechanisms for the assessment of flexibility of production systems described in the previous chapter. The detailed description of this software tool in terms of its architecture, its implementation and its operating principle will be the first topic discussed in this chapter. Since a software-based realization of the methodology alone is not sufficient to prove its viability in real conditions, the software tool was practically tested subsequent to its development through an industrial case study. The second focal point in this chapter is therefore the detailed explanation of the resulting experience from the analysis of Quantity, Mix and Expansion flexibility. From this the evaluation methodology can be verified a by considering a detailed review of all requirements and the fulfilment of these.

4.1 Implementation of the Evaluation Methodology

A fundamental task in the realization of the ecoFLEX tool was the implementation of a suitable software (in accordance with Sect. 2.5.4), the details of this which follow here. The software was developed based on modern technologies to achieve various technical advantages, such as simple advancement opportunities or higher versatility e.g. in distributed environments. This in turn results in ergonomic benefits for both the user and for the developers of the ecoFLEX software.

4.1.1 *Software Architecture of ecoFLEX*

The development of ecoFLEX focused on providing the necessary functionality required for the automation of the procedure for the flexible evaluation of production systems, as described in Sect. 3.2. With this in mind, a software concept was developed, intended to support three successive base iterations (see Fig. 4.1).

Base Iteration 1:

Construction of a production system model as an abstract representation of the production infrastructure which is under investigation

Base Iteration 2:

Collection and structuring of relevant data for flexibility calculation, based on the chosen evaluation objects/abstraction

Base Iteration 3:

Flexibility calculation through the application of the flexibility metrics to the evaluation objects of the production system model

Fig. 4.1 Base iterations for flexibility evaluation, automated through ecoFLEX

An aspect which until now was not supported by software was the automatic detection of flexibility deficits and a concurrent generation of the proposed solution for their closure. This *Base Iteration 4* (flexibility interpretation/evaluation) is, at the present stage of ecoFLEX development, reserved only for the user. The Fig. 4.2 shows the concept of the modular software architecture of ecoFLEX, which ensures the highest possible degree of user support in the flexibility assessment.

The basic elements of the architecture form the interfaces; the configuration module PSM; the module for data processing; the module for the flexibility assessment; the graphical user interface (GUI) and the database. These terms are explained below:

- **Interfaces:** Since the vast majority of data needed to conduct the flexibility assessment is already available in the different operational planning and control systems, the appropriate interfaces to these systems are necessary. As seen in Fig. 4.2, there are two basic types of interfaces. One type being the interfaces for collecting flexibility relevant data from the operational systems in a manufacturing environment. These can be used to implement planning and controlling related functions of short-and medium-term production and commercial operations. Prime examples are ERP systems, which cover products which possess such functionality. PPC- BDE-, SCM- systems or other systems for controlling and scheduling also partially contribute to the support of the overall functionality and therefore provide necessary flexibility information. The other type is made up of the ecoFLEX interfaces to digital tools usually used for long-term factory planning. These are used to transfer object relevant information on the production infrastructure to ecoFLEX in order to build the PSM. This information is obtained from the digital models for the layout plan and the line-and workplace configurations.
- **Configuration module PSM:** This module directly supports the first of the three base iterations listed in Fig. 4.1, namely the construction of the production system model. Using a configurable set of standards especially provided for this function, the hierarchical structure of the production system can be automatically generated. The structure is derived from the extracted object information from the CAD models built in the digital factory planning system. Modeled

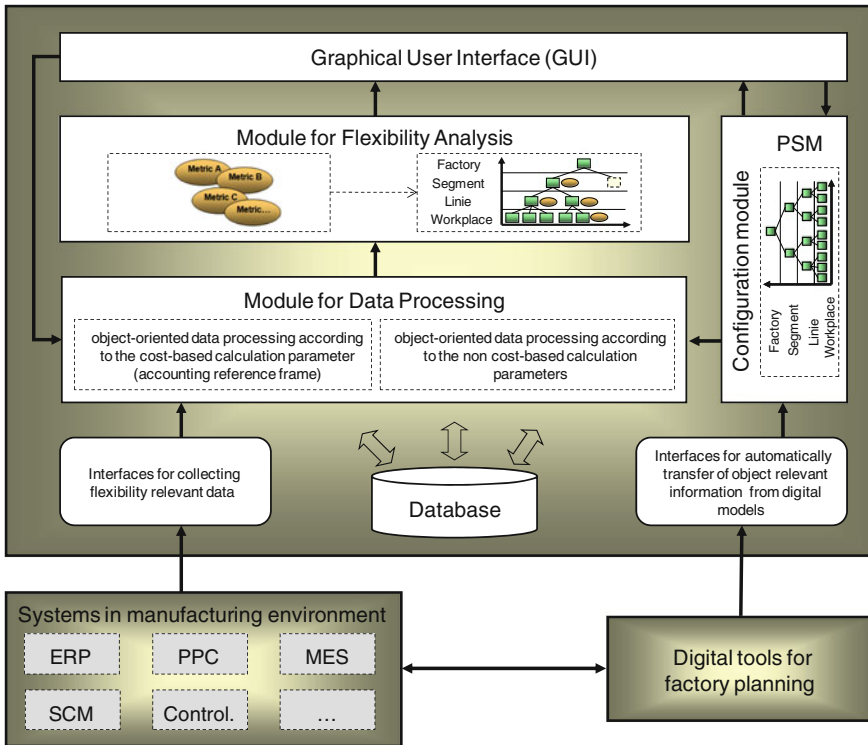


Fig. 4.2 System concept of software architecture of ecoFLEX and their integration into the IT landscape of the user companies

system objects like workplaces, lines and segments as well as their mutual dependencies can be identified due to the semantics contained within the standards. The semantics refer to the CAD Plant Design symbols from each block name, label, layer, line type etc. As a result, the corresponding information based objects can be compiled. Provided that an appropriate demand for manual rework exists and that automated model building is not possible, the PSM configuration module provides the relevant features which are also suited to the building of scenario alternatives.

- **Module for Data Processing:** This module forms the basis for the second of the three base iterations, the collection and structuring of relevant data for the flexibility analysis. A prerequisite for this is the PSM derived from the configuration module, since this can clearly define the system objects and their mutual dependencies. This results in a purposeful, object related data mapping. We distinguish between two types of data structure, which is why each has a separate sub-module available. The first is the object-oriented data processing according to the cost-related calculation parameter as shown in Table 3.3. The extracted cost information under the cost accounting reference frame presented

in Sect. 3.3 is hereby separated into variable and fixed cost components, which in turn are broken down for each object parameter. The second sub-module which defines the non-cost-related calculation parameters (see Table 3.2), deals with the assignment of the object data which fall into this category, taking into account the relationships modeled in the PSM. Fundamentally, the collection and structuring of both categories of flexibility relevant data on the respective sub-modules is automatically, as well as manually possible. This offers the advantage of a thorough data survey even in the absence of some system interfaces and allows user-specific value assignment for alternative scenarios, as well.

- **Module for Flexibility Analysis:** The third base iteration, the application of flexibility metrics to the evaluation objects of the production model, will be performed within this module which is divided into two sub-modules. The first deals with the implementation of the assessment methods described in Sect. 3.2 to determine the Volume-, Mix- and Expansion flexibility of production systems. The actual application of these methods, however, comes into play in the second sub-module in which the calculation parameters are transferred from the module to the data processing. The resulting calculation delivers the individual flexibility coefficients for the system objects identified by the PSM.
- **Graphical User Interface (GUI):** The graphical user interface, GUI for short, has two fundamental tasks. One being the visualization of the production system model created in the PSM configuration module, as well as the object based calculation results of the flexibility analysis. Secondly, the GUI gives the user the possibility to exercise a simple influence on the structure of the PSM to be evaluated and its accompanying data allocation, because it allows the interactive access to the PSM configuration module and the module for data preparation (see the preceding description of the two modules).
- **Database:** The database provides the foundation for the persistent, model-related filing of all the information on a production system needed for the flexibility analysis. All of the collected data and structures can be permanently stored in the database, enabling, for example, comparisons between different production systems or different developmental statuses of a system. Data from the internal information management of ecoFLEX are also stored here, such as semantic information to CAD Factory Design symbols which are used in the PSM configuration module standards.

4.1.2 Implementation of ecoFLEX

The basis for the implementation of the evaluation methodology was the open development platform *Eclipse*. The result represents the flexibility evaluation tool ecoFLEX, the development of which involved the following software development technologies:

- The implementations were performed in version 3.4.0 of the *Eclipse Development Environment*, using the Java programming language based on the *Java Development Toolkit* (JDK) version 1.6_10.
- The *Rich Client Platform* (RCP) of Eclipse (Eclipse RCP) version 3.4.0 was used for the construction of the Graphical User Interface.
- The relational database *MySQL* version 5.1 was utilised for persistent data storage and data management. This allows the storage of ecoFLEX objects and their associations using the Java-compatible Open-Source-Persistence-Framework *Hibernate* version 3.3.1.

Figure 4.3 shows a screenshot of the window of the Eclipse development environment. The Project Navigator can be seen on its left side (1), which contains the project folder ecoFLEX. This includes, inspired by the modular structure of the developed software architecture (see Fig. 4.2), various subfolders in which the project files generated for the prototype compilation are stored. They in turn describe the specific ecoFLEX functionality in the form of source code stored there, as shown in the right side (2) of the Eclipse window. Shown there is the Eclipse

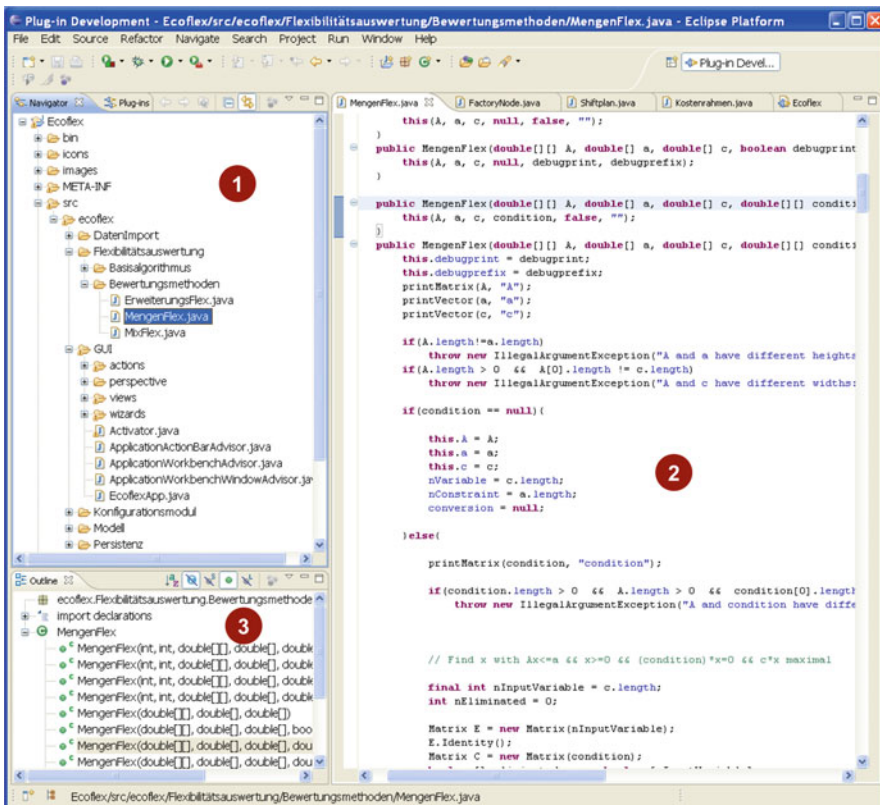


Fig. 4.3 Project structure of ecoFLEX in the Eclipse development environment

workspace with an excerpt from the source code of the file *MengenFlex.java* from the subfolder *Evaluation method*. The structure of the source code in the project files can be extracted from the *Outlines* in the Project Navigator in the Eclipse window (3).

As mentioned above, the Java programming language forms the basis of the implementations which were undertaken. A decisive reason for this is, for one, its object orientation which accommodates various mechanisms in the evaluation methodology (see Sect. 3.2). For another, the architecture neutrality is preserved, which is beneficial for the ease of integration of ecoFLEX into its intended IT infrastructure. Multiple project types can be distinguished for the Eclipse Development Environment which was implemented in this context and in the interest of a progressive, supportive implementation approach.

They are characterized by different development goals (such as Database applications, Internet applications, Eclipse Plug-ins or Rich Client applications) and therefore by different source file types, as well as their applicable tools and Plug-ins. For the development of ecoFLEX, the project type *Plug-in Project* (RCP) was selected, for which the RCP- Framework of Eclipse was used to ensure a modular, simple and clear configuration of the graphical interface. Another framework that ecoFLEX uses is *Hibernate*. It creates an object-relational bridge to the database, and can thereby store the status of an ecoFLEX object in the MySQL database and can also recreate it.

4.1.3 *Functionality of ecoFLEX*

In order for the ecoFLEX software to be employed in its basic configuration, a suitable computer system is required. The minimal requirements of such a system are the existence of 32-bit computer architecture with a processor capacity of 1 GB and a working memory capacity of 512 MB, as well as having Windows, Linux or Solaris as operating systems to support the required Java console. After installation of the ecoFLEX software, it may be started via a specially provided program icon in the program folder. The subsequent approach to the targeted flexibility analysis is described in the following sub-chapter.

4.1.3.1 *Structure of the Program Window*

As ecoFLEX starts, a special programme window will open which is divided from a functionality perspective, into an analysis area and parameter area (horizontal view). Regarding the flexibility analysis, these two areas are divided into an original- and an alternative representation (vertical view), as can be seen in Fig. 4.4.

The *analysis area* itself consists of three so-called functional fields. On the left in the original view associated field (1), the model of the considered production system is statically presented in its initial/original configuration with the associated

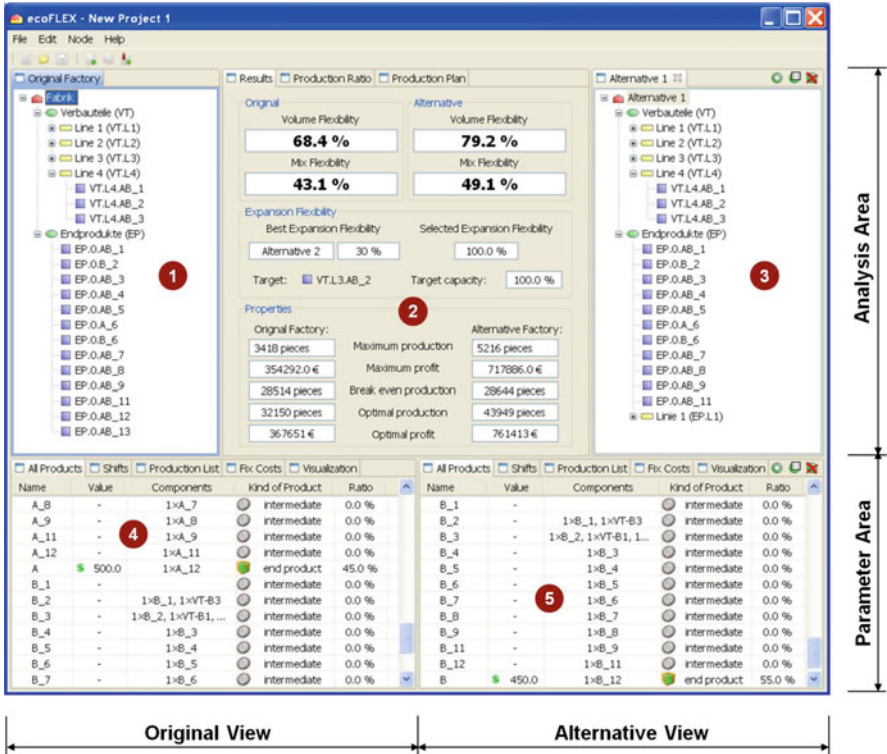


Fig. 4.4 Graphical user interface of ecoFLEX

system objects. On the other hand, configurations which differ from the original model can be compiled in the alternative view associated field (3). Here, in contrast to the field (1), a unique toolbar with the appropriate functionality for model changes is integrated. The middle field (2), which includes both an original and an alternative view, consists of three tabs. The first, called *Results*, allows the display of object-oriented indices to the original as well as to the alternative models. This does not only concern indices for Volume-, Mix- and Expansion flexibility of the different system objects, but also production management parameters such as break-even points or maximum capacities. The latter are regarded as so-called auxiliary parameters, which help to better assess the individual object-flexibilities. The second tab, *Production Ratio*, displays the product mix which underlies the flexibility calculations and the product mix for optimal production. The third tab, *Production Plan*, lists the various system object related production plans with their specific workloads.

All the required data for the calculation of the indices are encompassed in the *parameter area* of the ecoFLEX programme window. It is also possible to create a visualization of the CAD (simulation) models, built in the digital factory planning, of the system objects collected in PSM. This generally leads to, as in

the analysis area, a dissociation between the original configuration and alternative configurations of the production system, whereby the parameter area is separated into two identical *functional fields*. They contain, in terms of a structured data collection, corresponding tabs. The field related to the original view (4) provides all the necessary computation- and visualization information for the original model, which cannot be changed. The same is also true for the right field (5), the alternative view, but with the distinction that the data listed there are assigned to the different variations of the original model and can also be processed by these variations.

In order to access the various features offered in ecoFLEX, the upper chapter of the programme window also has a menu and a toolbar and provides further logically arranged, smaller toolbars in the function field of the alternative view (see Fig. 4.4).

4.1.3.2 Procedure of Flexibility Analysis

With ecoFLEX, flexibility investigations executed on production systems are generally referred to as *Analysis Projects* and are also stored as such. Intermediate backups of each processed state can be done independently of user activity, whether the user is concerned particularly with the creation of the PSM, the data allocation or the analysis. To create an Analysis Project the three basic steps shown in Fig. 4.1 are followed, starting with the structuring of the PSM (*1st base iteration*) through the “Configuration module PSM” of the software tool ecoFLEX (see Fig. 4.2). The user has two options available to him:

- Firstly, the user may access the digital factory planning system through the interfaces provided by ecoFLEX to automatically transfer the stored CAD models of the production system into the PSM-specific structure. In addition, the user has to call the *Import* function in the *File* menu, through which the ecoFLEX supported files can be accessed using the Wizard. The generated PSM is then represented in the alternative view in the right field (3) of the analysis area (see Fig. 4.4) and can then be manually re-processed.
- The second option is to build the PSM entirely by hand, which is especially necessary when digital factory models are incomplete or not available at all. This is performed in the alternative view of the analysis area, where the necessary functions for model construction can be found.

Once the PSM has been fully created in ecoFLEX, the system objects required for the flexibility calculations are assigned the necessary data (*2nd base iteration*). Once again the user has the choice of an automated or manual procedure:

- For the automatic execution of the second base iteration, the *Import* function within the *File* menu is used. With the support of the Wizard, the user can access the systems which are coupled to ecoFLEX from the operational production environment. These are then sorted for flexibility relevant data by the “Data Processing Module” (see Fig. 4.2), formatted and allocated to the system objects contained within the PSM. All the data interpreted in this way can later

be displayed in the parameter area of the alternative view (see Fig. 4.4) as normalized within a uniform evaluation period.¹

- In case automatic data imports are not feasible or if re-processing is necessary due to incorrect data interpretation, ecoFLEX also supports manual data capturing. The relevant Wizard-based functions are available in the parameter area of the alternative view and can be run directly from the parameter area (see Fig. 4.5). It is important to note that the input data is normalized over a standard evaluation period.

Example. To make the procedure of manual data mapping more understandable for the reader, Fig. 4.5 illustrates an ecoFLEX screenshot that demonstrates the capture of flexibility relevant data using the example production system from Sect. 6.4. It shows that the first step (1) allows for the selection of the system object, thus enabling the already allocated object data to be viewed via the tabs in the parameter area. Workplace *API.1.1* can be seen in the screenshot. The workplace is allocated a “manufactured on-site” product, *Product 1*, with its object-specific properties such as production time, scrap rate, variable costs etc. To allow this data to be modified or new data to be collected in the second step (2), the corresponding icons which start the relevant Wizard are made available in the toolbar. The wizard “Add Product” shown in the screenshot illustrates how to add an additional product, *Product 2*, which is assigned to workplace *API.1.1* along with its data necessary for the flexibility analysis.

The entire procedure can be carried out successively for all other system objects in the PSM, the processing is however limited exclusively to the alternative view.

Once the PSM and the flexibility relevant data of a production system have been completely represented in ecoFLEX (i.e. the first two base iterations have been completed), the last of the three base iterations, the calculation of the object-related flexibilities, is prepared (**3rd base iteration**). In addition, the data represented in the alternative view are transferred to the original view and at the same time the required Product mix necessary for the flexibility analysis is established. The function “Set Alternative as Original” in the “Edit” menu is provided for this purpose, through which the calculation of the various object-related flexibility parameters is automatically executed via the “Module for Flexibility Analysis” (see Fig. 4.2). The same happens during the scenario observations, in which flexibility calculations are immediately updated with any revised value-assignment.

In conjunction with an update of the flexibility indicators, the additional auxiliary parameters are also recalculated (see field (2) in Fig. 4.4) which supports the user to quickly identify any flexibility deficits and to search for suitable alternative solutions. The specific procedure is discussed later in Sect. 4.2.3.

¹The evaluation period represents a sample average period in which all the parameter data necessary for the flexibility calculations (cost-related and non-cost-related) are normalized to a predefined time interval e.g. weekly or monthly intervals (see also Sect. 3.3.4.2).

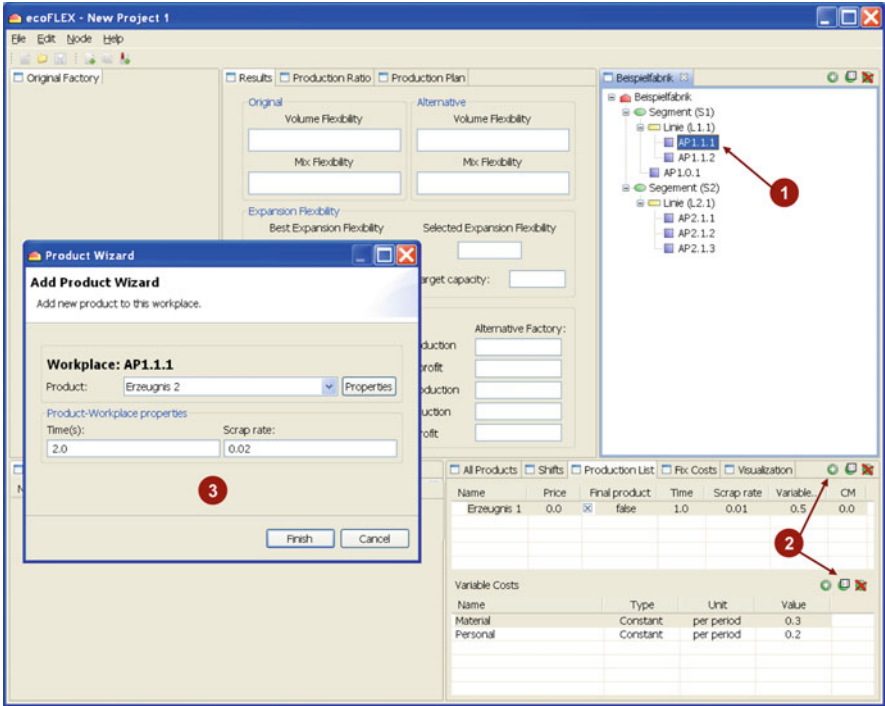


Fig. 4.5 Manual data capturing in ecoFLEX

4.2 Case Study-Related Application Experience

The models depicted thus far for the development and implementation of the evaluation methodology can be traced back to problems experienced in practice (see Sect. 1.2). It must also be investigated whether the methodology is suitable for its intended use. For this reason, a real production system of a series producer of infotainment systems² will be used as a case study to assess the methodology with respect to the flexibility metrics and the production model. Due to an existing confidentiality agreement between the author and the user company, the reader will only be privy to normalised information.

²The word “infotainment is formed from the two words information and entertainment and describes the link between the imparting of information and entertainment. An infotainment system makes use of a so-called Multi Media Interface and can be used for example in motor vehicles. In addition to the radio programme other complex tasks are also available, such as an instant, written reports of the current traffic situation, as well as the displaying of the map navigation system while simultaneously operating the phone and/or comfort features of the vehicle.

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