Abstract

Today's world of business is challenged by global markets that are becoming increasingly competitive due to globalization. Especially, small scale manufacturers have to rely on state-of-the-art manufacturing technologies to deal with today's ever-changing business environment and customer requirements. With the help of the right manufacturing technology portfolio high degrees of automation and cost efficiency can be realized without sacrificing the manufacturing system's flexibility. We developed a systematic decision-making process in manufacturing technology planning and selection of proper machinery for small scale manufacturing companies. This process takes a six step decision-making approach, which relies on a workpiece categorization to develop abstract manufacturing concepts which are then preselected, concretized and finally assessed. The outcome of the presented approach is a portfolio matrix which opposes the final manufacturing systems' degree of utility to their respective costs.

1. Introduction

Ensuring success and competitiveness is becoming increasingly difficult for manufacturing companies in today's era of globalization. The manufacturing industry worldwide is put under immense pressure by two major developments: growing customer preference diversity on one hand and competition between manufacturers in high-wage and low-wage countries on the other hand. In high-wage countries these two challenges are best met by improving flexibility, productivity and cost efficiency of the companies' manufacturing systems. Therefore, modern technology is important in enabling manufacturers to compete as world-class enterprises [2]. At the moment optimization methods usually focus on existing processes in terms of lean management methods focusing on eliminating waste. Due to innovations in the field of manufacturing technology concerning both subtractive and additive processes like 5-axis high speed milling and selective laser melting, this approach has a lot of potential, but it is not sufficient. The reason for that insufficiency is the fact, that only process flows are improved but technologies and resources performing the process are not scrutinized.

Nowadays customer requirements are constantly rising and changing, which results in shorter product lifecycles and higher levels of product diversification [6]. Especially for small scale production companies it is very difficult to make profound investment decisions because of ever-changing product requirements. In contrast to mass production firms, small scale manufacturers cannot afford to invest in specific production lines for every new product. Due to that, small scale production companies have to use their machinery for a very broad product spectrum. That in turn results in the need for both high degrees of flexibility and productivity of the machinery. By choosing the right manufacturing technologies and resources, cost efficiency and customer satisfaction in terms of quality and sustainability can be achieved [25].

In today’s literature there is no comprehensive method for technology planning and resource selection for small scale manufacturers. Some authors provide single steps for the selection process. There are approaches for the technology performance assessment [5] or for technology selection for advanced manufacturing technologies [7], [4], [27]. However, these steps were not developed for small scale manufacturers and just focus on a very small field of application. Chuu [7] for example provides a mathematical framework for the decision process only considering subjective and imprecise information.

This isolated information is not sufficient for a well-founded investment decision. Therefore, the purpose of this paper is to develop a comprehensive method by combining the fragments provided by other authors and the empirical knowledge from industrial projects which were conducted in Europe, China and India. This paper suggests a six step decision-making...
method regarding manufacturing-related investments in a small scale production company's manufacturing system. This means that the decision process presented in this paper is about the technology and resource selection in terms of investment decisions. It is not related to any production planning and control issues. The method takes the company, its customers as well as product-specific aspects into account and uses a workpiece categorization system to derive specific manufacturing requirements in order to systematize the everyday changing product spectrum of small scale manufacturers. Based on these requirements a procedure for the selection of manufacturing technologies and machine tool concepts is presented. In a next step, these concepts are compared to each other using a utility analysis (scoring model) in order to define a small set of concepts that appear technologically reasonable for further consideration. With the help of quantitative and qualitative valuation methods, these abstract concepts are then converted into an array of possible manufacturing systems. The final goal is to come up with a practical portfolio matrix in which the degree of utility is opposed to the costs of these manufacturing systems. The degree of utility is measured by taking the different machine tool performances, the manufacturing system’s ecological impact and an analysis of the sub-criteria into account. Using the final matrix, the best manufacturing system can be chosen. It is customized to the company's specific needs and combines the appropriate manufacturing technologies with the right choice of machinery. The six steps of this decision-making method are explained with the help of a case study drawn from the broad array of business cases of our benchmarking database. This benchmarking database contains several thousand useable data sets from the last ten years.

2. Workpiece categorization

The choice of the right manufacturing technologies as well as the final decision for a certain machinery is determined by the product requirements. The importance of the different product requirements for the manufacturing process varies between sectors and product types. Since different workpieces share several of their technical characteristics, the manufacturer can derive the workpieces’ manufacturing requirements in order to forecast the manufacturing technology’s requirements. Due to that, the decision-making method regarding manufacturing related investments starts with a proper workpiece analysis. Workpieces are bundled into groups that demand comparable manufacturing requirements. By doing so, it is possible to cope with one of the negative characteristics of small scale production. With the help of a proper workpiece categorization, the large product range, which might be made up of a huge amount of different workpieces, is broken down to several abstract workpiece representatives named workpiece categories.

Apart from reducing complexity, the categorization procedure helps to deal with other challenges of small scale production companies. Due to small production quantities, such companies face the impossibility of deriving benefits from learning effects as well as economies of scale through machine utilization. However, through bundling workpieces into groups of products with similar manufacturing related characteristics this negative effect can be lessened and a higher level of efficiency can be achieved by applying similar manufacturing processes to all products of a certain category.

As mentioned above, the relevant characteristics of products can vary between branches and sectors. Due to that, it is necessary to focus on those characteristics that are important for the manufacturing process of a certain product. A systematic approach for the derivation of these characteristics is recommended. Consequently, the main equivalent-criteria, which are used to categorize the range of products, have to be identified. These criteria should have a high impact on long-term technological superiority and the workpieces’ manufacturability.

In consideration of the aforementioned systematic approach, two types of characteristics have to be distinguished. The first consists of general criteria which are basically applicable for nearly every branch and product type – the following were elaborated: tolerances, surface requirements, material factor, aspect ratio, level of detail, shape complexity and workpiece size [5]. The second type consists of criteria that are product-, branch- and company-specific. Due to the definition of their uniqueness we cannot suggest a general enumeration of this type of criteria.

In order to reduce the complexity of conducted categorization, we suggest a second step, which reduces redundancies in the categorization. This is necessary because some of the elaborated characteristics can be mutually dependent on one another. Therefore, it is an important step to investigate these criteria respecting their relationship to each other. For this purpose a regression analysis is most suitable. Depending on the coefficient of
determination the number of critical manufacturing characteristics can be reduced. When we applied this procedure to a tool manufacturer a relationship between length and weight of the workpiece spectrum was found as shown in figure 1. This made it possible to reduce the number of critical parameters and to focus on workpiece length since the weight is dependent on the length.

![Figure 1. Case example, for criteria dependencies](image)

The next step is to generate product clusters regarding identified characterization criteria versus frequency of occurrence. With respect to act in the spirit of practicability, the 80/20 rule is to be applied [14]. Therefore the focus lies on the group of products that are responsible for about 80 percent of the profit. That implies subcontracting, outsourcing or even turning down the rest [17].

In order to group the various workpieces, accumulations of certain characteristics have to be examined. If a large amount of workpieces shares similar characteristics, this group can be chosen as one workpiece category. All products that belong to this category have to be excluded from the array of workpieces which should be clustered. The remaining workpieces have to be examined once again until no further resemblances can be found. The differentiation between the workpiece groups must be undertaken at reasonable values of products. These values may represent a technology step, a limitation of the capacity of a handling system or a restriction of any other parameter that might make sense in terms of manufacturability. Following this procedure, a reasonable sub-classification is created.

Referring to the case example of a tool manufacturer three classes were elaborated as presented in figure 2. Thereby, a classification was achieved by simply grouping workpieces in terms of length. No further differentiation was necessary.

To generate a manufacturing system that is applicable to each workpiece of a certain group, the respective product characteristics have to be investigated in detail. Therefore the maximum technological manufacturing requirements have to be elaborated for every category and characteristic in order to create a representative characteristics specification for each group. In the next step this is used as an input for the technology selection procedure in order to guarantee the capability of the final manufacturing system to produce the needed workpieces within the defined product requirements.

![Figure 2. Workpiece categorization example](image)

3. Technology selection

The right choice of manufacturing technologies is an important part of implementing a successful manufacturing system. Even though it is desirable to aim for a single complete machining process, which would result in a lean process chain, too many manufacturing technologies should not be applied. This is not only due to technical reasons. A combination of different technologies also enables high degrees of automation as well as flexibility, both crucial for a manufacturer’s success in today’s dynamic business environment in the field of small scale production.

Most manufacturing technologies, that are common in small scale production, can be grouped into two categories according to their material processing principles [23]. Therefore, this chapter focuses exemplarily on the following types of manufacturing technologies:

- subtractive manufacturing (machining) as well as its respective sub technologies
- and additive manufacturing (layered manufacturing).

Both subtractive and additive technologies exhibit certain degrees of effectiveness and performance depending on the context in which they are used. Additive manufacturing technologies are primarily used as pre-machining processes. The basic principle
that builds the foundation for most additive manufacturing processes is the same for all of them [28]. That is why the pros and cons of these technologies are quite similar.

Manufacturers are enabled to create extremely complex geometries without significant increases in production time or costs. Moreover, the implementation of additive manufacturing makes the usage of different materials possible [18]. Therefore, additive manufacturing processes add a lot of flexibility to a manufacturing system.

However, the surface quality created through additive manufacturing is usually worse than that of subtractive processes like CNC milling. In the additive manufacturing processes layers of uniform thickness are stacked on one another to fabricate the part. This results in the stair stepping effect [3]. Due to that, all additive manufacturing processes require post-processing.

In contrast to additive manufacturing technologies, subtractive manufacturing technologies’ characteristics are not that easily generalized because they are based on different underlying principles [16]. Through extensive research Bilsing [5] came up with a list of relevant subtractive technologies and their performances. Radar charts were created for each technology as shown in figure 3. To make these charts comparable to one another, each characteristic was scaled with regard to the highest occurring performance in each category.

Figure 3. Technology radar charts

The resulting radar charts symbolize the different process limitations of the manufacturing technologies and can be used to facilitate the technology selection process. Based on the information gathered during the previous workpiece categorization, workpiece requirements have to be converted into corresponding technology requirements. Afterwards, these can be compared to the presented process limitations in order to examine which manufacturing technologies should be selected.

As the workpiece requirements, which were examined in the previous step, depend on the company’s specific product focus, it is not possible to provide a translation of them into technology requirements, which is applicable to every business case.

In the metalworking industries, workpiece characteristics can be described using seven criteria which are based on Bilsing’s [5] work. For the technology selection process it is crucial to define reasonable scores for each workpiece category in all seven fields, as a workpiece category’s rating has to be representative for all its elements. Therefore, most of the times the highest requirement imposed by a specific workpiece towards a criterion should be used to develop an individual category’s score.

Relying on these scores, radar charts are created for any workpiece category representing the specific product requirements, which the manufacturer must be able to produce using its manufacturing system. With the help of these diagrams a portfolio of possible manufacturing technologies and their hybrids is created for every workpiece category. These portfolios should include all combinations of manufacturing technologies, which are able to fulfill the specific category’s requirements. Thereby, it is important to include hybrids to make sure that no possibility is left out.

We applied this approach to the tool manufacturer. The radar chart, which can exemplary be seen in figure 4, was created for every workpiece category representing the company’s workpiece characteristics and its requirements towards processing tasks.

Figure 4. Workpiece requirements radar charts

With the help of these category-specific radar charts, manufacturing technology options were examined by
comparing the categories’ requirement profiles to the process limitations of the manufacturing technologies.

In the end, combinations of rough-milling and finish-milling processes were identified as potential manufacturing technology solutions. With the help of possible hybridizations manufacturing technologies can be used to their limits and significant effects can be achieved [20]. That is why the selection of potential manufacturing technologies has to be taken very seriously. The manufacturing technology portfolio is the basis for the next step in the decision-making process.

4. Identification of possible machine tool concepts

In this section of the paper the manufacturing technology portfolio, which was created during the previous step of the technology selection, is used to derive an array of machine tool concepts, which have to be feasible for the defined workpiece requirements. The goal is to develop possible manufacturing technology combinations and the respective machinery the company can use. The company needs to concentrate on long-term strategic decisions because they are crucial for a competitive advantage [22].

In this step only abstract concepts have to be created. This means that it is not necessary to decide which specific machine tool from a certain provider has to be used. But it is necessary to sort out which constellation of different types of manufacturing machines is feasible. Therefore, all developed technology combinations have to be analyzed in order to cover all possible concepts. As manufacturing technology combinations were developed for every workpiece category, the first step is to pick the first workpiece category and create a list of machining sub-concepts for this category using the various manufacturing technology combinations. A machining sub-concept consists of the number of machines, the included manufacturing technology, the description of the manufacturing process of representative workpieces using these machines and a definition of the workpiece requirements each machine tool has to fulfill for this workpiece category.

This step is repeated until all possible machining sub-concepts are finished for any workpiece category and its individual technology combinations. Now, the sub-concepts have to be united into whole machine tool concepts with regard to the company’s entire manufacturing objective. To do that, all sub-concepts of a certain workpiece category have to be compared to those of the other ones to discover similarities in the required machine tool concepts. This is important, as such redundancies can then either be eliminated by using one machine tool for both categories to achieve a lean manufacturing system or they can be retained to increase the manufacturing capacity and flexibility of the whole concept.

As soon as the potential machine tool concepts are developed, specific requirements for machine tools have to be defined. Thereby the previously defined workpieces’ requirements have to be taken into account. These criteria are then used as primary machine tool requirements for the machine tool selection process in order to preselect useful manufacturing machines.

5. Assessment of the machine tool concepts

The machine tool concepts, which were created during the last step, can be very numerous depending on workpiece requirements, selected manufacturing technologies and production volume. In order to deal with this complexity in the decision-making process, the various machine tool concepts have to be evaluated and preselected before further analyses should take place. We propose a method using a weighted scoring model to identify the most promising concepts by determining technical performance parameters and the utility for the company’s production goals. An example is shown in figure 5.

In a first step the relevant evaluation criteria are defined distinguishing between high-performing machine tool concepts and those that are a less auspicious basis for an efficient manufacturing system. Through empirical research the following seven characteristics are proven to be successful in this selection process:

1. Manufacturing accuracy

Many industries, and especially high precision industries face increasing customer requirements in terms of product accuracy resulting in a demand for manufacturing systems that are capable of high precision machining and manufacturing. This allots a key role to manufacturing accuracy in determining a concept’s abilities. Today machine tool accuracies of less than 0.002 mm are a common requirement in several industries.

2. Productivity

A machine tool concept’s productivity influences both the cost efficiency and production capacity of
the future manufacturing system as the productivity describes the ability to produce a specific number of goods during a given time period. The higher a concept’s productivity, the more products can be produced per timeframe.

3. Flexibility
The flexibility of a machine tool concept covers its ability to adapt to new product requirements. As mentioned above, flexibility is becoming more and more important for small scale production companies because customer preferences, and therefore product requirements, are increasingly volatile.

4. Space requirements
In many cases machine tool concepts are developed in order to create a new manufacturing system in an existing environment. Due to that, the provided set-up area is limited and the required space of a concept must be taken into account.

5. Manufacturing redundancy
As most parts of today’s world of business rely on just-in-time production, redundancy is an important part of a manufacturing system ensuring its stability and reliability in situations when certain components fail to work.

6. Automation capabilities
Automation and mechanization have the potential to improve the quality and productivity while involving less manpower. That is why automation capabilities of machine tool concepts are very important in order to enable companies in high wage countries to compete with those in low wage countries in terms of costs.

7. Agility
Today’s fast-changing markets and customer needs require fast-reacting machine tool concepts. Because of that, the concept’s agility must be taken into account to measure how quickly a proposed manufacturing system can adapt to new regulations.

Before this set of criteria can be applied to evaluate the machine tool concepts by using a scoring model, the criteria have to be weighted with regard to the company's background that has already been examined with the help of its key figures. In our examples each of the seven criteria is matched head-to-head with the other six in order to determine the relative importance of the seven criteria. This results in seven scores that can range from -6 to 6. Now, seven is added to each individual score in order to get ratings from 1 to 13. These absolute results are now scaled from 1 (lowest importance) to 5 (highest importance) for each criterion.

In the next step the criteria' valuations regarding the performance and the utility form the basis for the scoring model that is used to rank the different machine tool concepts. To conduct the final assessment every single concept has to be evaluated with respect to the set of criteria that was defined and then weighted in the previous step. So, a score from 1 to 4 is assigned to each evaluation category. These scores depend on the machine tool concept's ability to establish a manufacturing system that can meet the defined requirements. Due to that, the ratings do not represent the real manufacturing systems’ strengths and weaknesses, but only exhibit what could be possible based on the specific concepts. After a concept is graded in all seven categories, each grade is multiplied by the specific criterion's weighted rating. That takes into account both the concept's possible performance in this field and the importance of this criterion for the success of the manufacturing system. For the overall result of each concept, the seven sub-scores are summed up. In accordance to these ratings, the concepts are then ranked and the best concepts are chosen for further consideration and development. Because of the generalization of the assessment company specific strategic orientations may not be sufficiently taken into account. It is accepted to ensure the comparability of different companies.

6. Identification of manufacturing systems

Different machine tool concepts have been elaborated in the chapters before. In the following one, these concepts have to be specified. This is done by identifying appropriate machine devices, components and pieces of equipment or facilities (all of these items will be referred to as equipment) for
each manufacturing technology. After the identification of equipment, these concepts have to be evaluated with respect to their technological capability and company related preferences. Each concept consists of a specific number of manufacturing technologies applied. Besides that, the technology specification and the number of machine tools per technology are defined for each concept. Considering this, the next step is the identification of potential equipment. Therefore, the requirements regarding the machine tools have to be elaborated and precisely defined in order to identify potential equipment providers. It is not unlikely to find different applicable equipment for a specific machine tool concept. Therefore we suggest additional steps. For this follow-up it is essential to gain as much information regarding the equipment as possible, since that is the only way to guarantee a comprehensive decision-making process. However, in the interest of economic efficiency, only the tool machines that have no shortfalls in technical requirements and fit within the investment budget have to be investigated.

However, to determine which equipment is most suitable for a specific manufacturing concept, also secondary order criteria and the ecological assessment index have to be evaluated. These aspects are discussed in the next chapter.

7. Assessment of manufacturing systems

Analog to the chapter “Assessment of the machine tool concepts” a head-to-head match and a scoring model using the abovementioned criteria is recommended. A comprehensive and balanced overview of the criteria’s impact on the individual company targets is provided. In order to achieve a useful result a team of experts is suggested for this approach.

The results of this analysis are the elaborated concepts, filled with different equipment, provided with a number that gives a value for the fit of the described solution to the individual company’s strategy. The completed work from previous chapters is the basis for the final decision process and the desired portfolio matrix. A utility value and the total costs have to be assigned to the possible machine tool concepts. The utility value consists of three different parts: a machine performance indicator, a second-order criteria analysis and an environmental index.

7.1 Derivation of machine performance indicators

First, the capability of a manufacturing system’s machine tools has to be evaluated. This is based on a machine performance indicator that was first announced by Bilsing [5]. This indicator represents the three most important aspects of a machine’s performance: productivity, flexibility and quality. Each of these aspects represents one component of the final machine performance vector, which is then converted into the scalar machine performance indicator.

A machine’s productivity can be defined as the ratio of its output to the required input factors and is a measure of a machine’s utility divided by the necessary expenses. As lead time is the limiting factor for a manufacturing system’s capacity productivity is closely related to the machine’s operating/machining time, set-up time, repair time and downtime [19] [8]. The time aspects of a machine’s productivity are divided into two categories. On the one hand all influences on a machine’s operating time have to be evaluated. The operating time is the time it takes to manufacture a workpiece. On the other hand all potential threats that can increase a machine’s downtime must be analyzed.

Moreover, the required deployment of personnel influences a machine’s productivity. Due to that, possibilities for the implementation of unmanned manufacturing processes have to be examined. Thereby, the ability of a machine to apply NC technology and high speed control systems are some of the most important criteria, because it ensures high manufacturing efficiency and less staff requirements. For all three aspects of productivity – operating time, downtime and automation ability – a weighted scoring model is applied to determine the influence on productivity. Each aspect is analyzed separately resulting in three sub-scores for the respective categories. Eventually these sub-scores are summed up to calculate the final productivity index.

As already mentioned, flexibility is another important aspect influencing a machine’s performance. A machine’s flexibility is in conflict with its productivity and its efficiency [1]. Highly specialized machines manage to achieve a high degree of efficiency and productivity but little flexibility. Their usage is only recommended if the company uses their capacities to the fullest. In any other case, which applies to most small scale production firms, flexible universal machines are the better choice. A higher degree of flexibility enables manufacturers to adapt to dynamic market demands and manufacture customer-oriented products at low costs [26].
To include this aspect in the machine performance indicator it needs to be measured. A machine’s flexibility is mainly influenced by its ability to manufacture workpieces of various sizes, materials and geometries. Sub-scores are created for these three categories analogous to the calculation of the productivity index. For that the machine’s characteristics have to be taken into account. For example, small dimensions of the machine’s workspace limit its flexibility in terms of size, whereas a high number of machining axes increases its flexibility of dealing with various geometries. After the three sub-scores are developed with the help of a weighted scoring model, the sub-scores are summed up to get the machine’s flexibility index.

The third aspect influencing a machine’s performance is quality. A machine’s quality can be evaluated by considering the four sub-categories: accuracy, surface quality, repeatability and process reliability. Analogous to the procedures used to evaluate a machine’s productivity and flexibility sub-scores for the four categories are determined and eventually summed up to get the quality index.

Finally, the machine performance indicator is aggregated for every machine of each concept. The values for all machines of one concept are summed up resulting in comparable values for each concept.

7.2 Second-order criteria analysis

Next, the second-order criteria analysis has to be conducted. Secondary order criteria are here defined as not being technically necessary for the manufacturing process, but being process supportive or as having a profit impact.

The motivation behind incorporating this aspect is not only to guarantee that the manufacturing system has the technological capability to accomplish the needed workpiece quality but to include further company and strategy specific aspects of the manufacturer in the decision-making process.

The following five aspects are considered as second-order criteria.

1. Operating costs
   Operating costs comprise costs for energy, licensing and for infrastructure as well as other costs that accrue continuously. Especially energy efficiency cannot be neglected because of rising energy costs and rising public ecological sensitivity [13].

2. Ergonomics
   An ergonomic environment plays an important role in long-term economic success. It can influence employee satisfaction, sickness rate and productivity. Because equipment design influences this factor it has to be included in the decision-making process [9][11].

3. IT-Infrastructure/ Data processing
   Software applications are crucial for profitability in manufacturing processes [21]. One reason is that human-machine interaction is increasingly concentrating on contact via display. Besides, in this context user-friendliness, general software quality and being up-to-date are the most important aspects [15].

4. Raw materials and supplies
   Raw materials are needed for many processes. A company may have preferences for a specific type, because this is already largely in use or rejects another due to environmental legislation.

5. Guarantee und service
   Even though the presented concept favors redundancy, this is often not given since small scale production often takes place in medium or small sized companies. In such an environment a machine breakdown has enormous consequences and may interrupt the whole production for a while. Therefore guarantee and services play significant roles. That’s why service quality and quick equipment replacement are questions that have to be considered.

7.3 Ecological assessment Index

Fińał provides a third indicator making it possible to take ecological aspects into consideration [10]. He elaborates an analysis of the ecological impact of different manufacturing related processes and the correlated industrial waste emitted. Therefore he provides an index that illustrates the environmental nuisance of a technological process by focusing his attention on the material and energy flow exchange between technical processes and the environment on a quantitative basis.

7.4 Final assessment of the manufacturing system

In order to apply the scoring model again, these three utility values have to be merged into one final parameter. The challenge of this step is the weighting of the three abovementioned parts. This has to be done with respect to strategic considerations and market position, for instance ecological aspects may play a more important role in a B2C market than in a B2B market.

This parameter is classified in the matrix shown in figure 6. This matrix uses the layout of the Boston consulting matrix and merges it with the principal of the McKinsey-Portfolio matrix. The McKinsey-factor
“competitive advantages” is substituted by “technological utility” and “market attractiveness” by “investment cost” [12]. Finally the demarcation has to be discussed. It is suggested that the separation between the fields is drawn at the arithmetic average of the minimum and maximum value of total costs and utility parameter. This is considered as correct, because it is expected to find no extreme outlier in a highly globalized and competitive world with respect to utility as well as to costs. Supportive is the fact that costs were already included in chapter 7. The resulting matrix provides a comprehensive overview of all possible concepts with its different machine concepts under consideration of its costs.

8. Conclusion

We presented a six step decision making process for investment decisions for manufacturing companies operating in small scale production business. For that purpose, we introduced a procedure for technology planning and selection, machine tool concept development as well as a distinctive evaluation procedure. Strategy and company specific requirements were also included in the approach. Ecological, technological and economic criteria were considered in the decision process in order to guarantee a high practical usability. The portfolio matrix is well suited for investment decisions and gives a good overview about potential manufacturing systems.

Further research has to be done in the field of secondary resource planning and selection like automation and IT infrastructure as well as on other manufacturing equipment necessary in a company. Furthermore, a study testing the applicability of the presented decision-process for companies operating in serial or mass production would add high value to the scientific community.

9. References


