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An Integrated Decision Support System Considering Interdependencies Between Time-to-Market and Market Diffusion under Competition

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Abstract

Industry faces fundamental challenges as new competitors from emerging countries enter markets. Thus, competition increases and time-to-market as intermediate span between R&D and series production gets more important. Additionally, customers ask for more individualized products. However, the resulting increase in product variety leads to rising complexity and costs and thereby, limited resources have to be allocated to a multitude of parallel product development projects.

To tackle these challenges and stay successful, companies aim at decreasing time-to-market with constant or even lower resource input. While complexity management and resource allocation have extensively been discussed for R&D and series production, approaches for the intermediate time-to-market phase are still scarce.

Against this background, the aim of this contribution is to analyze the interrelations between time-to-market and resource allocation in a competitive environment with a decision support system. To reach this aim, we present a system-dynamics simulation model analyzing the market diffusion of a product in a competitive environment. with the proposed model, we are able to derive information on interdependencies between resource input and time-to-market depending on competitors' behavior.

We apply the model to the gas turbine industry. In order to do so, we create a dataset merging recent data from literature with information gathered in expert interviews. Thus, we are able to quantify the parameters of the model. Results are presented highlighting the interdependencies between resources and time-to-market for the competitive environment of the gas turbine market.

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Keywords: Complexity management; time-to-market; new product development; market diffusion

1. Introduction

Production industry nowadays faces continuous change and various challenges. On the one hand, competition increases as companies from emerging countries like China, Brazil or India challenge industry leaders from Europe, Japan or the United States. [1, 2] In this competitive environment, established industry leaders often focus on innovation in order to preserve a unique selling proposition. [3, 4] Furthermore, first mover advantages and market entry timing are becoming increasingly relevant for company's success. [5]

On the other hand, consumer needs are increasing as consumers request highly individualized products at low costs (e.g. in textile [6] or food industry [7]). As a result, product variety has increased in the past and this trend is expected to continue. [8, 9] However, grown product variety leads to increasing costs as complexity rises in all phases of the product's life cycle. [10] Again, companies rely on innovation in order to tackle this complexity and to meet high cost pressure despite of the high product variability. [1, 3, 4] However, resources provided by industry are increasingly limited and have to be allocated among all product varieties and all life cycle phases (i.e. for product development, ramp-up, production and after sales). [11]

The afore mentioned challenges and characteristics lead to several implications. First, companies offer more products in less time, which is resulting out of a situation with permanent multi product development. [8] Second, despite this increase

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in the number of products, companies have to focus on an early market entry and thus reduce the time-to-market in order to stay successful in a competitive environment. [12] Therefore, companies have to shorten the early stages of the product's life cycle, i.e. the time span between project start and market introduction covering the phases of product development and production ramp-up. [13] This is possible by applying higher effort in product development and ramp-up [12, 14, 15], e.g. by parallelization of processes. [16] However, for multiple products this strategy is contradicted by limited resources. Thus, a goal conflict arises between early market entry with shortened time-to-market and limited resources. Additionally, resource allocation in product development and ramp-up is a crucial and demanding task due to high uncertainties in these early life cycle stages. [12, 13]

While quite some literature can be found on complexity and resource allocation for product development as well as for series production (e.g. [8, 17, 18]; reviews: e.g. [14, 16]), literature is still scarce for the intermediate phase (time-to-market) between project start and market introduction covering the phases of product development and production ramp-up.

Against this background, the aim of this contribution is to develop a decision support system (DSS) to analyze the interdependencies between time-to-market and resource allocation in a competitive market environment in order to consider current challenges and to derive managerial implications regarding interdependencies between resource input, time-to-market and market diffusion. To achieve this aim, we constitute several requirements for the decision support system.

First, project progress within time-to-market, especially during product development and production ramp-up, has to be depicted depending on the resources provided in the corresponding life cycle phases. Second, the market introduction and product diffusion has to be modeled and competition between a number of competitors as well as differing market entry times have to be regarded when modeling the market diffusion. Third, decisions should be based on an economic evaluation based on cash flows within time-to-market and market diffusion.

The paper is divided into five subsections: In section 2, an overview on related literature regarding project management during time-to-market and market diffusion of products is given. The decision support system considering interdependencies between time-to-market and market diffusion under competition is presented in section 3. A case study from the gas turbine industry is introduced in section 4, and the model is validated and results are derived in section 5. Section 6 concludes this paper with a short summary and an outlook on future research.

2. Literature Review

In this section we discuss main research streams regarding the afore mentioned model requirements. First, research focusing on measuring and describing project progress during time-to-market is presented. Second, research on market introduction and diffusion of innovative products is introduced with a specific focus on competition.

There is a high number of papers discussing interrelations of project progress in early life cycle stages, especially during product development. The *Phase-Review Process* is aiming at a standardization of cooperation between suppliers during product development. [19] Thereby, product development is subdivided into discrete sequential phases, each ending with a management review, at which a decision is taken on weather to proceed with the project or to terminate it. [19] This process allows for a structured handling of partially contrary tasks. [19] Nevertheless, the model is not applicable for our approach, since it requires sequential phases and does not allow for parallelization. Also, some phases of time-to-market are neglected (e.g. ramp-up), and no answers can be derived on the amount of resources needed during product development.

The *Stage-Gate Process* has been widely applied and extended in research and industry since its introduction by Cooper (1990). [20] Product development (or other tasks) are subdivided into discrete stages [20], which can be performed sequentially or parallelized. [20] The Stage Gate process shows a high applicability for modeling project progress during time-to-market. [21] Although the ramp-up phase is not considered in the original Stage Gate process, it can easily be added as an individual stage. As the approach consists of discrete stages, it can be modeled in a quantitative way. Most recent modifications of the Stage Gate process integrate customer and user interaction at the stages of the product development process [22], allowing for higher flexibility and agility. [22] However, resources are neither considered in the original Stage Gate process nor in its extensions.

Ulrich et. al. (1995) developed a process model that subdivides product development into the following five phases: concept development, system-level design, detail design, testing and refinement, and production ramp-up. [23] Detailed information is given on the tasks including qualitative indications on needed resources. In addition, the model aims to integrate different stakeholders and follows an interdisciplinary approach to problem solving. [23] While this model covers all relevant life cycle stages (including ramp-up) and provides qualitative insights into resource decisions, it does not quantify the amount of resources needed.

The *Value Proposition Cycle* by Hughes and Chafin (1996) aims to overcome the sequential progress of traditional project management by enabling continuous learning, consensus and identification of important information within project teams. [24] The model consists of four iterative loops in order to capture market value, to develop business value, to derive winning solutions and to apply project and process planning. [24] While the model regards resource input in a qualitative way, quantitative decision support is not considered.

Concluding, none of the discussed project management approaches fulfills our model requirements to derive quantitative decision support on resource demand in the time-to-market phase covering both, product development and production ramp-up, as shown in table 1. Two approaches take qualitative resource input into account, but are not able to quantify the resource demand. However, an extension of the Stage-Gate process seems to be the most promising option as quantitative resource input can be integrated into Stage or Gate definitions.

Table 1. Comparison of project management models.

Criteria	Cooper (1990)	Urban & Hauser	Ulrich et. al.	Hughes & Chafin	Cooper (2014)
Applicability to product development	✓	✓	✓	✓	✓
Resource input considered			✓	✓	
Quantitative decision support	✓	✓			✓

Market diffusion is also regarded in many papers. Thereby, it can be distinguished between aggregated and disaggregated models. [25, 26] While disaggregated diffusion models [e.g. 27] depict individual buying decisions on a detailed level, aggregated diffusion models subdivide customers into several groups in order to distinguish between early adopters (innovators) and late followers (imitators). [26] In the following, we focus on aggregated diffusion models since it is sufficient to model diffusion processes without information on individual buying decisions in our approach.

The most prominent example for an aggregated diffusion model is the *Bass Diffusion Model*. [28] It has been widely applied in marketing research, and numerous extensions, applications and modifications have been conducted. [28] The Bass Model states that the probability of an individual to adopt an innovation has a linear dependency on the number of previous adopters. [29] Cumulated sales predicted by the Bass Model typically show an S-shaped curve over time. [30] The model considers the total market size as well as innovation and imitation effects for modelling market diffusion. Due to the numerous model extensions as well as applications and modifications of the Bass Diffusion Model, we limit our review to models that refer closely to our model requirements (e.g. regarding competition, market entry times and economic evaluation). A review on other relevant research streams for diffusion models can be found in [25] and [28].

Mahajan et. al. (1993) introduce an extension of the original Bass Model to assess the impact of a new competitor that is challenging a former monopolist in an existing market. [31] Competition is modeled between three competing products from two brands since the monopolist offers a new and an old generation of the same product. [31] Market size and market share of each product as well as sales of brands and replacement effects between the product generations are assessed. [31] With regard to our model requirements, the model lacks of various market entry times as the old product is already in the market, and the new products are introduced at the same non-specific point in time.

Krishnan et. al. (2000) regard a situation with a late entrant joining a so far duopoly situation. [32] The authors analyze the effect of the entrant on the brands (e.g. sales and market share) and on the total market. [32] With regard to our requirements, the approach allows for a variable market entry timing of brands. However, competition is limited to three competitors as the approach lacks of a generalization for the late entrant(s). Thus, real world competitive market situations can not be modelled. Additionally, no economic evaluation is carried out.

Savin and Terwiesch (2005) calculate optimal product launch times in a duopoly including life cycle revenues and costs. The effect of product launch time is assessed by sales based on a Bass Model for a duopoly. [33] As can be shown, a Nash equilibrium results for the launching strategy of two competitors with symmetric diffusion parameters. [33] However, the approach lacks of a general formulation for more than two competitors as well as a differentiation between the two competitors for the innovation and imitation parameters. Nevertheless, this approach builds an important basis for our research as it connects costs of the earlier life cycle phases with revenues from expected sales after market diffusion.

Liao and Seifert (2015) propose a model to estimate the optimal frequency for the launch of new generations of one product considering the tradeoff between sales revenues from a Bass Model and product development costs. [34] The approach integrates life cycle costs, especially costs for product development, into the decision of optimal product introduction frequency. However, the approach lacks of the description of a competitive market structure and does not account for competition.

Regarding the presented market diffusion models, none of the approaches models competition for a variable number of competitors including variable market entries and cash flows, as can be seen in table 2. To meet our requirements, it is most promising to combine different solution approaches from the aforementioned literature and to develop an extension of the original Bass Diffusion Model.

Table 2. Comparison of market diffusion models.

Criteria	Bass	Mahajan et. al.	Krishnan et. al.	Savin & Terwiesch	Liao & Seifert
Strategic orientation	✓	✓	✓	✓	✓
Competition		✓			
Various market entry			✓	✓	
Evaluation of cash flows				✓	✓

Concluding, none of the existing project management and market diffusion models covers all aspects of our planning problem. Furthermore, to the best of our knowledge, no integrated approach exists combining project management during time-to-market and market diffusion of an innovative product. Thus, we are the first to propose an integrated decision support system combining project progress in product development and market diffusion for competitive market environments.

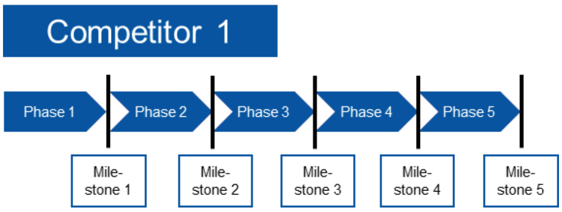

Fig. 1. Example of a milestone model for competitor 1

3. Methodology

In this section, we present an integrated decision support system that considers interdependencies between resource input during time-to-market and market diffusion under competition. First, to model project progress within product development, we use a milestone model based on the Stage Gate process. The market diffusion starts as soon as a company accomplishes the last milestone. Second, to model the market diffusion in a competitive market environment, we apply a modified Bass Diffusion Model.

The milestone model is modeled by a modified Stage Gate approach based on three input parameters: number of milestones for the project, productivity per employee and productivity loss.

Within our modified milestone model based on the Stage Gate process, the tasks of the time-to-market phase, i.e. product development and production ramp-up, are subdivided into a certain number of milestones as shown in figure 1. Milestones are points in time at which a management review is carried out and a decision on weather to proceed with or to exit the product development project is taken. Within our model, we currently assume that each milestone accounts for the same amount of resources needed and thus resembles one of the tasks that have to be carried out during product development and production ramp-up. Therefore, we assume that all milestones require the same resources and the same time effort, and milestones are not yet characterized for specific tasks within the product development or ramp-up process. However, an extension of this basic model regarding specific milestones is aimed at in the next modelling steps.

Achieving a certain milestone depends on the amount of resource input. We measure resource input as number of employees that are working for the project since employees are the most important factor during time-to-market. The milestone process is modeled by a Poisson point process, typically used in queueing theory. Within this theory, the completion time of the whole process is gamma distributed. For our application, the probability value of the gamma distribution depends on two parameters, the productivity of a company and the number of milestones that have to be achieved within the project. Since we implement the milestone model in an iterative way, it is sufficient to calculate the completion time of the very next milestone. That is why we can set the second parameter of the gamma distribution to one. The productivity of a company and thus the probability for achieving a milestone is calculated based on two parameters. First, a productivity value is defined in order to account for the productivity per employee. Also, a productivity loss is specified accounting for decreasing productivity per employee with increasing group size, e.g. due to communication and interaction among employees. [35–38] While all competitors have to accomplish a certain number of milestones, they differ in resource input during time-to-market.

As shown in figure 1, after achieving the preceding milestone a company proceeds to the next milestone. If a company fails to achieve a milestone, it continues to work on this milestone during the next period and the probability to achieve the milestone in the next period increases. The last milestone is defined as market introduction. It depicts the last step of the ramp-up process and determines the time-to-market. Right after accomplishing this last milestone, a company enters the market and starts the sales phase and market diffusion.

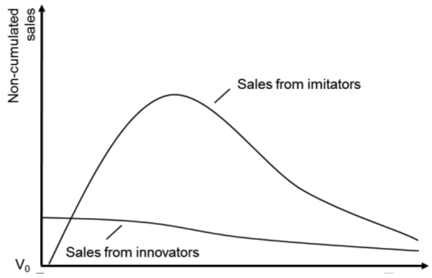

Fig. 2. Typical sales curves of the Bass model for one competitor [30]

The market diffusion is modeled by a modified Bass diffusion approach based on three input parameters: the total market size, the imitation parameter and the innovation parameter.

At the start of the diffusion process, all companies in the market compete for the same market size. After every period, this market size is reduced by the number of products sold within this period. After a certain time, since no further sales are possible the market is saturated. [29] Two customer groups can be differentiated with regard to buying behavior. Innovators tend to buy a product early after the market introduction and decide based on marketing activity, brand recognition or brand loyalty. Thus, their buying behavior does not dependent on the cumulated sales of the product. [29] The innovation parameter describes the share of this costumer group in each period. [29] The imitators buy a product after the first innovators have adopted the product. They take their decision based on word of mouth and observing the product in the market. [29] Figure 2 shows typical curves of non-cumulated sales over time for innovators and imitators.

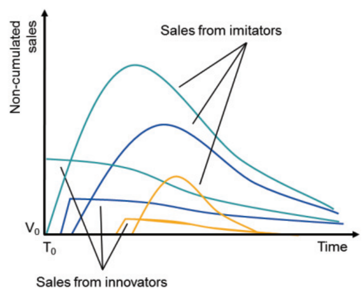

Fig. 3. Typical sales curves of the Bass model for three competitors

In the following, we describe extensions and assumptions to the original Bass model that are necessary in order to fulfil our model requirements. First, we assume a homogeneous market without cross-brand influences. Thus, products of the different competitors are interchangeable. Therefore, all competitors are competing for the same market. [28] Due to the interchangeability of products, the imitation parameter is set equal for all competitors in the market. [28] Second, we assume that companies differ with regard to brand loyalty, recognition, marketing activities and previous market share. Thus, innovation parameters are specifically determined for every company. We derive the innovation parameter from the current market share assuming that a high market share corresponds to a high brand recognition. Third, we assume that the competing products enter the market at different points in time, since the market entry time depends on the completion of the last milestone of the whole process as described in the Stage Gate model. This implies that the available market size for a product depends on the market entry time as sales from competitors that entered the market earlier in time may have already reduced the overall market. Figure 3 shows curves of non-cumulated sales for three brands in a competitive market situation with different market entry times.

Concluding, the combination of all individual diffusion processes determines the development of the market. It allows for an estimation of the non-cumulated as well as cumulated sales for every company starting at time-to-market.

Based on this data and through a Net Present Value (NPV) approach, an economic evaluation of the resource input decision is carried out. The NPV approach discounts all future cash flows to present time. [39]

In order to derive the NPV, we introduce three parameters: a parameter to estimate full costs per employee during time-to-market, a parameter to estimate profit during market diffusion and the interest rate for discounting.

The parameter full costs per employee accounts for the costs per period that occur within the time-to-market phase and includes wages, costs for prototypes, equipment, administration and other tasks needed during product development and ramp-up. Total costs for the time-to-market phase are calculated as number of employees per period multiplied by the full cost parameter, and are then discounted by the interest rate. The profit parameter is derived as balance of turnover and costs per product sold during the market diffusion phase. The total profit is calculated by multiplying non-cumulated sales of each period with this profit parameter. The total profit is again discounted using the interest rate. The sum of the discounted cash flows reveals the NPV of the complete product project covering the time-to-market phase and the market diffusion.

Concluding, we have developed a model consisting of three sub models to combine project management and market diffusion. The model structure for one company is shown in figure 4. The structure is the same for all competitors in the market and is applied simultaneously.

4. Case Study

In this section, we apply the previously proposed model to a case study of the gas turbine industry. The case study is based on a dataset derived from literature as well as from expert interviews.

The gas turbine industry currently gains global importance since power generation using natural gas (instead of coal or oil) saves greenhouse gas emissions and thus helps to fulfill international treaties against climate change. [40, 41] Thus, a lot of new natural gas fields are currently exploited especially in the United States. [40, 42]

The gas turbine industry is characterized by several characteristics. First, it exhibits strong market barriers for new competitors because of a high technology orientation and very high research and development costs of about 300 million Euro per gas turbine. Second, gas turbines have long learning cycles in the field of about 8 years, during which the gas

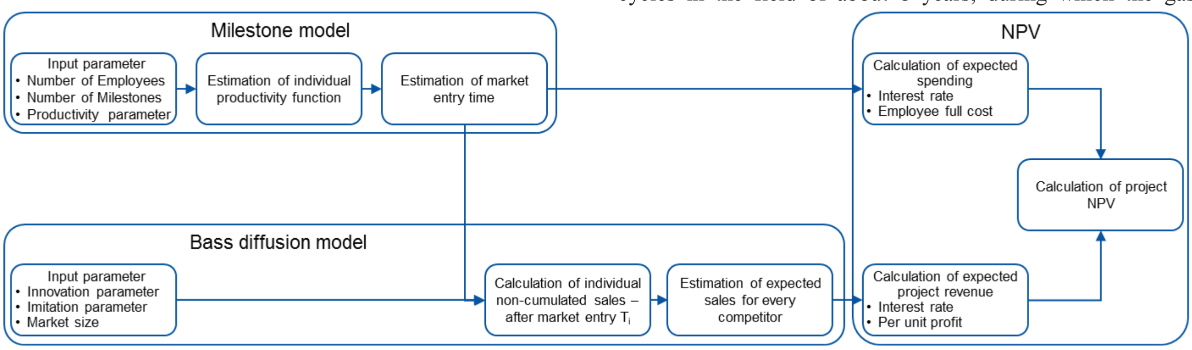

Fig. 4. Model structure of the combined Bass diffusion and milestone model

turbine manufacturer supports and improves the gas turbine continuously. Third, a gas turbine is offered and sold over a period of about 25-30 years. Forth, product variety is a challenge as new generations of gas turbines are introduced into the market every 7-9 years.

Although there are minor variations in national legislation, we chose to model the gas turbine market as a global market. There are currently four brands that cover 87% of total market of the gas turbine industry. The market leader is General Electric (USA) followed by Siemens (Germany) and Mitsubishi (Japan). Alstom (France) is fourth, but was merged with General Electric recently. The market shares of the four relevant brands are shown in table 3.

Table 3. Relevant brands in the global Gas Turbine Industry

Brand	Market share [43]
General Electric	39%
Siemens	28%
Mitsubishi	16%
Alstom	4%

We derive the input parameters for our model from recent literature as well as from expert interviews. According to industry forecasts and our experts' statements, we determine a market size of 2,500 gas turbines for a single power class over the medium life cycle of a gas turbine. [44] Ten milestones are assumed to be achieved during the time-to-market phase. The maximal accepted spread between planned and achieved time and cost targets is limited to 20% according to experts of the gas turbine industry. An average productivity coefficient of 0.0053 is derived from the annual report of the companies in the gas turbine market based on expenditures for R&D, current research projects to be carried out, previous time-to-market as well as full costs per employee in the time-to-market phase. We assume this coefficient to be equal for all competitors. According to studies, employees loose about 20% of their in individual productivity due to group effects, bad management or communication effort. [45] Therefore, the productivity loss parameter is set to 0.000106.

For the market diffusion part of our model, we derive the following parameters. The imitation parameter is set to 0.005 based on a meta study from Sultan et. al. [46] and the experts' estimations. We estimate the innovation parameter for every company based on the market share which holds as an indicator for brand recognition. Table 4 shows the innovation parameters for all competitors.

Table 4. Innovation coefficients

Brand	Innovation coefficient
General Electric	0.0007
Siemens	0.0005
Mitsubishi	0.0003
Alstom	0.00007

To conduct the monetary evaluation through the NPV approach, we set the interest rate to 15%, the average profit per unit without expenditures during time-to-market to 3,000,000€, and full costs per employee in the time-to-market phase to 160,000€ per year. All these parameters are based on experts' statements. We limit the range of possible resource input for the time-to-market phase to {270,272,…,498,500} employees as there are no profits expected for less employees due to the productivity function. The simulation time is set to 8,000 days (i.e. 32 years regarding 250 working days a year). All model parameters are summed up in table 5.

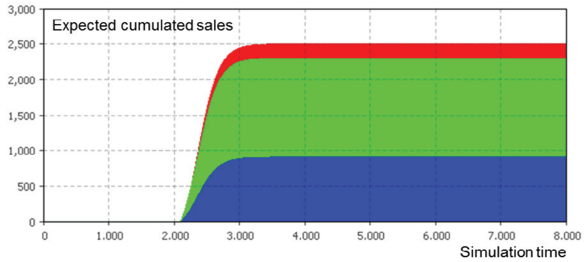

Fig. 5. Expected market shares for the gas turbine industry after simulation

Table 5. Simulation parameter equal for all competitors

Parameter	Value
Imitation coefficient	0.005
Market size	2,500
Number of milestones	10
Productivity coefficient	0.0053
Productivity loss parameter	0.00106
Interest rate	15%
Profit	3,000,000€ per unit
Full costs per employee	160,000€ per year
Range for resource input	{270,272,…,498,500} employees
Simulation time	8,000 days

5. Results

The model was implemented in AnyLogic 7.2.0 as described in section 3. For deriving specific model results, we take the perspective of Siemens and evaluate the optimal resource decision based on the NPV regarding the performance of the competitors. To do so, we increase resource input in steps of two employees within the defined simulation range. Since our simulation includes random effects in the milestone part of the model, we simulate 50 iterations per parameter step.

In the following, we present results and discuss the validation of our model. Furthermore, we derive some general results and managerial insights regarding interdependencies between resource input, time-to-market and market diffusion.

First, we present the model results for the whole market

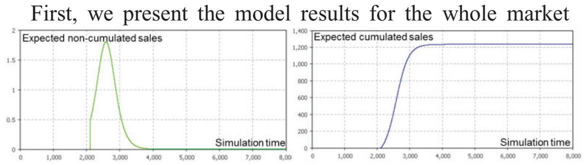

Fig. 6. Expected sales for Siemens after the simulation

and specific results for Siemens. The average market shares after the simulation run are shown in figure 5. As shown, General Electric (green) and Siemens (blue) can strengthen their market position and shift their market shares to approx. 48% and 31% respectively. The market share of Mitsubishi (red) decreases to 7% at the end of the simulation runs. Alstom exits the market. Siemens' optimal resource input is estimated to an average of about 370 employees in product development and ramp-up leading to average costs of about 280 million Euro, and an average expected project NPV of 68 million Euro per developed gas turbine. The average market entry time is estimated to be about 2,200 days or 8.5 years. The non-cumulated and cumulated sales of Siemens are depicted in figure 6.

Second, based on these results, we validate the proposed model in a qualitative and quantitative way. Qualitatively, the sales curves match those of the Bass diffusion processes. In addition, the sales curves follow the expectations of our experts in the sense that these proposed few innovators and many imitators as customers. Quantitatively, our results show a high congruence with the experts' estimations and literature. For instance, the calculated time-to-market of 8.5 years resembles the experts' estimation of 8.4 years. Additionally, project costs of 280 million Euro calculated by our model fit the experts' estimations of about 300 million Euro. Furthermore, the market structure fits market projections of experts and literature, as e.g. the future market share of GE is

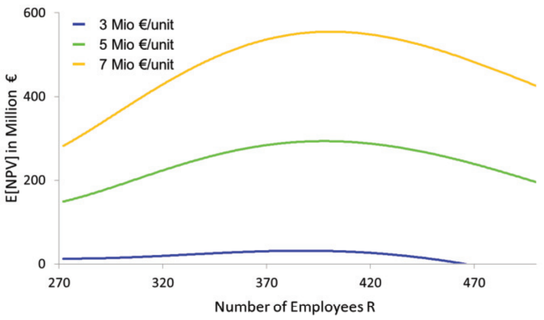

Fig. 7. Effects of changes in resource input and per unit profit on expected NPV

projected with 47% by [44]. Thus, our model shows a high accuracy of forecasting the gas turbine market.

Third, we derive some general results from the simulation in order to evaluate the impact of resource decisions during time-to-market on the market diffusion of a new product. Therefore, we analyze the interdependencies between resource input, time-to-market and market diffusion. In order to do so, we compute fixed resource inputs within our simulation range increasing these in steps of two employees per parameter step. This results in a (smoothed) curve combining resource input and average expected project NPV for Siemens that shows a digressive character (see fig. 7; blue curve). Thus, we can assume that there is an optimal resource input located at the maximum of this curve.

Per unit profit excluding expenditures during time-to-market can usually not be estimated precisely in advance. Therefore, we evaluate the effect of different per unit profits on the optimal resource input and the expected project NPV. As can be seen in figure 7 there is a strong connection between project NPV and both resource input and per unit profit. Thus, we can constitute an interdependency between resource input, time-to-market and market diffusion effecting project profit.

Specifically, our model can be applied to derive managerial insights for project planning. For instance, the model allows for an estimation of costs and lost sales if delays occur during product development (e.g. problems with the supplier or the technology). Also, decision support can be derived regarding allocation of limited resources (e.g. budget or workforce) to several product development projects. Furthermore, the model supports decisions regarding the selection of the most profitable product development project in advance taking competition into account.

6. Conclusion and Outlook

By extending existing approaches, we develop an integrated model combining project management and market diffusion. Thus, we are able to derive insights into interdependencies between resource input, time-to-market and market success of products. We apply the model on the gas turbine market. We found out that our model achieves a good consensus with data from literature as well as with experts' expectations. Thus, the model can be regarded to be valid. Using the model, managers get a decision support for resource allocation decisions during early stages of the product life cycle. Additionally, the model allows for an estimation of costs and lost sales due to delays in product development and market introduction. Also, allocation decisions in budget and workforce are supported if a company is involved in several different product development projects.

The proposed model represents a first step to combine time-to-market, namely project management and ramp-up, and market diffusion. However, there is potential to extend the proposed model in order to integrate more realistic aspects.

First, the basic milestone model can be extended considering specific requirements of tasks with regard to resources and time. Second, the milestone model should be compared to more recent approaches in project management. Although project management today usually follows the original Stage Gate Process, new concepts for project management have been developed recently. [e.g. 22] Those approaches integrate flexibility and agility into product development and ramp-up as well as feedback of customers and users. Against this background, our Stage Gate milestone model could be replaced by a more agile project management approach.

Regarding competition, the model is currently based on several assumptions. These assumptions need either to be validated or the model must be extended to real life constraints. For instance, the imitation parameter is currently set equal for all competitors. The underlying assumptions, i.e. that products are interchangeable and that no cross-brand influences occur, need to be validated for each application of the proposed model as these effects might vary within different sectors. Also, we assume that all competitors start their product development project at the same time. Since this is rarely the case in reality, the model should be extended in order to model competitors with differing or random start times of their product development.

Ramp-up is seen as a crucial phase between product development and series production. Thus, problems during ramp-up, e.g. delays and lagging learning curves, can have a strong effect on the duration of the time-to-market phase, and thus on the market diffusion of a product. Hence, the project management part of the proposed model could be extended with a stronger focus on ramp-up.

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