An Exploratory System Dynamics Model of Strategic Manufacturing Capabilities

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Abstract

This paper investigates the dynamics of accumulation processes of strategic capabilities in manufacturing, i.e. cost, quality, delivery and flexibility. The analysis is conducted with the help of an exploratory system dynamics model that represents a hierarchy of these accumulative capabilities. By applying a dynamic view, concepts from the operations management literature are tested and shortcomings are identified. In a further step, the exploratory model is parameterized with empirical data from a large international survey of manufacturing plants. Implications concern the distribution of managerial attention on the different capabilities and its dynamic consequences. The value of this paper lies in the insights gained by the transformation of a verbal model in a quantified simulation model and the learning resulting from simulation experiments.

Keywords: manufacturing, strategic capabilities, simulation, system dynamics, accumulation

Whether, how and which internal strengths of companies can be translated into success factors at the market place is one of business administration's most central issues. In the field of operations and production management there is some agreement that the role that manufacturing can play in generating potential success factors is primarily dependent on the strategic capabilities it possesses. These capabilities are responsible for offering products and services that are consonant with the company's corporate strategy and that—when translated into competitive factors—influence the company's success. However, how such strategic capabilities are related to each other (and to a firm's performance) and which dynamic consequences result from these relationships is still a matter of debate.

This paper tries to shed some light on the last question. Therefore, in the first section the concept of strategic capabilities is reviewed and different conceptualizations concerning their relationships are presented. In the second section, a system dynamics model is introduced that has proven to be helpful in further exploring the dynamics of strategic capabilities. This section also includes a methodological discussion on the validity of exploratory system dynamics models. In the third section, results derived from the modelling process and from simulation experiments are discussed. The paper closes with a discussion and a summary of results and some points for further research.

Perspectives on manufacturing capabilities

In a manufacturing management view, strategic capabilities are a plant's contribution to a company's success factors in competition, i.e. the strengths of a plant with which it wants to support corporate strategy and which help to succeed in the market place. The development, nurturing and (arbitrary) abandoning of strategic capabilities are a major task of manufacturing strategy. Often this task is in conflict with day-to-day solving of problems and fire-fighting activities of operations management (Trought, 1994; St. John and Young, 1993; March and Simon, 1958).

Going back to one of the most prominent writers in the field, mostly four strategic capabilities are identified in operations and manufacturing: The ability to produce (1) with low cost, (2) in high quality, (3) with reliable delivery and (4) with flexibility concerning mix and volume of products (Wheelwright, 1984). Although other capabilities are discussed occasionally, e.g. innovativeness or environmental soundness, and might be relevant in specific cases, the four capabilities *cost*, *quality*, *delivery* and *flexibility* are seen to be of general importance (Ward et al., 1998; Ward et al., 1996; Swink and Way, 1995). Therefore, this paper as most other articles in this area concentrate on these four capabilities.[i]

The concept of strategic capabilities that determine a manufacturing's contribution to the success of a firm is closely related to the notions of strategic resources, competences and priorities.[ii] From the so-called resource based view of the firm, the discussion in this paper benefits insofar as it is a major assumption of this study that the primary determinant of success is the bundle of resources and capabilities that characterizes an organisation (Wernerfelt, 1984; Penrose, 1959; Selznick, 1957). In difference to capabilities, resources are something a firm possesses or has access to, not what a firm is able to do. Resources can be tangible, e.g. specialized production systems, and intangible, e.g. level of training of workers (Hall, 1992; Hall, 1991). Based on such resources, capabilities are developed. For instance, flexible production systems in combination with highly skilled workers (= resources) allow to produce in a flexible way (= capability). Capabilities allow an enterprise to develop and to exploit resources in order to generate profit through its products and services (Amit and Schoemaker, 1993). With the help of an organisation's capabilities, resources are transformed (literally or metaphorically) into products and services (Warren, 2002).

Although a distinction is sometimes made in the literature (e.g., Koufteros et al., 2002), in this paper 'competences' are supposed to be a synonym for 'capabilities'. 'Priorities' are intended capabilities (Roth and van der Velde, 1991; Wood et al., 1990). In other words, priorities are capabilities that operations management wants to have in the future or capabilities on which emphasis in the future should be put on. In contrast to this, capabilities are not of prospective character; they are actually and currently available to the firm. Priorities are the results of an explicit strategy process in manufacturing; capabilities are the result of deliberate, but also of emergent decisions and policies in the field of manufacturing strategy (Mintzberg and Waters, 1985). The relationship between intended and realized manufacturing strategy and its influence on performance of companies is further discussed in Devarja et al. (2004).

Furthermore, in common uses of the term 'priorities', results (i.e., performance) and the measures in order to achieve these results (i.e., capabilities) are frequently mixed and not differentiated (Swink and Hegarty, 1998). However, to a certain degree this is also the case for strategic capabilities as defined in this paper because they inherently possess a dyadic nature: on the one hand—and as the term ‘capability’ implies—they are firms’ sets of routines to achieve specific strategic objectives, for instance, to produce with low cost. On the other hand, naturally the achievements towards these objectives can be measured as performance scores as, for example, the level of low cost manufacturing measures the performance of a firm regarding its cost capability.[iii] In this example, ‘cost’ symbolizes the set of routines used to produce with low cost (i.e., the capability in a narrower sense of the word) as well as a performance score that represents how far the capability is developed (cf. also De Toni and Tonchia, 2001). Terminologically, this ambiguity can be somehow circumvented when the meaning of ‘capability’ is restricted to a more disaggregated view of capabilities (Slack and Lewis, 2002). For instance, when ‘working with low overhead cost’ and ‘high manufacturing productivity’ are seen as capabilities that result in an aggregated performance score named ‘cost’ (but not in an aggregated cost capability). This paper does not follow this route; the dyadic nature of capabilities is accepted in a way that they represent mechanisms of resource exploitation, which is measured by a performance score.

Although strategic capabilities in manufacturing are crucial in order to allow a company to compete successfully, they are by no means sufficient. For example, a firm which is capable to produce its goods with very little cost, will not necessarily be successful: if the price of a product is just a qualifier in competition—but not an order-winner—other firms can easily achieve better results by concentrating on alternative competitive factors, like functionality of product or promotional activities (Hill, 2000). Thus, there is a bi-directional relationship between manufacturing’s strategic capabilities, which are internally focused, and the marketing strategy of a company, which has an external perspective. On the one side, strategic capabilities should reflect requirements posed by the marketing strategy of a company. In this view, manufacturing strategy acts as a dependent function of marketing. On the other side, manufacturing strategy should either be supportive towards the marketing goals of the firm or even offer new strategic possibilities (Wheelwright and Bowen, 1996). An example for this would be the manufacturing capability to produce with zero set-up time which would allow for fast deliveries and high product mix flexibility. On the basis of this capability, the marketing strategy could emphasize product variety as a competitive factor within a given market.[iv]

There exists a transformation and reconciliation process (Slack and Lewis, 2002) between manufacturing strategy (with its capabilities *quality*, *delivery*, *cost* and *flexibility*) and marketing strategy of a firm (consisting of decisions about price, product features, place of competition and promotional activities; Kotler and Armstrong, 1991). With the bi-directional exchange process in place, manufacturing strategy becomes a competitive force that not only supports a given marketing strategy, but also re-designs it by offering innovative strategic chances.[v] Thus, manufacturing evolves from a “corporate millstone” to a “formidable competitive weapon” as Skinner (1985) describes it.

It is quite clear that in a world without constraints all strategic capabilities should be improved indefinitely because this would offer many possible alternatives for a firm to compete. However, resources are constrained and management always is decision-making under the regime of finite resources (St. John and Young, 1992). Thus, not all capabilities can be maximized. Therefore, manufacturing management has to focus financial and other resources (e.g., management's attention) on some of the capabilities. Not all capabilities can be supported with an arbitrary level of resources. Additionally, some capabilities might be negatively coupled to each other: the improvement in one might hamper improvements in another, trade-offs might exist. The question is of which nature, strength and direction are these trade-offs and what dynamic consequences result from these trade-offs?

So far there is no widely accepted theory about the kind of relationship among strategic capabilities. When reviewing the publications in that field three concepts emerge: the trade-off perspective, the "world class manufacturing" view, and accumulative models.

The classical trade-off school argues that one manufacturing capability can only be improved at the expense of other capabilities (Skinner, 1974; Skinner, 1969), at least when the firm works close to its efficiency border, i.e. no organizational slack exists (Porter, 1996). For instance, producing on a lower cost level would only be possible with a simultaneous decrease in quality. The rationale behind the trade-off argumentation is that a manufacturing plant that is supposed to provide a high level of performance in all of the relevant capabilities suffers from a high level of complexity in its goal system, generating a great deal of confusion, contradiction and misdirection of resources (Skinner, 1985).

Contrasting to this concept, some authors take the viewpoint that no trade-offs exist at all between different capabilities. Modern manufacturing systems do allow for parallel improvements in more than one manufacturing capability simultaneously (Boyer and Lewis, 2002). This would be the reason that the best performing manufacturing plants exhibit improvements in all strategically relevant capabilities ("world class manufacturing"; Schonberger, 1986). However, this assumption has been questioned since empirical evidence indicates that the underlying causes for trade-off relationships still do exist but only their amplitude has decreased due to technological and organizational improvements (New, 1992).

Frequently, it has been discussed that "middle courses" between the extreme positions of absolute or no trade-offs must exist, meaning that neither the strict trade-off perspective nor the "everything at once" approach is a valid conceptualization of the development of manufacturing capabilities. Schmenner and Swink (1998) postulate that in such middle courses both perspectives from above can be valid simultaneously and do not contradict each other. Thus, it is possible that improving in certain capabilities can amplify certain other capabilities, while other capabilities are in a trade-off relationship.[vi] In particular, quality improvements are found to be simultaneously supportive to improvements in cost performance (Ferdows and De Meyer, 1990; Skinner, 1986).[vii]

The way in which manufacturing capabilities relate to each other plays a major role when crafting manufacturing strategies and designing programs to improve performance of manufacturing systems. Because of supportive relationships between some capabilities, it can be assumed that certain patterns of capability development are more common among organizations: such capability patterns that follow a supportive route are simpler to achieve and, ceteris paribus, more successful than other trajectories because they allow a higher level in capability performance applying a constant effort, compared to other ways of capability improvement. Therefore, the capability trajectories that firms followed can also be understood as generic patterns of manufacturing strategy (cf. Miller and Roth, 1994; Kotha and Orne, 1989). Considering the importance of the 'law of cumulative capabilities', it is rather surprising that only little empirical research or modelling studies have been conducted to deepen the understanding of those relationships (Mapes et al., 1997; Noble, 1995).

This paper assumes a mixed nature of the relationships of strategic capabilities (see Figure 1). Thus, it is hypothesized that there are supportive relationships and inhibiting relationships between capabilities. The Y-form of strategic capabilities is derived from an empirical examination of capabilities within manufacturing plants. In that study, 465 manufacturing plants from 14 countries were investigated with the help of the IMSS questionnaire (International Manufacturing Strategy Survey; Laugen et al., 2005). The Y-form of strategic capabilities was tested applying a structural equation model (Grübner and Größler, 2004).

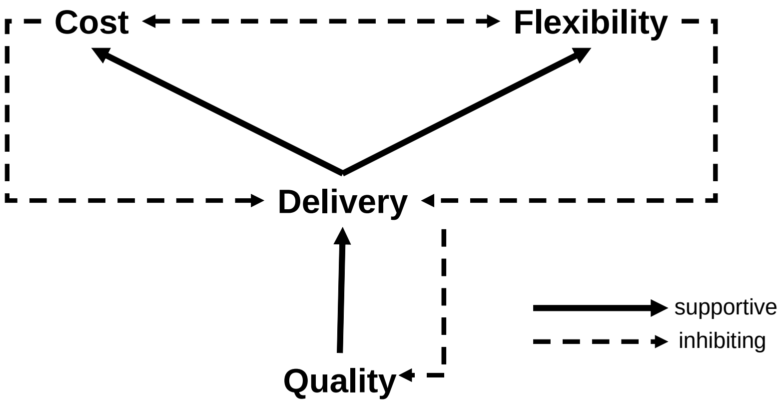

Figure 1: Conceptual model of strategic resource hierarchy

The sequence of capabilities proposed in this paper is in line with the literature as far as most authors agree: in particular, the lower levels (first 'quality' and second 'delivery') are widely seen as the fundament for an accumulation of capabilities. However, because the literature is rather indefinite concerning higher levels, 'flexibility' and 'cost' are put on one level and it is assumed that an trade-off relationship rather than a supportive relationship exists between the two (Anand and Ward, 2004).[viii] Strategic capabilities that are not discussed by the majority of authors are consequentially not included into this model, for instance 'innovation' or 'waste reduction'. Also in line with the ideas prevalent in the literature, there are only direct supportive links between "adjacent" capabilities (e.g., from quality to delivery capabilities); between capabilities that are not directly adjacent in a layered model, only indirect supportive links exist (e.g., from quality to cost capabilities).

A dynamic model of strategic capabilities

The conceptual model outlined above can rather easily be translated into a system dynamics stock-and-flow model (Forrester, 1961; Forrester, 1968). Identification of stocks and flows is straight-forward because in the operations management literature capabilities are described as accumulating entities. Thus, a strategic capability can be modelled as in Figure 2: strategic capabilities are modelled as stocks that are increased by management putting attention and resources on them (Ferdows and De Meyer, 1990); they are continuously decreased over time through attrition or arbitrary neglect.

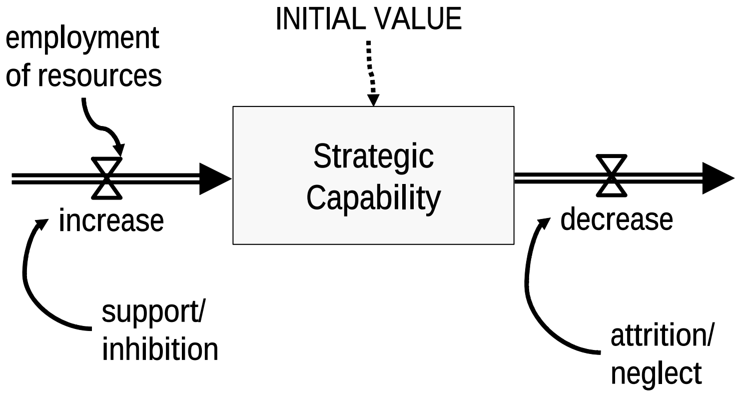

Figure 2: Strategic capabilities as level variables

Supportive or inhibiting linkages between a capability A and a capability B are caused by the level of capability A, compared to this of capability B (Ferdows and De Meyer, 1990). These linkages influence the effect size that management's resources have on the growth of a capability. The total structure of strategic capabilities as depicted in Figure 1 is translated into a system dynamics model, which is shown in Figure 3.

The basic model structure follows the conceptual model outlined above: *quality* on the first tier, *delivery* on the second, and *cost* and *flexibility* in a trade-off relationship on the third tier. Capabilities are increased by effort which is put in their development by management. How effective any effort put into a capability is, depends on a comparison between capability stocks and one or more functions that translate this comparison into a supporting or an inhibiting factor. Let us consider *delivery* and *cost* as examples: *delivery* supports the development of *cost*, meaning that whenever *delivery* is greater than *cost*, any effort put on *cost* is effective and amplified by the favourite relationship between the two. However, if *cost* is greater than *delivery*, the basis for further improvements in *cost* is missing, meaning that any effort put into this capability is dampened and not effective. *Delivery* is affected by *cost* only, when the level of the *cost* capability is greater than that of *delivery*: with many *cost* capability measures in place, *delivery* can hardly be improved effectively. Between *cost* and *flexibility* only a trade-off or inhibiting relationship exists: improvements in one of the two, inhibits further improvements in the other.

Functional relationships between capabilities are modelled as table functions. Their concrete appearance can be altered easily. In the first simulation runs reported, equality between levels of two capabilities results in neutral behaviour. At this point of neutral behaviour, efforts put into capabilities are neither amplified nor inhibited. There is no general argument in favour of this specific tipping point and, indeed, Ferdows and De Meyer (1990) argue for different tipping points on the different tiers. In later parts of this paper, the values of the different tipping points as well as the strength of support and inhibition between capabilities are quantified with data from the IMSS empirical study (see above).

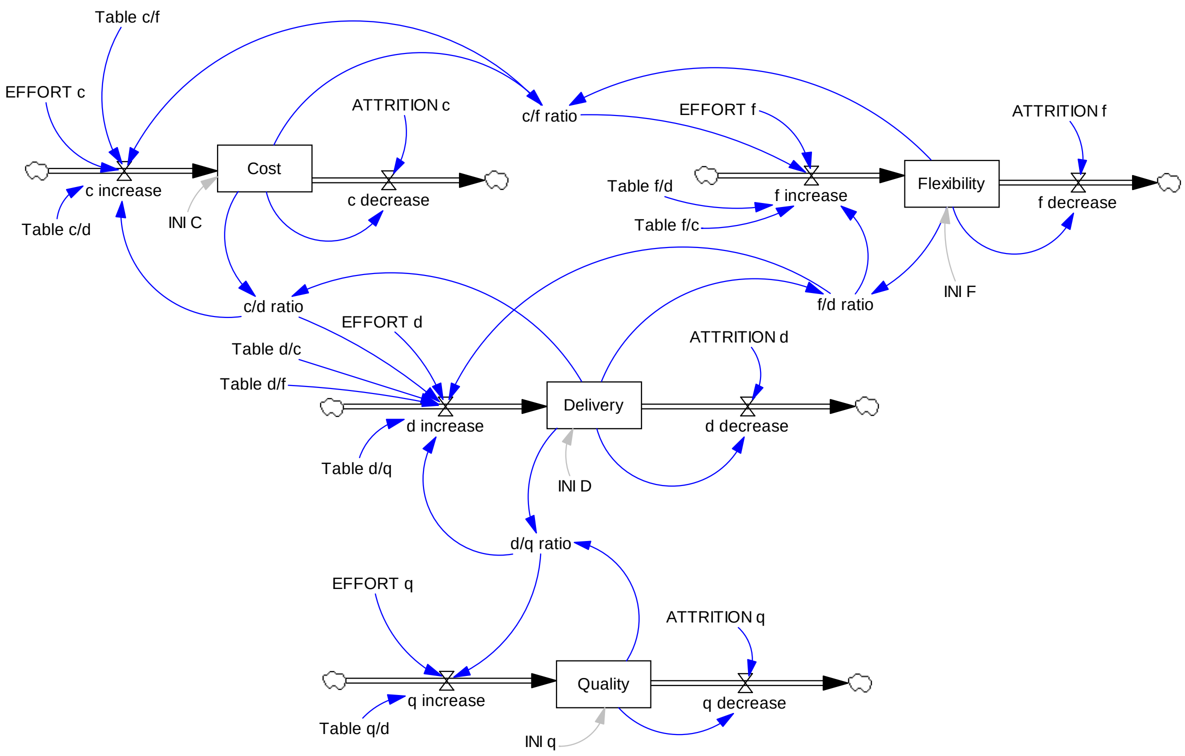

Figure 3: Exploratory system dynamics model of strategic capability hierarchy[ix]

The units of the model are abstract index points. Although this does not allow for interpretation of absolute values, it does make it possible to compare variables with each other, to study their behaviour over time, and to compare different scenarios. All stocks have an initial value of one capability point (an assumption that is altered in later parts of this paper). Total effort that can be used to increase capabilities is four resource points, i.e. in the base run effort for each capability is one resource point per simulation interval, which is also varied in the course of the following simulation experiments. Total effort is limited because otherwise all capabilities could be increased arbitrarily which is not the case under the realistic assumptions of limited resources that a firm can access. In principle, the model units 'resource points' and 'capability points' are equivalent, i.e. one resource point results in one capability point. However, the actual effect size of one resource point on a capability's increase is moderated by the supporting/inhibiting factors from other capabilities (as described above).

In the simulation model, no autonomous or unintended development of capabilities takes place; only when deliberate effort is put into them, they can be increased. Also, capabilities cannot be developed just by increasing the level of other, supportive capabilities: management attention must be directed to a capability that is to be increased.[x] Attrition of capabilities is a constant fraction of the level and set to 1 %

for each capability. Without attrition capabilities could grow forever; capability attrition causes asymptotic behaviour, reflecting limits to growth in a finite world. Model behaviour has proven to be insensitive to the 1 % assumption; other values—as long as they are the same for every capability—do not lead to principally different simulation results as the ones reported in the following.

In order to compare simulation runs a *total performance* score is calculated by adding the values of the four capability stocks, assuming that manufacturing's capabilities support the market strategy and objectives of the company (Vickery et al., 1993; Devaraj et al., 2004). Note that such a performance measure can only be used to compare different scenarios, and thus, the performance of manufacturing functions of manufacturing companies. It is by no means a measure to express the performance of a company in the market place. In order to do this, the different capabilities would need to be translated into competitive factors (e.g., cost into price) and these compared to competitors' performance and customers' demands. Only in this way it could be secured that firms did not experience, for instance, the so-called "productivity paradox" (Skinner, 1986). Furthermore, the *total performance* score does not incorporate the notion of diminishing returns, thus rewarding putting effort into 'lower' capabilities (e.g. *quality*) without any limitations.

The objective of the model in this version is to build a dynamic instance of the conceptual model of cumulative capabilities as depicted in Figure 1. Right now, parameterization is arbitrary and simple. In later stages of model development this will be changed in a way that parameter gained in empirical studies can be used to control supportive and inhibiting functionality. Main goals for the following simulation runs are to mimic behaviour as indicated by the theory and to test different management policies for distributing effort (resources) to the capabilities.

Internal validity of the model is satisfactory. It produces replicable outcomes. Results from extreme conditioning tests and sensitivity analyses show consistent and robust model behaviour: parameter variations over a wide range produce comparable simulation results. Concerning external validity one has to keep in mind the aim for which the model was built. The objective for building the system dynamics model was not to represent a real-world problem or to reproduce behaviour in a numerically exact way that can be compared to real values. Rather, a dynamic model of a conceptual theory was to be built. In my view, the model is useful (and therefore valid) for this purpose (Oreskes et al., 1994).

From a methodological point of view, this article also tackles one of the still pertinent issues in system dynamics: "when to map and when to model" (Richardson, 1996, 150). The conceptual model as depicted in Figure 1 is similar to a causal diagram (even though links are not interpreted in a strict causal way, rather as functional, supportive relationships). Can a system dynamics model by means of quantification and simulation add any new insights to what can be achieved with this kind of model? And is developing and simulating a quantified model therefore useful and should be ventured?[xi] While the earlier literature in system dynamics mostly is quite definite on this point (namely that system dynamics always includes simulating quantified models; Forrester 1961), some doubts have been explicated during the last decades (Wolstenholme, 1999; Wolstenholme and Coyle, 1983). Mostly, proponents of qualitative modelling do not deny that deriving behaviour from a complex model based on human cognitive skills alone is virtually impossible (Dörner, 1996; Forrester, 1994; Richardson and Pugh, 1983); their claim is that mapping of system structures *per se* (i.e. without succeeding simulation) has value. In some cases, their argument continues, it is even preferable to quantification and simulation because—when empirical data is lacking or spurious—simulation results might be totally distracting or plainly wrong (Coyle, 2000). While proponents of a more simulation-focused approach do not doubt the usefulness of mapping itself they hardly see reasons to omit simulations as long as resources permit it because it always adds further knowledge about the system that is studied (Homer and Oliva, 2001).

Although this paper is more in line with the latter perspective (considering simulation as *quasi* always possible and useful), it appears rather obvious that validating exploratory simulation models is a crucial but difficult endeavour. When simulations are run that are based on theories not on real situations, one critical validation step is only possible in a limited way: behaviour validation (Barlas, 1996). Even when we accept that structural validation is more important in system dynamics anyway, the impossibility to compare historical and simulated behaviour means that one of the most intuitive arguments for the usefulness of a simulation model is not available. Furthermore, the missing chance to validate the model against real-world behaviour raises the difficulties and the rigour necessary for the rest of the validation process.

But, what is the use of exploratory simulation models if direct comparisons with and transfer to real-world systems is neither possible nor intended? I want to demonstrate that simulation has—nevertheless—the following advantages:

- More than causal-loop diagrams and other tools from qualitative modelling, a fully quantified simulation model demands that underlying assumptions about relations between variables are made explicit, i.e. simulation improves the clarity and the depth of a model.
- Possible behaviour modes of the model can be generated by simulation which helps to gain insights into the dynamic consequences of the assumed (cause-effect) relationships (Lane [2000, 17] names this a paradox: "the results of a quantitative system dynamics study are qualitative insights").
- Analyses of simulation results offer an additional way to detect inconsistencies in the model.
- By use of techniques such as optimization, units check, sensitivity analysis, etc. further confidence in the validity of the model can be gained and critical parameter settings can be identified, thus allowing for additional empirical research or refined estimation.

In my view, these advantages justify the usage of exploratory simulation models. In the light of the ongoing discussion described above, this paper supports the second view, which is that simulation adds value in most cases. However, the possible dangers of exploratory models of theories should have been made clear as well. First, validation is more difficult and second, the transfer to the behaviour of real-world systems can only be made in principle: the behaviour of any specific, real system will most probably deviate from the behaviour of an exploratory simulation model.

Methodologically, the value of exploratory simulation models lies in the area of developing and scrutinizing theories. System dynamics provides a structural theory of social systems (Lane, 2000). This structural framework can be used to explore and test content theories of social systems. For example, in this paper the theory of cumulative capabilities is tested from a dynamical perspective and possible amendments to the theory are explored. However, in contrast to more "conventional" applications of system dynamics, the model presented here does not incorporate causal relationships between objects from a content perspective nor does it aim at identifying such causalities. Rather, it takes functional relationships between the capabilities for granted and examines the results that originate from these relationships as dynamic consequences.

Results of modelling and simulation experiments

While transforming a conceptual or verbal model into an exploratory simulation model, shortcomings, over-simplifications and blind-spots of the original models become obvious. It is one of the major advantages of building formal models that they are necessarily more precise and comprehensive than verbal or conceptual models. By this feature, not only the model itself but the complete process of building it becomes important in promoting understanding of complex systems (Lane, 1995). Some of the blind-spots of conventional theory of strategic capabilities, and the insights gained by model building, led to model assumptions, which were presented above. Some open issues are discussed in the following because they were not included in the model, in order to keep it as much according to conventional wisdom in the operations management literature as possible.

For instance, the original 'law of cumulative capabilities' does not imply relationships between capabilities that are not adjacent. From a system dynamics point of view this appears a bit awkward: why should not a direct influence exist between quality and cost? The causal perspective in system dynamics modelling implies such direct linkages between capabilities that are "further away" from each other. The literature in the operations management field does not discuss such indirect effects. Thus, they are also omitted in the simulation model presented in this paper. Nevertheless, this might be an issue where operations management theory could be improved by insights from model development.

Another issue, which is at least only partially discussed in conventional studies, is the nature of inhibition between capabilities. It is quite clear from the literature that capabilities can be supportive when they are developed in the right sequence. How the other direction functions, however, is only rarely discussed. Does a non-supportive function always result in an inhibiting or trade-off relationship, as implied by most authors in operations management (and as modelled in the system dynamics model shown in Figure 3)? Or, can this also result in neutral behaviour, such that for instance 'delivery' does not affect 'quality' at all?

In addition to these two points, system dynamics usually considers delays and information distortion. Both are not discussed in the operations management literature and not included into the model. Nevertheless, that they exist in the real process of capability development seem quite reasonable. For modelling purposes, empirical measurement of such delays would be beneficial: presumably, different delays between the capabilities would result in amplified changes and oscillations.

As a basic behaviour mode can be stated that the level of the capabilities can never sink below zero because they are initialized positively, *increase* is always greater than or equal to zero (dependent on *effort*) and *decrease* is always a fraction of what is in the level. Figure 4 shows the level of the four capabilities for four different scenarios. In lines 1 in this figure, the base run of the model is depicted which is initialized with an equal distribution of *effort*, which is one for each of the four capability increase functions. Because of the tipping point between supportive and inhibiting relationships also equals one and also in every simulation period 1 % of each capability stocks deteriorates, the model slowly approaches an equilibrium value of 100 index points for each capability (in simulation period 458 it reaches 99 index points). Figure 5 shows the related graph with the total performance score depicted. The base run scored second in a set of four tested policies.

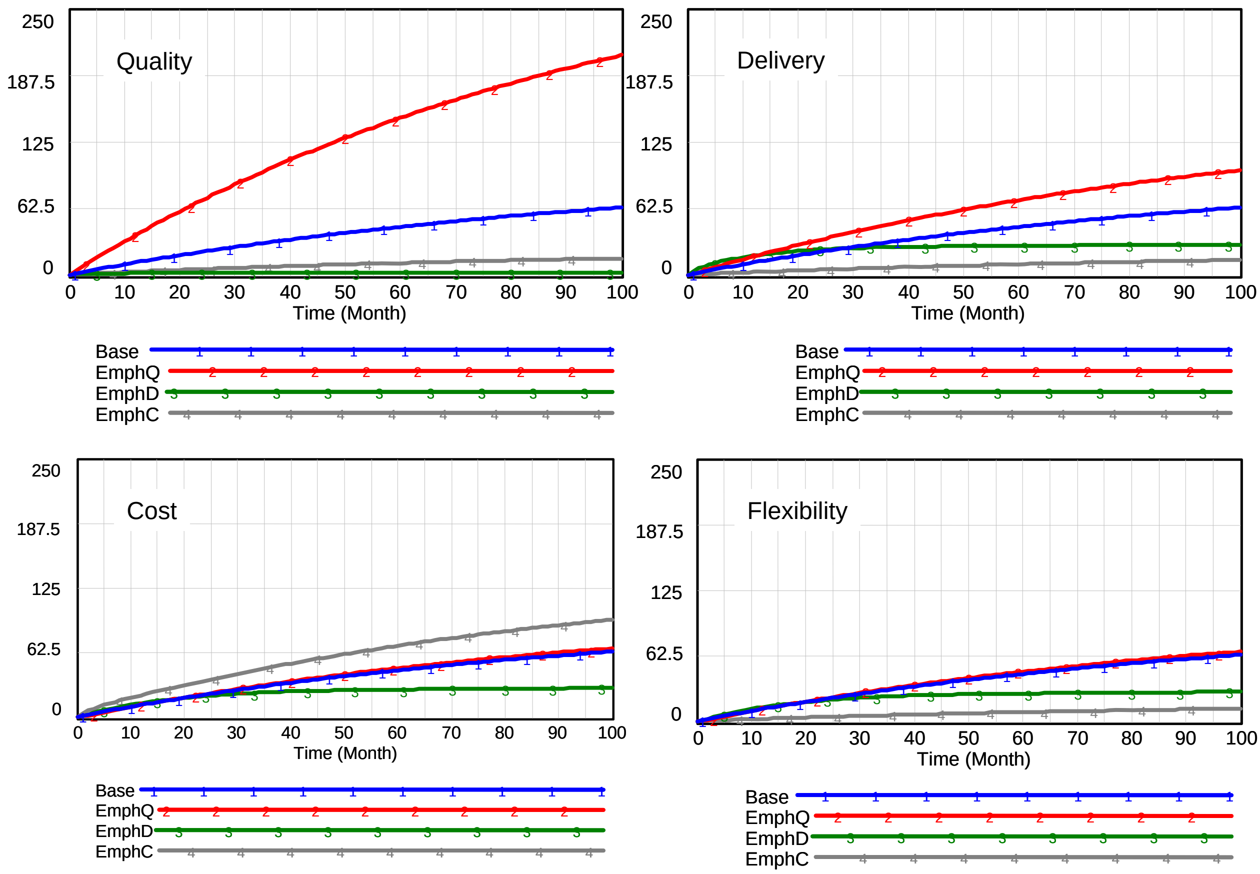

Figure 4: Development of capabilities under different effort policies

Lines 2, 3 and 4 depict the simulation results for different effort policies. In the simulation run *EmphQ* the focus of management's attention lies on improving the quality capability; in *EmphD* it is on delivery, in *EmphC* on cost (effort is 3.25 for the capability in focus, 0.25 for each other capability). Behaviour in the simulation is in accordance to theory: when quality is emphasized (scenario *EmphQ*) total performance is highest because via supportive links any gains in quality have positive effects on the other capabilities as well. Thus, not only quality reaches a high level, also all other capabilities—except cost—reach the highest level in this scenario compared to all others.

When emphasis is on delivery (scenario *EmphD*) the lowest total performance score of all simulation runs is achieved. This is because the focus on delivery inhibits improvements in quality; without a foundation in quality, however, no substantial increases in delivery are possible. Thus, both capabilities stay low. Although cost and flexibility are not inhibited, due to the small level of delivery they are also not substantially supported.

When the focus of management's attention and resources is on cost (scenario *EmphC*), a slightly better score is achieved compared to a focus on delivery. Cost grows steadily in this case, inhibiting flexibility and delivery. However, because there is no direct connection to the first tier of the capability hierarchy, quality can—although slowly—improve. In the end, this also leads to a quite moderate improvement in delivery. This very slow improvement process initiated by quality is also the reason, why in the beginning of the simulation a focus on delivery scored better, but in the long run, a focus on cost succeeded. A scenario with focus on flexibility is not discussed here because the results are similar to the one with emphasis on cost due to the parallel position of the two capabilities in a trade-off relationship on top of the capability hierarchy.

Line 5 in Figure 5 depicts model performance when effort shifts between capabilities (scenario *EmphShift*). In this effort policy, focus is on quality first, but in the course of the simulation attention shifts to delivery (in simulation period 40) and, finally, cost (in simulation period 70; a shift to flexibility would have had the same effect). With this policy an even better total performance score can be achieved within the time frame observed in the simulation.[xii] When managerial effort does not shift in order of the sequence suggested by the conceptual model (i.e., from quality to delivery to cost) results are inferior: for instance, a policy giving attention in reverse order (first cost, then delivery, then quality) achieves a final score of about 240 (not depicted in the figure). Nevertheless, this result is better than sticking with the "wrong" capability all the time (as in scenarios *EmphD* or *EmphC*).

As a result of the simulation experiments can be stated that focusing on the basic capabilities pays off most. Because of the supportive nature of the relationships towards the higher tiers of the hierarchy not only quality, also the other capabilities gain from this effort policy. Additionally, the results of the simulation experiment indicate that capabilities in the middle of the hierarchy (i.e., delivery) are more likely to be influenced by supporting and inhibiting forces. Thus, it might in the long run even be better to break up the suggested order of capabilities than to focus on a capability in the middle without laying the ground by improving on the more basic capabilities. Furthermore, an equal distribution of effort achieves better results than focusing on the wrong capabilities, i.e. a "no strategy" policy is better than emphasizing capabilities on higher tiers too early.

Although I would not claim that the results so far are intuitively clear to everyone they should not be a surprise for system dynamicists that are trained in deriving behaviour from a level and rate structure. The relatively simple model structure together with the mathematically non-complex functionality, which has been employed in the simulation runs up to this point, allows for guessing of dynamic behaviour modes, i.e. without the necessity to run a simulation. This will change with the following adjustment of the system dynamics model to real world data.

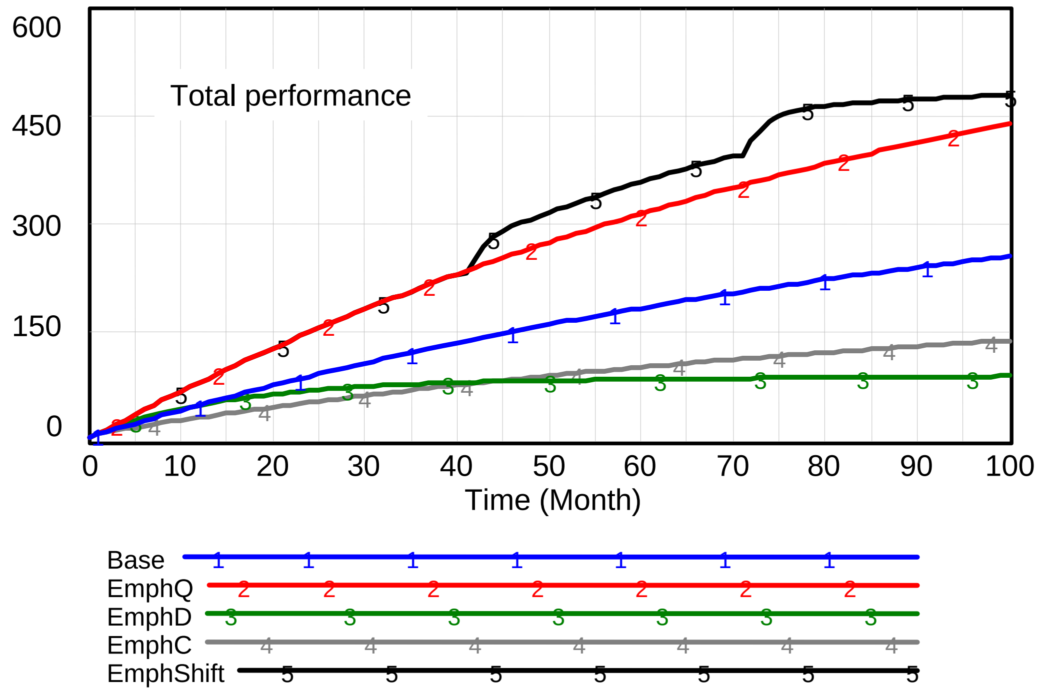

Figure 5: Development of performance under different effort policies

In the succeeding simulation runs, data from an empirical study (Grübner and Größler, 2004) has been used to parameterise the model. In a first step, initial values for the four capabilities were derived. While the absolute strength of capabilities in firms is difficult to measure, by statistical analyses of data about order winning criteria of manufacturing firms, the strength of the capabilities relative to each other could be approximated. It was found that the ratio between 'quality' : 'delivery' : 'cost' : 'flexibility' had been 4.13 : 3.61 : 3.74 : 3.31 at the time of the survey.[xiii] The level variables in the system dynamics model were initialised using these values, in order to express initial differences in a capability relative to the other capabilities.

Based on the same data, the following coefficients between capabilities have been identified with the help of a structural equation model: between 'quality' and 'delivery' 0.54, between 'delivery' and 'cost' 0.63, between 'delivery' and 'flexibility' 0.58 and between 'flexibility' and 'cost' -0.08 (with the negative value indicating a trade-off relationship between these two capabilities).[xiv] The assumption used when quantifying the model with these values is that the coefficients found in the empirical study express the strength of the supportive functions between pairs of capabilities; when the ratio between capability levels is as in the initial condition (see above) the amplification factor between the capabilities is as great as the coefficient. Depending on whether a supportive or an inhibiting relationship is modelled, this factor can either grow or shrink.

An example might explain this parameterisation process. The initial ratio between ‘delivery’ and ‘quality’ is 3.61 to 4.13 resulting in 0.87; this quotient serves as the reference point, where ‘quality’ supports ‘delivery’ with a factor of 0.54 (value obtained from the structural equation model) and where no inhibition from ‘delivery’ to ‘quality’ occurs. When ‘quality’ rises compared to ‘delivery’, ‘delivery’ is even more supported by ‘quality’ (maximum: doubling of ‘quality’ while ‘delivery’ remains constant leads to a doubled support coefficient of 1.08); ‘quality’ is not affected by ‘delivery’ in this condition. When ‘delivery’ rises compared to ‘quality’, the support of ‘quality’ for ‘delivery’ decreases (minimum: zero support when ‘delivery’ rises to the double value compared to the initial condition and ‘quality’ stays constant). In this case, ‘quality’ is affected due to the inhibiting nature of the relationship from ‘delivery’ to ‘quality’: a maximum inhibition takes place when ‘delivery’ is twice as big as ‘quality’ or bigger.

With the help of a simulation model parameterised in such a way different scenarios concerning the dynamic nature of strategic capabilities are possible. In the following, I concentrate on the effect that different effort policies have on the growth of the capabilities, i.e. on the question, how management should focus its attention and distribute available resources to the four strategic capabilities. Other possible scenarios might include effects of different initial values (path dependency), possibilities of strategic changes, results of different attrition rates, and behaviour modes with dynamically changing supporting and inhibition coefficients.[xv] These research issues are not further investigated in this paper.

Figure 6 depicts two simulation runs that are achieved with the help of the system dynamics model depicted in Figure 3, quantified based on the empirical values from the study just reported and the assumptions described in the preceding paragraphs. The left hand side shows the development of capabilities when effort is equally distributed over all four capabilities. In this case, all capabilities develop well, and the overall picture is similar to the one derived from the non-parameterised model above. According to the initial values and the strength of the supporting coefficients ‘quality’ rises more than ‘delivery’ which increases stronger than ‘cost’ and ‘flexibility’. The reason for the relatively big difference between ‘cost’ and ‘flexibility’ is that ‘cost’ has a stronger supportive relationship to ‘delivery’ than ‘flexibility’ to ‘delivery’. Because of the inhibiting trade-off relationship between ‘cost’ and ‘flexibility’ this difference (and the slightly better initial condition) is further amplified during the simulation run, which results in a classical “success-to-the-successful” behaviour (Senge, 1990).

Considering the current discussion about the competitive advantage provided by flexibility, these results it could be argued that ‘flexibility’ seems to be one of the more pressing issues for manufacturing companies in the future. Thus, management might be tempted to focus its attention on ‘flexibility’ in order to grow it to a higher level. However, as the right hand side in Figure 6 indicates, the situation becomes worse when management’s attention is concentrated on the flexibility capability. In this case, only ‘quality’ reaches a significant level of development. All three other capabilities (including ‘flexibility’ which is emphasized by management) basically show stable or even declining levels resulting in a low total performance score.

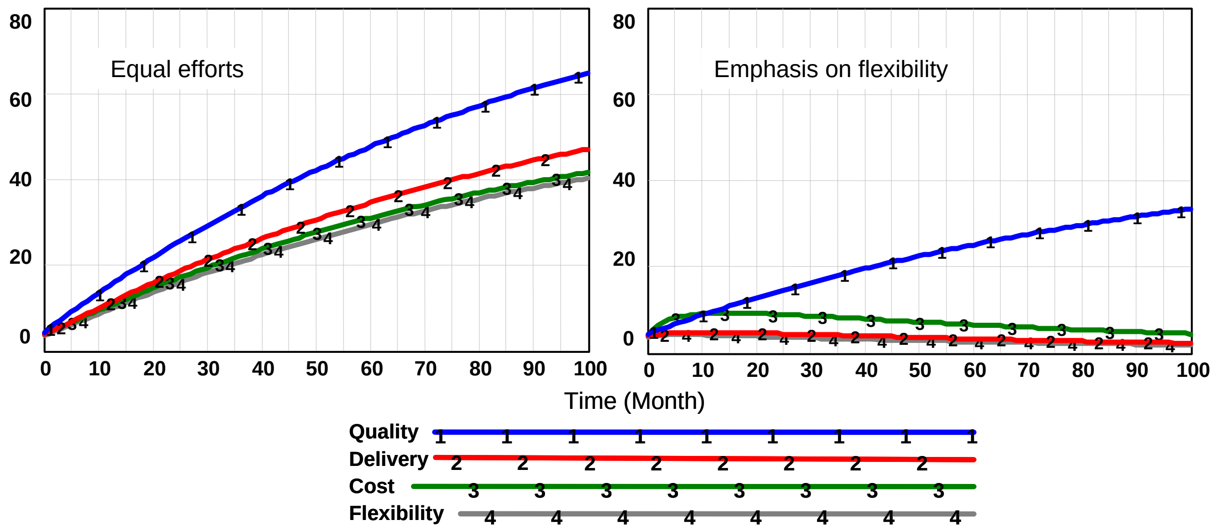

Figure 6: Simulation results for empirically parameterised model – Effort policies I

In Figure 7 two other possibilities are depicted, how the inferior results of ‘flexibility’ could be improved (graphs are differently scaled). On the left hand side, a simulation run is presented that yields rather good results concerning *total performance* (i.e., the sum of all capability levels). The effort policy followed in this scenario is that capabilities get the more effort the lower in the hierarchy they are. Thus, fundamental capabilities are always more developed as capabilities on top of the hierarchy. Despite the good overall performance, naturally both ‘cost’ and ‘flexibility’ do not achieve good results in this case.

The graph on the right demonstrates a way, how ‘flexibility’ can be alleviated. In this case, ‘flexibility’ is considerably higher than in the base run and the second best in the ranking of capabilities. However, this could only be achieved when management effort is taken away from ‘cost’ and shifted to the flexibility capability. Because both capabilities are in a trade-off relationship, ‘cost’ shows very unsatisfactory results in this scenario.

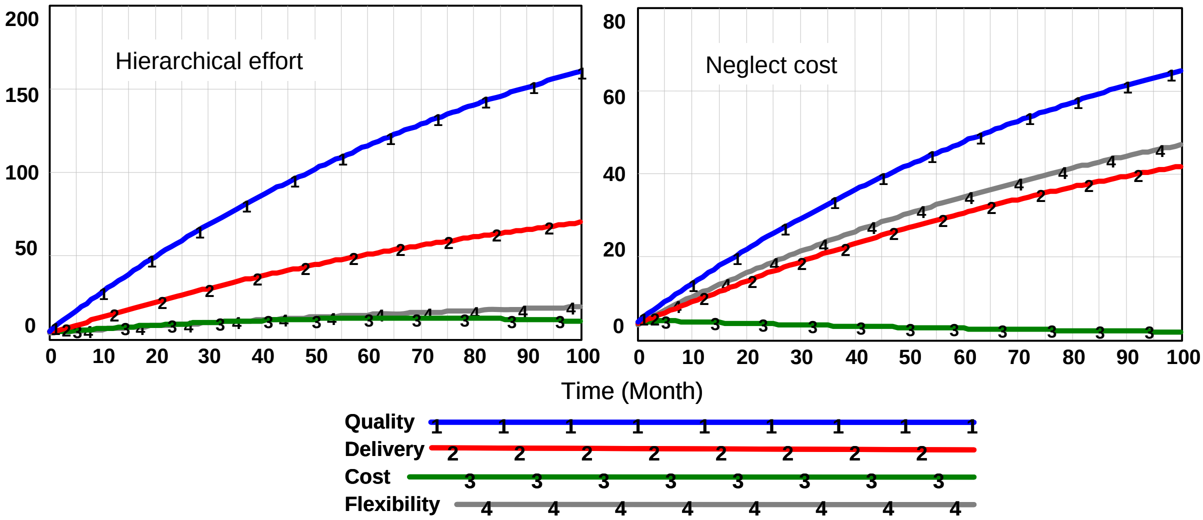

Figure 7: Simulation results for empirically parameterised model – Effort policies II

Finally, Figure 8 shows the simulation results of a scenario that uses a dynamically changing effort policy. In the first third of the simulation, emphasis is on ‘quality’ as the fundamental capability. After that, management’s attention shifts to ‘time’. In the last third of the simulation period, considerably much effort is put on the flexibility capability. With this shifting effort policy not only the highest flexibility level of all scenarios tested here can be achieved. Additionally, overall performance also is slightly higher as in the base run with equal efforts (see Figure 6, left). Thus, a dynamic effort policy offers an option for a strategic change and the concentration on an otherwise underdeveloped capability (‘flexibility’) without too much compromising other capabilities and *total performance*.

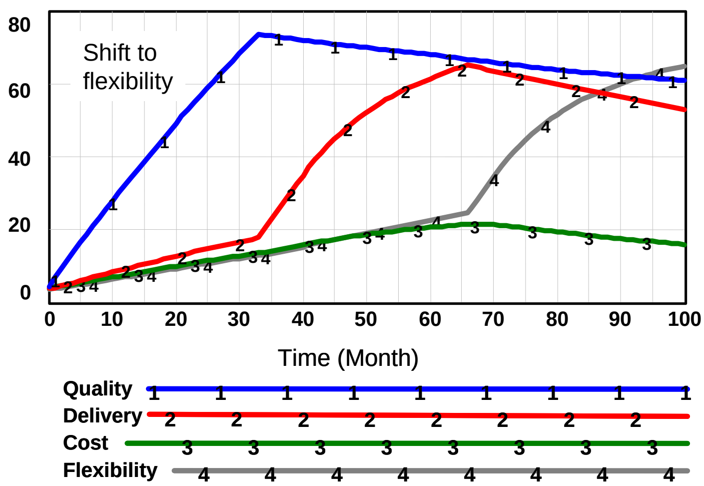

Figure 8: Simulation results for empirically parameterised model – Effort policies III

As long as the nature and the value of the supportive and inhibiting links between capabilities persists as in the sample from which the model parameter were drawn, the only chance to develop ‘flexibility’ in a satisfying way above the level as in the base run seems to be to employ a shifting effort policy.[xvi] A totally different approach, however, would be to induce changes in the routines and resources of the firms which result in changed supporting and inhibiting coefficients and, finally, in different behaviour modes. In such a way, for instance, ‘flexibility’ could also reach a higher development level without compromising the cost capability at all. However, in order to achieve such an improved capability structure, knowledge about the causal factors influencing the sequence of capabilities and their relationships would be necessary.

Conclusions and further research

The exploratory system dynamics model as depicted in Figure 3 was able to support the investigation of the ‘law of cumulative capabilities’. By way of model development and simulation experiments, dynamic implications of the theory could be examined, short-comings identified and the consequences of different policies could be tested. Potential improvements of the model include the further empirically based quantification of certain parameters, for instance, tipping points between supportive and inhibiting relationships, maximum and minimum support/inhibition factors, occurrence and duration of delays, and attrition rates.

The model in its current version reflects the mechanism of capability accumulation and trade-off. However, similar to the literature in operations management it adds little to the question what exactly causes supportive relationships between capabilities and how they can be exploited. For instance, the successful application of appropriate improvement programs seems to be crucial concerning this matter (Ferdows and De Meyer, 1990; Grübner and Größler, 2004; cf. also Laugen et al., 2005) as well as the development and conservation of strategic resources. The system dynamics model might be improved by “digging deeper” into the factors that causally affect the nature of the relationship between two capabilities. In addition, the model assumes that the underlying structure and relationship between capabilities remain stable over time. However, it seems quite reasonable that this structure changes—at least over a longer time interval. In order to incorporate this change of structure, either another modelling and simulation technique needs to be used (e.g., agent based simulation; Schieritz, 2004; Schieritz and Milling, 2003) or changing structures are represented by shifting loop dominance in a system dynamics model. Again, this would require the modelling of causal factors that trigger these shifts.

A possible extension of the model would also be to include strategic priorities, i.e. planned capabilities, into the model. With the help of such a model, a two-stage process could be represented: first, strategic priorities would be formulated and intended, second, these priorities and the actions to achieve them would result in changes to the strategic capabilities. Due to biases, inefficiencies, politics and external influences, the relationship between intended and achieved capabilities is non-trivial. For a first empirical analysis of this issue see Wood et al. (1990). In general, this extension would shift the model more than it is the case now from content to process of manufacturing strategy (Ward et al., 1990; Voss, 1992; Swink and Way, 1995; Mills et al., 1995; Mills et al., 1998; cf. also Mollona, 2002).

Another possibility for further research regards the level of sustainability of capability configurations. Ferdows and De Meyer (1990) emphasize in their article that although performance might also be satisfying when other sequences of capability accumulation are followed, these might not be as sustainable as when the “right” sequence (from quality, to delivery, to flexibility and cost) is followed. Partially, this notion is supported by the system dynamics model because it is possible to achieve a rather good performance score when, for instance, concentrating on *cost* without first developing *quality*. However, in order to model different degrees of sustainability, attrition rates within the model must be made endogenous and the decrease of a capability be made dependent on the levels of the other capabilities, similar to the increase of capabilities.

The scenarios presented in this paper are based on an empirical foundation that basically uses averages from a large sample of firms. Thus, as a practical implication, this study provides information for operations managers, on what level they can expect capabilities to be depending on the policies they follow, provided in their firm exists the same structure of capabilities as on the average of the sample. From a strategic point of view, however, the greatest leverage might lie in not doing what the majority of competitors do, but in achieving a specific and unique set and sequence of strategic capabilities. For this end, it might also be interesting to parameterize the model with values of specific (real or hypothetical) firms. In this way, superior positions concerning capability structures could be found and best paths regarding management policies for capability growth could be identified. Additionally, other industries than the ones used to parameterize the model in this paper could be tested and the outcomes compared to the results reported in this paper. This information might help new entrants into existing industries (or companies in relatively young industries) to learn from successful examples from more mature industries.

Starting from a literature-based discussion of the existence and relevance of strategic capabilities, this paper presented a conceptual model of the relationships of four strategic capabilities: quality, delivery, cost and flexibility. The conceptual model was transferred into a system dynamics model which allowed for running scenarios on the effects of different resource allocation policies. The dynamic behaviour of the capability model was analyzed and possibilities for further improvement were discussed.

References

Amit, R. and Schoemaker, P.J.H., (1993), “Strategic Assets and Organizational Rent”, *Strategic Management Journal*, Vol. 14, pp. 33–46.

Anand, G. and Ward, P.T., (2004), “Fit, Flexibility and Performance in Manufacturing: Coping with Dynamic Environments”, *Production and Operations Management*, Vol. 13, No. 4, pp. 369–385.

Ansoff, H.I., (1988), *The New Corporate Strategy*, Wiley, New York.

Barlas, Y., (1996), "Formal Aspects of Model Validity and Validation in System Dynamics", *System Dynamics Review*, Vol. 12, No. 3, pp. 183–210.

Bennigson, L.A., (1996), "Changing Manufacturing Strategy", *Production and Operations Management*, Vol. 5, No. 1, pp. 91–102.

Berry, D.C. and Broadbent, D.E., (1995), "Implicit Learning in the Control of Complex Systems", Frensch, P.A. and Funke, J. (Eds.), *Complex Problem Solving–The European Perspective*, Erlbaum, Hillsdale, pp. 131–150.

Boyer, K.K. and Lewis, M.W., (2002), "Competitive Priorities: Investigating the Need for Trade-offs in Operations Strategy", *Production and Operations Management*, Vol. 11, No. 1, pp. 9–20.

Chussil, M., (2005), "With All This Intelligence, Why Don't We Have Better Strategies?", *Journal of Business Strategy*, Vol. 26, No. 1, pp. 26–33.

Clark, K.B., (1996), "Competing Through Manufacturing and the New Manufacturing Paradigm: Is Manufacturing Strategy Passé?", *Production and Operations Management*, Vol. 5, No. 1, pp. 42–58.

Coyle, G., (2000), "Qualitative and Quantitative Modelling in System Dynamics: Some Research Problems", *System Dynamics Review*, Vol. 16, No. 3, pp. 225–244.

De Toni, A. and Tonchia, S. (2001), "Performance Measurement Systems", *International Journal of Operations and Production Management*, Vol. 21, Nos. 1-2, pp. 46–70.

Devaraj, S., Hollingworth, D.G. and Schroeder, R.G., (2004), "Generic Manufacturing Strategies and Plant Performance", *Journal of Operations Management*, Vol. 22, pp. 313–333.

Dörner, D., (1996), *The Logic of Failure*, Metropolitan Books/Henry Holt, New York.

Ferdows, K. and De Meyer, A., (1990), "Lasting Improvements in Manufacturing Performance: In Search of a New Theory", *Journal of Operations Management*, Vol. 9, No. 2, pp. 168–184.

Forrester, J.W., (1961), *Industrial Dynamics*, MIT Press, Cambridge.

Forrester, J.W., (1968), *Principles of Systems*, MIT Press, Cambridge.

Forrester, J. W., (1994), "System Dynamics, Systems Thinking and Soft OR", *System Dynamics Review*, Vol. 10, Nos. 2/3, pp. 245–256.

Frohlich, M.T. and Dixon, J.R., (2001), "A Taxonomy of Manufacturing Strategies Revisited", *Journal of Operations Management*, Vol. 19, pp. 541–558.

Größler, A., (2004), "Quantification Makes Sense Even When Empirical Data Is Limited: A Model of the Bhopal Crisis", Kennedy M. et al. (Eds.), *Proceedings of the 22nd International Conference of the System Dynamics Society*, Oxford.

Grübner, A. and Größler, A., (2004), "An Empirical Model of Accumulation Effects of Manufacturing Capabilities", Van Wassenhove, L.N. et al. (Eds.), *Operations Management as a Change Agent – Proceedings of the 11th International Annual Conference of the European Operations Management Association,* Fontainebleau, pp. 179–188.

Hall, R., (1991), "The Contribution of Intangible Resources to Business Success", *Journal of General Management*, Vol. 16, No. 4, pp. 41–52.

Hall, R., (1992), “The Strategic Analysis of Intangible Resources”, *Strategic Management Journal*, Vol. 13, No. 2, pp. 135–144.

Hayes, R.H. and Pisano, G.P., (1996), “Manufacturing Strategy: At the Intersection of Two Paradigm Shifts”, *Production and Operations Management*, Vol. 5, No. 1, pp. 25–41.

Hill, T., (2000), *Manufacturing Strategy – Text and Cases*, 2nd edition, Palgrave, Basingstoke.

Homer, J., (1996), “Why We Iterate: Scientific Modeling in Theory and Practice”, *System Dynamics Review*, Vol. 12, No. 1, pp. 1–19.

Homer, J. and Oliva, R., (2001), “Maps and Models in System Dynamics; a Response to Coyle”, *System Dynamics Review*, Vol. 17, No. 4, pp. 347–356.

Kaufman, R.S., (1992), “Why Operations Improvement Programs Fail: Four Managerial Contradictions”, *Sloan Management Review*, Vol. 34, No. 1, pp. 83–93.

Keating, E.K., Oliva, R., Repenning, N.P., Rockart, S. and Sterman, J.D., (1999), “Overcoming the Improvement Paradox”, *European Management Journal*, Vol. 17, No. 2, pp. 120–134.

Koufteros, X.A., Vonderembse, M.A. and Doll, W.J., (2002), “Examining the Competitive Capabilities of Manufacturing Firms”, *Structural Equation Modeling*, Vol. 9, No. 2, pp. 256–282.

Kotha, S. and Orne, D., (1989), “Generic Manufacturing Strategies: A Conceptual Synthesis”, *Strategic Management Journal*, Vol. 10, pp. 211–231.

Kotler, P. and Armstrong, G., (1991), *Principles of Marketing*, Prentice-Hall, Englewood Cliffs.

Lane, D.C., (1995), “On a Resurgence of Management Simulations and Games”, *Journal of the Operational Research Society*, No. 46, pp. 604–625.

Lane, D.C., (2000), “Should System Dynamics be Described as a 'Hard' or 'Deterministic' Systems Approach”, *Systems Research and Behavioral Science*, Vol. 17, No. 1, pp. 3–22.

Lane, D.C. and Husemann, E., (2004), “Movie Marketing Strategy Formation with System Dynamics: Towards a Multi-Disciplinary Adoption/Diffusion Theory of Cinema-Going”, Kennedy, M. et al. (Eds.), *Proceedings of the 22nd International Conference of the System Dynamics Society*, Oxford.

Laugen, B.T., Acur, N., Boer, H. and Frick, J., (2005), “Best Manufacturing Practices: What Do the Best-Performing Companies Do?”, *International Journal of Operations and Production Management*, Vol. 25, No. 2, pp. 131–150.

Mapes, J., New, C. and Szwejczewski, M., (1997), “Performance Trade-offs in Manufacturing Plants”, *International Journal of Operations and Production Management*, Vol. 17, No. 10, pp. 1020–1033.

March, J.G. and Simon, H.A., (1958), *Organizations*, Wiley, New York.

Miller, J.G. and Roth, A.V., (1994), “A Taxonomy of Manufacturing Strategies”, *Management Science*, Vol. 40, No. 3, pp. 285–304.

Mills, J., Platts, K. and Gregory, M., (1995), "A Framework for the Design of Manufacturing Strategy Processes", *International Journal of Operations and Production Management*, Vol. 15, No. 4, pp. 17–49.

Mills, J., Neely, A., Platts, K., Richards, H. and Gregory, M., (1998), "The Manufacturing Strategy Process: Incorporating a Learning Perspective", *Integrated Manufacturing Systems*, Vol. 9, No. 3, pp. 148–155.

Mintzberg, H. and Waters, J.A., (1985), "Of Strategies, Deliberate and Emergent", *Strategic Management Journal*, Vol. 6, pp. 257–272.

Mollona, E., (2002), "A Competence View of Firms as Resource Accumulation Systems: A Synthesis of Resource-Based and Evolutionary Models of Strategy-Making", Morecroft, J., Sanchez, R. and Heene, A. (Eds.), *Systems Perspectives on Resources, Capabilities, and Management Processes*, Pergamon, Amsterdam.

New, C., (1992), "World-class Manufacturing versus Strategic Trade-offs", *International Journal of Operations and Production Management*, Vol. 12, No. 6, pp. 19–31.

Noble, M.A., (1995), "Manufacturing Strategy: Testing the Cumulative Model in a Multiple Country Context", *Decision Science*, Vol. 26, No. 5, pp. 693–721.

Nonaka, I., (1991), "The Knowledge-Creating Company", *Harvard Business Review*, November/December, pp. 96–104.

Oreskes, N., Shrader-Frechette, K. and Belitz, K., (1994), "Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences", *Science*, Vol. 263 (4 Feb), pp. 641–646.

Penrose, E.T., (1959), *The Theory of the Growth of the Firm*, Blackwell, Oxford.

Porter, M.E., (1996), "What Is Strategy?", *Harvard Business Review*, Vol. 74 (November-December), pp. 61–78.

Richardson, G., (1996), "Problems for the Future of System Dynamics", *System Dynamics Review*, Vol. 12, No. 2, pp. 141–157.

Richardson, G. P. and Pugh, A. L., (1983), *Introduction to System Dynamics Modeling with Dynamo*, MIT Press, Cambridge.

Roth, A.V. and van der Velde, M., (1991), "Operations as Marketing: A Competitive Service Strategy", *Operations Management*, Vol. 10, No. 3, pp. 303–328.

Schieritz, N. and Milling, P.M., (2003), "Modeling the Forest or Modeling the Trees – A Comparison of System Dynamics and Agent-Based Simulation", Eberlein, R.L. et al. (Eds.), *Proceedings of the 21st International Conference of the System Dynamics Society*, New York City.

Schieritz, N., (2004), "Exploring the Agent Vocabulary – Emergence and Evolution in System Dynamics", Kennedy, M. et al. (Eds.), *Proceedings of the 22nd International Conference of the System Dynamics Society*, Oxford.

Schmenner, R.W. and Swink, M.L., (1998), "On Theory in Operations Management", *Journal of Operations Management*, Vol. 17, No. 1, pp. 97–113.

Schonberger, R.J., (1986), *World Class Manufacturing – The Lessons of Simplicity Applied*, Free Press, New York/London.

Selznick, P., (1957), *Leadership in Administration: A Sociological Interpretation*, Harper & Row, New York.

Senge, P.M., (1990), *The Fifth Discipline – The Art and Practice of the Learning Organization*, Currency&Doubleday, New York.

Skinner, W., (1969), "Manufacturing – Missing Link in Corporate Strategy", *Harvard Business Review*, Vol. 47 (May-June), pp. 136–145.

Skinner, W., (1974), "The Focused Factory", *Harvard Business Review*, Vol. 52 (May-June), pp. 113–121.

Skinner, W., (1985), *Manufacturing: The Formidable Competitive Weapon*, Wiley, New York.

Skinner, W., (1986), "The Productivity Paradox", *Harvard Business Review*, Vol. 64 (July-August), pp. 55–59.

Slack, N. and Lewis, M., (2002), *Operations Strategy*, Pearson, Harlow.

St. John, C.H. and Young, S.T., (1992), "An Exploratory Study of Patterns of Priorities and Trade-offs among Operations Managers", *Production and Operations Management*, Vol. 1, No. 2, pp. 133–150.

Swink, M. and Way, M.H., (1995), "Manufacturing Strategy: Propositions, Current Research, Renewed Directions", *International Journal of Operations and Production Management*, Vol. 15, No. 7, pp. 4–26.

Swink, M. and Hegarty, W.H., (1998), "Core Manufacturing Capabilities and Their Links to Product Differentiation", *International Journal of Operations and Production Management*, Vol. 18, No. 4, pp. 374–396.

Trought, B., (1993), *Managing Advanced Manufacturing Systems*, Avebury, Aldershot.

Vickery, S.K., Droge, C. and Markland, R.E., (1993), "Production Competence and Business Strategy: Do They Affect Business Performance?", *Decision Sciences*, Vol. 24, No. 2, pp. 435–455.

Voss, C.A., (1992), "Manufacturing Strategy Formulation as a Process", Voss, C.A. (Ed.), *Manufacturing Strategy – Process and Content*, Chapman&Hall, London, pp. 121–132.

Ward, P.T., Leong, G.K. and Snyder, D.L., (1990), "Manufacturing Strategy: An Overview of Current Process and Content Models", Ettlie, J.E., Burstein, M.C. and Fiegenbaum, A. (Eds.), *Manufacturing Strategy – The Research Agenda for the Next Decade*, Kluwer, Boston, pp. 189–199.

Ward, P.T., Bickford, D.J. and Leong, G.K., (1996), "Configurations of Manufacturing Strategy, Business Strategy, Environment and Structure", *Journal of Management*, Vol. 22, No. 4, pp. 597–626.

Ward, P.T., McCreery, J.K., Ritzman, L.P. and Sharma, D., (1998), "Competitive Priorities in Operations Management", *Decision Sciences*, Vol. 29, No. 4, pp. 1035–1046.

Warren, K., (2002), *Competitive Strategy Dynamics*, John Wiley & Sons, Chichester.

Wernerfelt, B., (1984), "A Resource-Based View of the Firm", *Strategic Management Journal*, Vol. 5, pp. 171–180.

Wheelwright, S.C., (1984), “Manufacturing Strategy: Defining the Missing Link”, *Strategic Management Journal*, Vol. 5, pp. 77–91.

Wheelwright, S.C. and Bowen, H.K., (1996), “The Challenge of Manufacturing Advantage”, *Production and Operations Management*, Vol. 5, No. 1, pp. 59–77.

Wolstenholme, E.F., (1999), “Quantitative vs. Qualitative Modelling: the Evolving Balance”, *Journal of the Operational Research Society*, Vol. 50, pp. 422–428.

Wolstenholme, E.F. and Coyle, R.G., (1983), “The Development of System Dynamics as a Rigorous Procedure for System Description”, *Journal of the Operational Research Society*, Vol. 34, pp 569–581.

Wood, C.H., Ritzman, L.P. and Sharma, D. (1990), “Intended and Achieved Competitive Priorities: Measures, Frequencies, and Financial Impact”, Ettlie, J.E., Burstein, M.C. and Fiegenbaum, A. (Eds.), *Manufacturing Strategy – The Research Agenda for the Next Decade*, Kluwer, Boston, pp. 225–232.

Notes

[i] Sometimes, the terms *dependability, time orientation*, or *speed* are used instead of *delivery*, emphasizing either the aspect of reliable deliveries or the aspect of fast deliveries. The *delivery* capability as used in this article comprises both aspects, to be reliable and to be fast in delivering products. Furthermore, *delivery* is the most frequently used term and occurs from the first publications on strategic capabilities in manufacturing. Therefore, it is used in this paper.

[ii] Unless otherwise stated, in the context of this paper ‘resources’ always means ‘strategic resources’ and ‘capabilities’ stands for ‘strategic capabilities’ and ‘priorities’ for ‘strategic priorities’.

[iii] In this argumentation, it is assumed that capabilities are actually in use, no matter whether the firm knows “consciously” that it possesses the capabilities or not. In general, four combinations of knowing and using capabilities are possible. (1) The combination in which a firm uses and knows about its capabilities is the most regular one and goes along with deliberate strategy formulation. (2) That a firm does deliberately not exploit its capabilities—although it knows about them—seems awkward and can be excluded from the discussion because it is assumed to be very rare behaviour. (3) That a company has capabilities but does not know about it is conceivable (“tacit, implicit knowledge”; Nonaka, 1991; Berry and Broadbent, 1995). However, also in this case the notion of a dyadic nature of capabilities holds and the hidden capabilities should result in increased performance (for instance, if the firm does not know that it is capable of producing high quality, nevertheless this capability should result in high quality performance). (4) The case that a company neither uses nor knows about its capabilities is irrelevant because it has no effect on the firm (at least not at that point in time; in the future, hidden capabilities that are developed unknowingly at the current time might become known and used).

[iv] Actually, one of the strategic capabilities has also a direct, immediate effect on the financial performance of the firm: cost. While all other capabilities need to be translated into competitive success factors, which take a while to affect organisational performance, decreasing cost directly increase profit. This short-term effect might be the reason why so many companies focus on cost reduction solely, without fostering their basis in competition (and thus laying the grounds for sustainable success).

[v] Some authors do not strictly distinguish manufacturing strategy from marketing strategy, for instance Miller and Roth (1994; see also Frohlich and Dixon, 2001) in their well-known taxonomy of manufacturing strategies. However, in my view this simplification does not adequately represent manufacturing’s role in an organization (e.g., although manufacturing influences price setting, prices at the market place are not set by manufacturing). Additionally, it implies a direct effect from capabilities and improvement programs to the performance of the firm. At best, this effect can be indirect: all improvements at the manufacturing function need to be transformed into competitive factors at the market

place. Even worse, often improvement programs deteriorate performance (also called “improvement paradox”, Keating et al., 1999; see also Kaufman, 1992).

[vi] Another “middle course” between trade-off and no-dependencies approach basically claims that although all capabilities are related to each other in a trade-off manner, these trade-offs can be overcome (or, more precise, put into a more favourable frame) by switching to another trade-off curve (Bennigson, 1996; Clark, 1996). Yet another “middle course”, as formulated by Hayes and Pisano (1996), accepts the existence of trade-offs but claims that management is not so much about emphasizing one capability about another. Rather, operations management’s task is to lay down the rates of improvement for each capability (not so much whether there should be an improvement at all or not). Hayes and Pisano call this “second order trade-offs”.

[vii] Trade-offs always exist when considering a short-term perspective: managerial effort that is put into the development of quality cannot simultaneously be used to develop cost performance. Because this trade-off effect is rather trivial, this article is interested in the long-term effects of supportive and inhibiting relationships between manufacturing capabilities.

[viii] As the simulation analyses in later parts of the paper show, the structure on top of the capability hierarchy does not affect overall behaviour and performance to a great degree. The actual nature of the link between *cost* and *flexibility* is therefore less important than, for instance, between *quality* and *delivery*.

[ix] With the meaning intended here, the term ‘exploratory system dynamics model’ was originally coined by Lane and Husemann (2004). Cf. also Homer (1996).

[x] The process of shifting management attention and resources from the development of one capability to another can be understood as a learning process. Thus, when effort put into one capability supports the effort put into another one, learning is effective; when there are inhibiting effects prevalent, learning can be seen as ineffective.

[xi] For a more comprehensive discussion of this issue together with a different example see Größler (2004).

[xii] This result does not hold for longer time frames, for instance 200 simulation periods. With this simulation setting it can be observed that performance decreases for scenario *EmphShift* around simulation period 100. This effect is due to a missing base of the quality capability (which additionally deteriorates over time) that renders counter-productive any further effort put into ‘higher’ capabilities, in particular ‘cost’.

[xiii] From the third round of the International Manufacturing Strategy Survey (IMSS-3) question A6 was used that asks for order winning criteria of the respondent’s organization. Sub-items A62, A63, A64 and A66 were assumed to represent *quality*, A65 and A68 *delivery*, A61 *cost*, A67 and A69 *flexibility*. The means over these sub-items were calculated and then the average over the complete sample of firms taken as initial value for the capability variables in the simulation model. It is assumed that order winning criteria are proxies for capabilities although their point of reference is not manufacturing, but the entire firm’s performance. However, the capabilities that correspond with the order winning criteria at the market place are the minimum set of capabilities a company must have (in a subjective view), although it might possess more capabilities that are not needed as competitive advantage. Therefore, firms might have a higher level of capabilities concerning the qualifying criteria, in particular *quality* and *delivery*, which are not assumed to be order winners. Initial values might be under-estimated regarding these (lower level) capabilities.

[xiv] Question D2 was used from IMSS-3 for this purpose. Sub-items D21, D22 were used to represent *quality*, D28, D29, D210 *delivery*, D213, D214, D215, D216 *cost* and D24, D25 *flexibility*. This factorization was tested with a confirmatory factor analysis that showed sufficient goodness-of-fit scores. Next, several conceivable patterns of capability relationships were tested with structural equation models (using Lisrel), resulting in the one model which is depicted in Figure 1 (Y-form) as having the best goodness-of-fit characteristics and also being the one most consonant with the literature. This result was cross-validated using another data set.

[xv] In general, scenarios could be designed along the three characterizing dimensions of system dynamics models: structure (including parameter values), policies (and decision variables) and initial condition (i.e. starting values of levels). Structure and policies could be static in the course of a simulation experiment or dynamically changing.

[xvi] The following table shows the results of all tested scenarios for total performance and the flexibility capability (highest scores are in bold; values after 100 simulation periods).

Policy name	*Effort pattern (Q-D-C-F)*	*Total Performance*	*Flexibility*
Equal effort (base run)	1-1-1-1	193.49	40.12
Emphasize quality	2.5-0.5-0.5-0.5	245.30	25.57
Emphasize delivery	0.5-2.5-0.5-0.5	59.16	15.10
Emphasize cost	0.5-0.5-2.5-0.5	41.01	1.57
Emphasize flexibility	0.5-0.5-0.5-2.5	40.28	3.54
Shift to cost	2.5: Q->T->C, else 0.25	205.36	22.10
Shift to flexibility	2.5: Q->T->F, else 0.25	194.19	**64.74**
Neglect cost	1-1-0.4-1.6	155.04	46.81
Hierarchical effort	2.5-1-0.25-0.25	**258.15**	18.72

The “optimal” effort pattern regarding *total performance* (2.5-1-0.5-0)—found via a grid simulation search with Vensim—yields an overall performance of 269.44 and a flexibility score of 1.21. Although I did not do so, in a deterministic model as the one presented in this paper a true optimal solution can be calculated as well. However, I would argue that the calculation of such an optimal solution does not yield additional insights in the context of this paper because (1) the development of capabilities over time could not be observed when just calculating an optimal score or would require an additional round of simulation after the calculation, (2) I doubt whether managers in reality follow too sophisticated rules, and—most important—(3) it would imply a level of preciseness that is not even remotely corresponding to (a) the abstract nature of the concept of strategic capabilities, (b) the simplicity of the assumed mathematical relationships between variables in the model, (c) the necessarily impreciseness of the empirical data on which the parameterization of the model is based and (d) the degree of precision required in most strategic analyses (Chussil, 2005).