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Simulation-based planning of production capacity through integrative roadmapping in the wind turbine industry

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Abstract

The development and effective implementation of a production strategy requires an interdisciplinary planning of products, manufacturing technologies and factory concepts. The integrative roadmapping allows the merging of these planning areas and takes into account the occurring interactions. This article shows the concept and software implementation of the integrative roadmapping for a systematic creation of roadmaps using the example of rotor blade production in the wind turbine industry. To reduce planning time and cost the workflow in the rotor blade production has been transferred to a material flow simulation to estimate the mutual impact on the production capacity by product, technology and factory within the planning phase.

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Keywords: planning; simulation; decision making

1. Introduction

The planning fields of product, technology and factory are important components of a successful business strategy because they have a significant influence on the efficiency of manufacturing companies [1]. Both, in the strategic as well as in the operational level, the planning fields have strong mutual interactions. This makes the achievement of competitive advantages by an isolated consideration of individual planning disciplines increasingly difficult for companies. To minimize the risk of overcapacity in production in the wind turbine industry, it is therefore mandatory to synchronize the three planning fields through a systematic approach.

For example, the location of a wind turbine determines, due to existing wind conditions, the length of the rotor blades to be used. The length of the rotor blades, in turn, determines the design and the materials to be used. The processing of the materials can again require a new manufacturing technology, which is subsequently integrated into the existing factory concept. This relationship already shows that considering only one planning field separately will lead to wrong decisions.

Roadmapping is one method proven and recognized in practice to support the coordination of several planning areas [1, 2]. The term “roadmapping” stands for a creative process, which allows the analysis and visualization of the long-term development paths like product innovations, technologies or industries [2]. Roadmapping pursues the objective to forecast the future, to evaluate and derive specific actions. As the result of roadmapping a roadmap is created including possible decision alternatives and is used as an internal communication tool of strategic planning. Within the integrative roadmap the possible development paths of product, technology and factory planning are merged.

One possibility for simplifying the roadmapping is the use of methods for decision making and their implementation in a software tool. These provide an enormous support to the user for the description, visualization and maintenance of roadmaps. Many software tools are available on the market, but there is a lack of applications for synchronizing the three planning fields. In addition, these software tools are merely tools to visualize, but not to support by decision making methods for planning. In practice there is a wide variety of methods that permits structuring, analysing and evaluating alternative actions to facilitate the decision making process in roadmapping. A comparison of methods shows, depending on the planning area

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and task, that the use of certain methods is more appropriate than others.

For this reason, the present article shows a concept, which allows the systematic coordination of product, technology and factory planning. To simplify the roadmapping, methods for decision making have been developed and integrated in the concept. Besides the development of a concept, also its implementation in form of a software tool as well as first simulation results are presented.

Based on a systematic analysis and evaluation of current and potential markets, resulting requirements on wind turbines are used for evaluation in the product planning. The result of this planning phase is a product roadmap by means of how the product-related corporate strategy is visualized. On the one hand this represents impulses for the technology and factory planning, on the other hand existing manufacturing technologies and factory concepts already have to be kept in mind for evaluation within the product planning. The roadmaps for technology and factory are created respectively, taking into account the occurring interactions and evaluation methods. Thus, the technology caused costs and benefits over the life cycle are used to evaluate technologies, while in factory planning the resulting production capacity is determined by using a material flow simulation. A final merging of the generated roadmaps to an integrative roadmap serves as a plausibility check and helps to avoid temporal and contextual inconsistencies.

2. Concept of integrative roadmapping

The procedure of integrative roadmapping is divided in three separate steps following the planning areas. The integrative combination follows in a subsequent fourth step. The individual steps are executed successively, which can be repeated iteratively as part of a consistency check, see Fig. 1.

For each of the three planning areas decision relevant data and criteria are acquired, evaluated and the results are presented in a roadmap, see Fig. 1. Depending on the planning area, different methods for decision making are used and developed further. Below, the methodical approach within the individual planning areas in detail, as well as results of the material flow simulation, is presented.

2.1. Product planning

Objective of the first phase of integrative roadmapping is, both, definition of the current and future product portfolio of a company and adaption to the demands of the market. The data acquisition is the initial step of product planning, when primarily potential future products and then appropriate criteria for a product evaluation are defined. The systematic definition of the product portfolio is done by using a product configurator.

Besides the name of the product, information on product field (product group) and time of market launch are gathered in order to be able to position the products in the roadmap later. While the time of market launch ensures a shift along the time axis, the product field affiliation allows a clear positioning along the object axis.

The different product fields arise as the use case from the corresponding type classes for wind turbines based on the international standard IEC 61400 [3]. This standard classifies wind turbines according to their suitability for certain wind speeds and turbulence intensities, see Fig. 2.

Product field	IEC-I-a	IEC-I-b	IEC-II-a	IEC-II-b	IEC-III-a	IEC-III-b
Turbulence intensity	High	Medium	High	Medium	High	Medium
Average wind speed	10 m/s	10 m/s	8,5 m/s	8,5 m/s	7,5 m/s	7,5 m/s

[Wn/72081 © IFW]

Figure 2: Type classes of wind turbines according to IEC 61400

The product configurator provides different maturity levels to choose from based on the life cycle model of products. On the one hand, the products currently positioned "on the market"

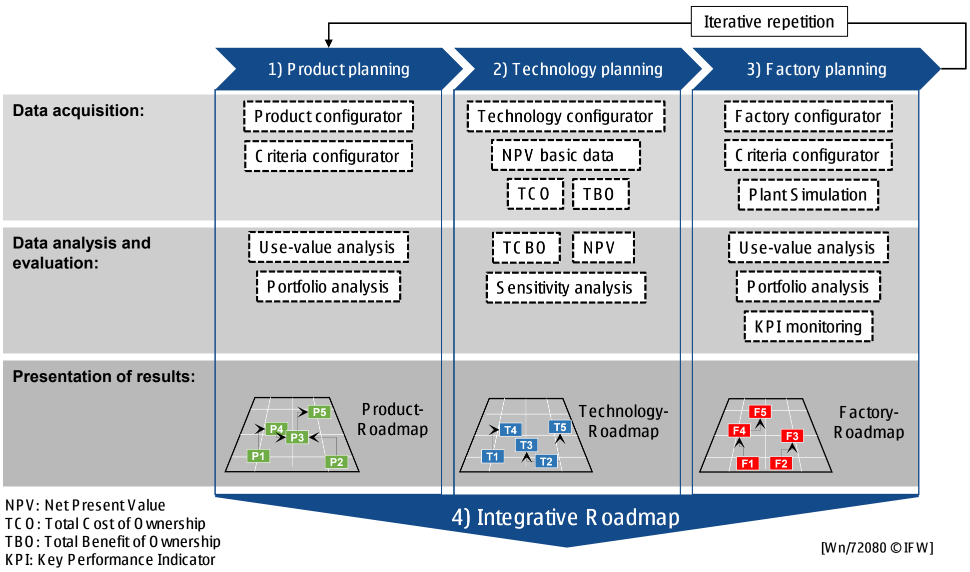

Figure 1: Procedure of integrative roadmapping

and currently manufactured are detected. On the other hand, both, in the development stage ("in development") being products and future product innovations ("idea") are included.

After the complete definition of the product portfolio, the identification and evaluation of relevant market and product evaluation criteria follow. A combination of market and product evaluation, in accordance to the McKinsey portfolio, allows the comparison of a company's external and internal factors [4]. Thus, the market attractiveness describes the fulfilment of the factors from the company's environment, while the achievement of the company's internal factors represents the competitive strength of a wind turbine. For the use case, the following criteria have been established to evaluate the market attractiveness:

- Political circumstances (subsidisation and restrictions)
- Geographical circumstances (wind class, designated areas)
- Infrastructure (grid connection, transport routes, access to raw materials, production facility)
- Competition (rivalry of the market participants, supplier market)
- Labor market (qualification of workers, wages and salaries)

The criteria used to describe the product characteristics have been defined from a customer point of view, for the determination of profitability of operating a wind turbine:

- Profitability (price, nominal power, swept area of the rotor, cut-in-/cut-out velocity, tower height)
- Service (maintenance, repair, stop periods)
- Compatibility (sound emission, total height)

The calculation of a use value, in terms of market attractiveness (P_{MA}) and product characteristics (P_{PC}) is done according to equation 1 and 2:

$$P_{MA} = \sum_{i=1}^{n} \left(w(P_{MA_i}) * A(P_{MA_i}) \right) \quad (1)$$

$$P_{PC} = \sum_{j=1}^{m} \left(w\left(P_{PC_j}\right) * A\left(P_{PC_j}\right) \right) \quad (2)$$

With: n number of P_{MA} criteria
m number of P_{PC} criteria
w (P) weight of P_{MA}/P_{PC} criteria
A (P) achievement of P_{MA}/P_{PC} criteria

After that, the presentation of results happens in a portfolio in which the intended product field (color) and the level of maturity (size) are visualized, see Fig. 3.

Based on the position in the portfolio, a recommended course of action by integration, selection or disintegration of product is given, in order to derive strategic product decisions. The selected products are transferred to the product roadmap, in which products are arranged with respect to the product field and market launch date. Arrow connections show the relationship to technological predecessors or belonging to the same product platform, see Fig. 4.

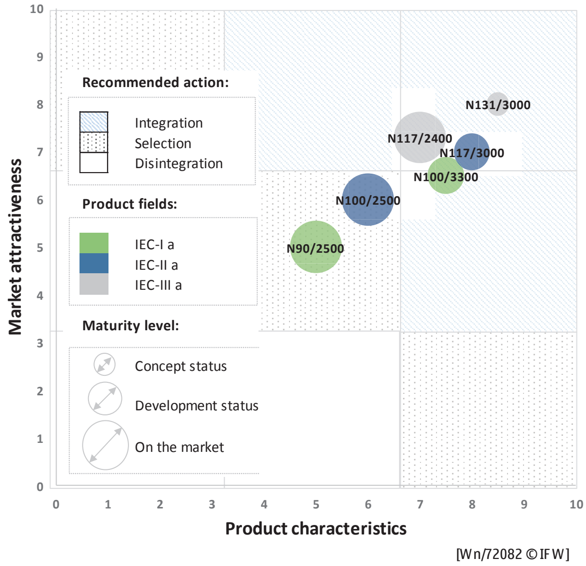

Figure 3: Exemplary portfolio analysis in the product planning

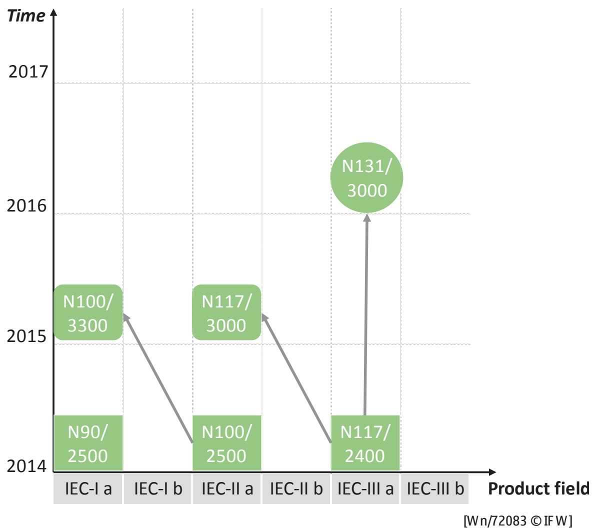

Figure 4: Product roadmap as result of the product planning

2.2. Technology planning

The goal of technology planning is the identification and selection of manufacturing technologies that are suitable for manufacturing of defined products. In order to acquire and evaluate the potential of various technologies, the method is structured similar to product planning in data acquisition, data evaluation and presentation of results.

Potential technologies are classified on basis of technology fields in the data acquisition. Using the example of rotor blade production, there are six main manufacturing processes (laying, infusion, annealing, cutting, coating and transportation), which can be derived as technology fields.

By using a consideration of Total Costs and Benefits of Ownership (TCBO) the potential of identified technologies (e. g. automated laying, cutting or coating) can be monetarily assessed in terms of their costs and benefits. First, following data must be recorded for the TCBO analysis:

- Cost of capital (WACC) and life cycle time of technologies (T)
- Life cycle costs of technologies (TCO)
- Life cycle benefits of technologies (TBO)

Initially, technology life cycle times and substantial economic variables, used to calculate the cost of capital, are gathered. This information enables an integration of the net present value method in the TCBO analysis. The weighted average cost of capital (WACC) is calculated as the weighted average of equity and debt costs, while cost of debt takes into account the tax advantage.

In the next step, the quantification of all costs incurred in the different life cycle phases of a technology is done. The costs are divided into three major cost blocks [5]:

- Investment costs: This cost block includes all costs incurred once in course of procurement, provision of an infrastructure, as well as commissioning of a technology.
- Operating costs: This cost block includes current costs, which are incurred for materials, staff, usage and maintenance of a technology.
- Utilization costs: This block includes all costs incurred once in the context of decommissioning.

Subsequent to the determination of the costs, benefit characteristics of manufacturing technologies are identified and monetized. The benefit characteristics are divided into direct, indirect and potential effects [6]:

- Direct benefits: This benefit effect involves all benefit items that are directly associated with a technology.
- Indirect benefits: These include benefit features that affect the surroundings of a technology (e. g. saving an upstream or downstream process step) positively.
- Potential benefits: In this category benefit factors are classified, which are difficult to measure in general and influenced by significant external effects (e. g. reputation).

A large number of factors can improve the accuracy of TCBO essentially [7]. However, the increased accuracy is also causing an increased methodical effort within the evaluation. For this reason, the software tool offers criteria catalogues including all cost and benefit factors from which relevant criteria can be selected.

Then the costs and benefits are compared with each other and charged as a TCBO sum. In a life cycle technology consideration costs and benefits emerge at different times. Therefore, it is necessary to include the dimension "time" in the evaluation and weighted costs and benefits depending on their time of origin. With the help of the dynamic NPV method the present value of future cash flows is determined and summarized in a single figure within the software tool. By integrating this method in the TCBO evaluation all benefit and cost values can be discounted to the present and used to calculate a TCBO net present value NPVTCBO:

$$NPV_{TCBO} = \sum_{t=0}^{T} \frac{\sum_{i=1}^{k} TBO_i - \sum_{j=1}^{m} TCO_j}{(1+WACC)^t} \qquad (3)$$

With:

k		number of TBO criteria
m		number of TCO criteria
TBO_i		value of TBO criteria
TCO_i		value of TCO criteria
WACC		weighted average capital cost
T		life cycle time of technology

To decide on the integration or disintegration of a technology the sign and level of the net present value will be used. A positive value indicates the economic profitability of an investment and therefore the technology should be selected [8]. The uncertainty of future cost and benefit effects and their impact on the investment decision can be countered by using the integrated sensitivity analysis to weight the effects individually, see Fig. 5. The selected technologies will be transferred equivalent to the product planning in the technology roadmap.

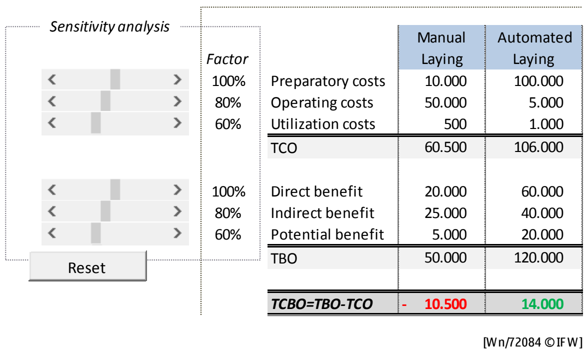

Figure 5: Sensitivity analysis in the technology planning

2.3. Factory planning

In the factory design a modification or extension of an existing plant with a new factory concept is elaborated. Whereas in the past a factory manufactured just one product throughout its life cycle, frequent product changes are taking place these days [9]. Furthermore, the operational resources available must be replaced at even more frequent intervals due to shortening technology life cycles. The factory planning, therefore, deals with the arrangement and interaction of the identified manufacturing technologies with other planning objects to increase the efficiency of the production process. A subsequent evaluation using the material flow simulation statements can be made regarding the performance of individual factory concepts and the optimal concept will be selected for the actual implementation.

The data acquisition is primarily used for the deployment of possible factory concepts, which are created similar to the morphological box by combining characteristics within definable factory fields, see Fig. 6.

Factory fields	Current situation	Alternative 1
New Technology	None	Automated laying
Layout	Current Layout	New Layout
Capacity	Current capacities	New shell Mould
Production Control	Push	Pull
Personnel	2-shift system	3-shift system
Production type	Construction site	Flow production

[Wn/72085 ©IFW]

Figure 6: Deployment of factory concepts in the factory planning

The process of rotor blade production is dominated by manual labor: In addition to automated technologies improvements in material flow (production type, production control), the number of workers employed, affect the performance significantly. Therefore, using the material flow simulation, the effects of conversion of the shift system and of a new layout were examined in terms of production capacity, measured in blades per year and depending on the number of workers, see Fig. 7.

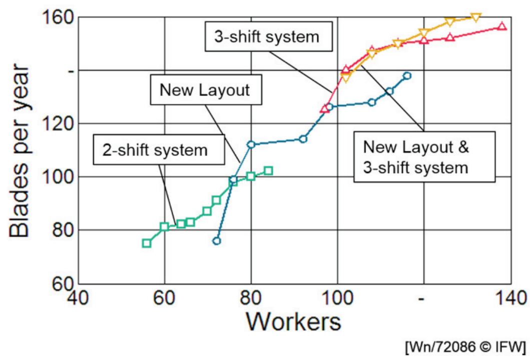

Figure 7: Simulation results for different factory characteristics based on interim input data

The graph shows the performance of the production system for changing one or more characteristics within the factory fields. The software tool accesses figures from the simulation to evaluate the use value of the factory concept in terms of performance. This value is compared with a use value for the costs of implementation of the factory concept in the context of a portfolio analysis, so that the alternative with the best cost-benefit ratio is selected and transferred into a factory roadmap.

2.4. Integrative roadmap

In the final step, the individual roadmaps in the areas of product, technology and factory are linked to an integrative roadmap. In the course of this linkage a final plausibility check of the interdisciplinary planning relations is performed. Thus, it is ensured that no temporal, contextual or financial inconsistencies due to incorrect assumptions are left, despite

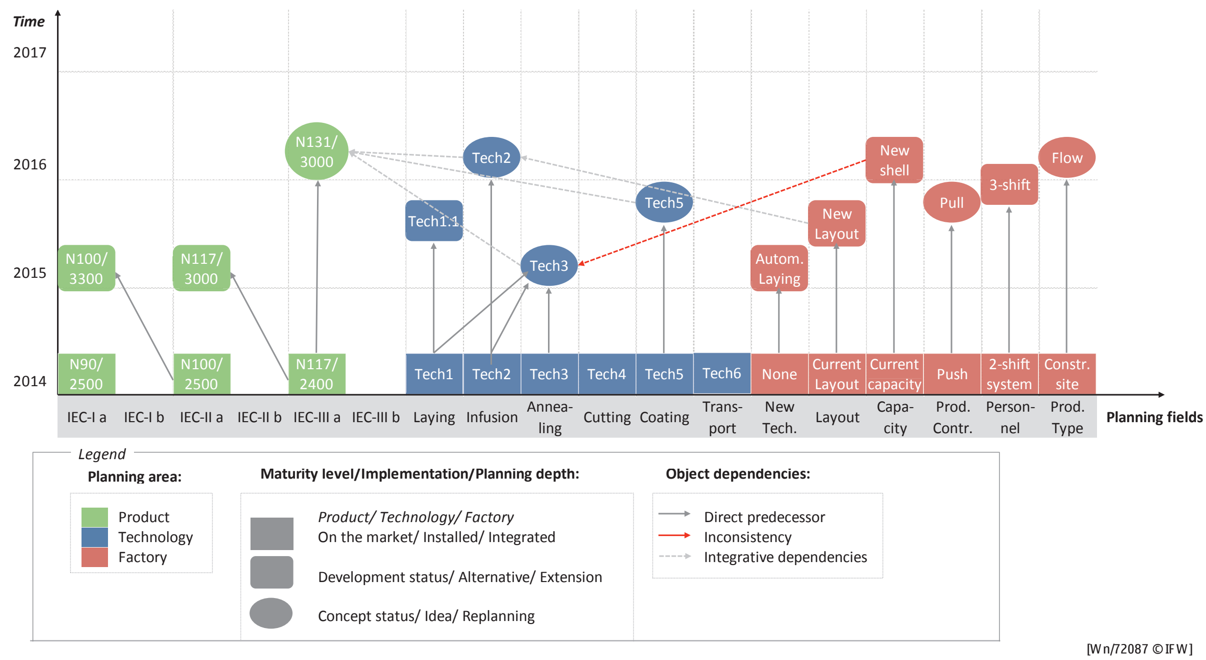

Figure 8: Plausibility check in the integrative roadmap

the successive procedure through the previous three planning phases.

Three basic types of inconsistencies are distinguished [6]:

- Temporal inconsistencies (e. g. product cannot be manufactured because a required technology is not available on time)
- Financial inconsistencies (e. g. premature introduction of a technology involves additional costs)
- Contextual inconsistencies (e. g. factory characteristic is linked to a technology, whereby planning objects do not depend on each other)

Temporal inconsistencies are detected automatically and marked accordingly, see Fig. 8. The implementation dates have to be adjusted in an order that no more arrows direct in the past and all temporal inconsistencies are eliminated. Financial inconsistencies are indicated by an arrow which points far into the future. This inconsistency as well as contextual inconsistencies have to be checked manually with the aid of the integrative roadmap.

3. Summary and outlook

The presented concept shows how using the integrative roadmapping, both, a product-related business strategy as well as their requirements in the technology and factory planning can be systematically developed. Methods for evaluation and tools used for consideration of interactions in order to improve the efficiency of decision making among different alternatives have been developed. The definition of an integrative roadmap serves as a basic framework for the transfer of strategic planning to operative.

In the following project progression, the method will be used and validated further in cooperation with a manufacturer of wind turbines, as well as a manufacturer of domestic and system technology to ensure the general validity of the concept. The identified manufacturing technologies and factory concepts will be evaluated using the material flow simulation in terms of resulting production capacity in order to avoid overcapacity.

Furthermore, the interactions of product, technology and factory to personnel planning will be analysed. Especially in production types dominated by manual labor, like job shop and construction site production, the production efficiency is determined by the qualification of workers. The results of personnel deployment alternatives analysed by the material flow simulation (new layout and 3-shift system as factory characteristics) have shown that there is a big potential to increase the production capacity by merging production departments, see Fig. 9.

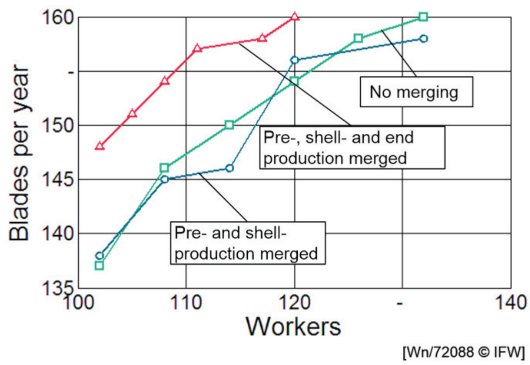

Figure 9: Simulation results for different personnel deployment planning based on interim input data

To deploy workers in different departments (e. g. pre-, shell- and end production in the rotor blade production), they have to be skilled for the tasks in another department. In case workers possess the necessary qualification for different tasks, personnel bottlenecks can be broken and the production capacity can be increased. Similar to the measures in the factory planning, the benefit of higher qualification has to be compared with the effort of further training.

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