An exploratory system dynamics model of strategic capabilities in manufacturing

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Abstract

Purpose – The purpose of this paper is to investigate the dynamics of accumulation processes of strategic capabilities in manufacturing, i.e. cost, quality, delivery, and flexibility. By applying a dynamic view, concepts from the literature are tested and shortcomings are identified.

Design/methodology/approach – The analysis was conducted with the help of an exploratory system dynamics model that represented a hierarchy of these accumulative capabilities. The exploratory model was parameterized with empirical data from a large international survey of manufacturing plants.

Findings – The major finding of this paper is that results from a static analysis can be transferred into a dynamic model, which can be used to test allocation strategies of resources to strategic capabilities.

Practical implications – The practical implications concern the distribution of managerial attention on the four capabilities and the consequences of different distributions.

Originality/value – The value of this paper lies in the insights gained by the transformation of a verbal model into a quantified simulation model, and the learning resulting from simulation experiments.

Keywords Strategic capabilities, Simulation, System dynamics, Accumulation

Paper type Research paper

Introduction

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 success 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. When translated into competitive factors, they positively 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, an exploratory system dynamics model is introduced that has proven to be helpful in further studying the dynamics of strategic capabilities. In the third section, results derived from the modelling process and from simulation experiments are discussed. The paper closes with implications for management and for further research.

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The relationship between manufacturing capabilities: a focussed literature review

In an operations management perspective, strategic capabilities are a plant's contribution to a company's success factors in competition; they are the strengths of a plant with which it supports corporate strategy and which help to succeed in the market place. The development, nurturing and neglect of strategic capabilities are a major task of manufacturing strategy (Slack and Lewis, 2002). 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, input factors to production are transformed into products and services (Warren, 2007). Usually, four strategic capabilities are differentiated.

The ability to produce:

- with low cost;
- in high quality;
- with reliable delivery; and
- with flexibility concerning mix and volume of products (Wheelwright, 1984).

Therefore, this paper – as most other articles in this area – concentrates on these four capabilities, despite the fact that other capabilities are conceivable and do most likely exist.

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 bidirectional relationship between manufacturing's strategic capabilities, which are internally focused, and the market strategy of a company, which has an external perspective. On one side, strategic capabilities should reflect requirements posed by the market strategy of a company. On the other side, manufacturing strategy should either be supportive towards the market 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. Based on this capability, strategy could emphasize product variety as a competitive factor within a given or a new market.

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, firms are constrained and management always is decision-making constrained by finite resources (St John and Young, 1992). Thus, not all capabilities can be maximized. Therefore, operations 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 the field of operations management three concepts emerge:

(1) the trade-off perspective;

(2) the "world class manufacturing" view; and

(3) accumulative models.

In particular, accumulative models as "middle courses" between the extreme positions of absolute or no trade-offs are of interest in the context of this paper. Schmenner and Swink (1998) postulate that in such middle courses it is possible that improving in a certain capability can amplify "related" capabilities, while other capabilities are in a trade-off relationship to the capability. In particular, quality improvements are found to be simultaneously supportive to improvements in cost performance (Ferdows and De Meyer, 1990; Skinner, 1986).

The way in which manufacturing capabilities relate to each other plays a major role when designing manufacturing strategies and designing programs to improve the performance of manufacturing systems. Because of supportive relationships between certain capabilities, it can be assumed that some patterns of capability development are more common among organizations than others are. 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 similar effort, compared to other ways of capability improvement. Therefore, the capability trajectories that firms follow can also be understood as generic patterns of manufacturing strategy (Miller and Roth, 1994; Kotha and Orne, 1989).

The relationship of strategic capabilities as shown in Figure 1 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 International Manufacturing Strategy Survey (IMSS) questionnaire (Taylor and Webster, 2006; Laugen *et al.*, 2005). The plants were from the machines, electrical devices, transportation devices, and measurement utilities industries. The Y-form of

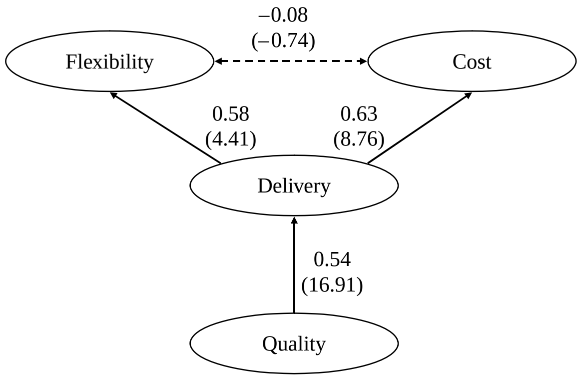

Figure 1.
Path model of strategic capability hierarchy

strategic capabilities was tested applying a structural equation model. In Figure 1, path coefficients as well as *t*-values for significance of coefficients are given. The structural equation model fulfils common goodness-of-fit criteria. Details are given in Größler and Grübner (2006) and are not further discussed in this paper, since Figure 1 only serves as a starting point for subsequent dynamic modelling in the following sections.

Figure 1 proposes a hierarchical relationship between capabilities that 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 a trade-off relationship rather than a supportive relationship exists between the two (Anand and Ward, 2004; Adler *et al.*, 1999). 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, but not to cost or flexibility).

Methodology: a dynamic model of strategic capabilities

The structural equation model outlined above is translated into a system dynamics model (Forrester, 1961, 1968). System dynamics offers a theory about the structure (and the resulting behaviour) of social systems as well as a method to represent this structure in form of diagrams and mathematical equations (Größler, 2007). By doing so, the method aims at producing simulation models that can be used to conduct experiments. While originally being designed for the analysis of industrial enterprises, nowadays system dynamics is applied to a variety of systems that change over time, in particular to socio-economic systems (Morecroft, 2007; Sterman, 2000; for the history of system dynamics, see Lane, 2007). The fundamental structural elements that are considered in system dynamics models are:

- feedback loops;
- accumulation processes;
- delays, which result in; and
- non-linear behaviour modes of systems (Größler *et al.*, 2008).

In this study, the static model of relationships between strategic capabilities as shown in Figure 1 is transferred into a system dynamics model in two steps: first, the hierarchical structure of capabilities is used to construct a formal representation of the capability structure; second, relationships between capabilities are parameterised using path coefficients and other numerical values derived from the statistical analysis.

In the first step of the modelling and simulation endeavour, the basic model structure is constructed. Identification of stocks and flows is straightforward because in the literature on strategic management, capabilities are described as accumulating entities (Dierickx and Cool, 1989; Warren, 2007). Thus, a strategic capability can be interpreted as in Figure 2. Strategic capabilities are modelled as accumulating variables ("stocks" in system dynamics terminology) that are increased by management employing resources (Ferdows and De Meyer, 1990); this effect is moderated by the influence of other capabilities. Strategic capabilities are continuously decreased over time through erosion or arbitrary neglect.

Supportive or inhibiting linkages between capabilities A and B are caused by the level of capability A, compared to the level of capability B (Ferdows and De Meyer, 1990). These linkages influence the effect size that management's employment of resources has on the growth of a capability. The total structure of strategic capabilities as shown in Figure 1 is translated into an exploratory system dynamics model, which stock and flow structure is shown in simplified form in Figure 3 (full model listing in Appendix 1).

The basic model structure follows the empirical 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 resources, which are employed for their development by management. How effective resources are that are used to grow a capability, depends on a comparison between the capability stock and the level of adjacent capabilities. 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 efficient and amplified by the favourable 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 efficient.

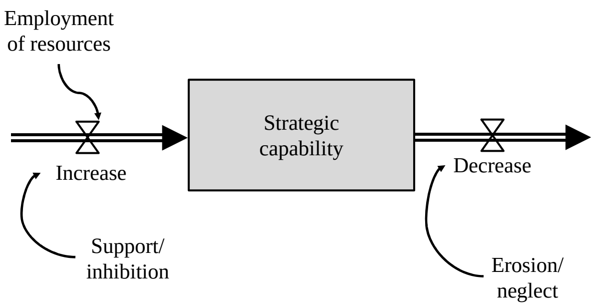

Figure 2.
Strategic capabilities as accumulating variables

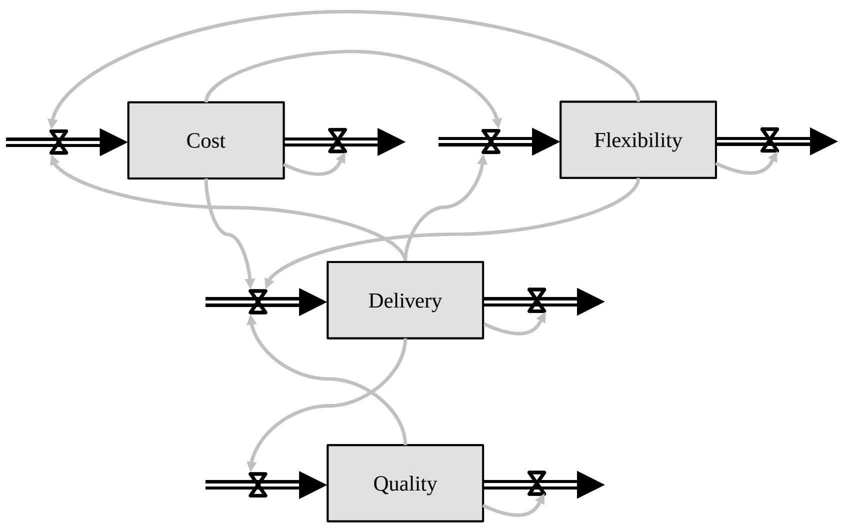

Figure 3.
Simplified stock and flow structure of exploratory system dynamics model

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 simple linear functions. Their concrete appearance can be altered easily. Ferdows and De Meyer (1990) argue for different tipping points between amplification and inhibition on the different tiers. Therefore, 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-based study (Größler and Grübner, 2006), which also was the basis for the original path model as shown in Figure 1.

As the first part of this process, initial values for the four capabilities were derived. While the absolute strength of capabilities in firms is difficult to measure, the strength of the capabilities relative to each other could be approximated by statistical analyses of data about order winning criteria of manufacturing firms. 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 (technical details about the questionnaire data used is given in Appendix 2). 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.

For the supporting/inhibiting parameters between capabilities, the coefficients from the structural equation model shown in Figure 1 were employed (see Appendix 2 for technical details). The assumption used when quantifying the model with these values is that the coefficients found in the IMSS study express the strength of the supportive functions between pairs of capabilities; when the ratio between capability levels is as in the initial condition, 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 3.61-4.13 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 the initial ratio 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 the initial ratio is half as big as originally). 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 (it remains constant thereafter). This factor of two has been set arbitrarily for the formulation of supporting and inhibiting functions. A greater factor strengthens the effects reported here; a smaller factor lessens them. However, general systems behaviour is not affected by the actual value.

The units of the model are abstract index points. Although this does not allow for interpretation of absolute values, it makes it possible to compare variables with each other, to study their behaviour over time, and to compare different scenarios.

Total effort that can be used to increase capabilities is four resource points; in the base run, resource employment 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. Thus, 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. Erosion of capabilities is a constant fraction of the level and set to 1 per cent per time step for each capability. Without erosion, capabilities could grow forever; capability erosion causes asymptotic behaviour, reflecting limits to growth in a finite world. Model behaviour has proven to be insensitive to the 1 per cent 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. Underlying this performance score is the assumption that manufacturing's capabilities support the strategy and objectives of the company (Vickery *et al.*, 1993; Devaraj *et al.*, 2004). Note that this performance measure can only be used to compare different scenarios and represents the performance of the manufacturing functions of companies. It is by no means a measure to express the performance of a company in the market place. For instance, manufacturing companies can experience the so-called "productivity paradox", which means becoming ever more productive for products nobody wants to buy (Skinner, 1986). In order to consider the market performance of a company, the different capabilities would need to be translated into actual competitive advantages that are valued by customers, which is beyond the scope of the model presented in this paper. Furthermore, the total performance score does not incorporate the notion of diminishing returns, thus rewarding employing resources into capabilities without any limitations.

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 this system dynamics model was not to represent a concrete real-world problem or to reproduce empirical behaviour in a numerically exact way. Rather, a dynamic model of a conceptual theory was built. From this perspective, the model is useful (and, thus valid) for this purpose (Oreskes *et al.*, 1994; Barlas and Carpenter, 1990). The model presented here does not identify the nature of the causal relationships between objects from a content perspective. Rather, it takes functional and quantitative relationships between the capabilities for granted. The dynamic consequences that originate from these relationships are simulated.

Simulation experiments investigating different resource employment policies

With the help of the exploratory simulation model, different scenarios concerning the dynamic nature of strategic capabilities are possible. In the following, the focus is on the effect that different resource employment policies have on the growth of the capabilities or, put differently, 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 other initial values (path dependency), possibilities of strategic changes, results of different erosion rates, and behaviour modes with dynamically changing supporting and inhibition coefficients. These research issues are not investigated further in this paper.

Figure 4 shows two simulation runs that are achieved with the help of the exploratory system dynamics model parameterised according to the procedure described in the preceding section. The left-hand side shows the development of capabilities when effort is equally distributed over all four capabilities. 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 difference between cost and flexibility is that cost has a slightly stronger supportive relationship from delivery than flexibility from delivery (0.63 versus 0.58). Because of the inhibiting trade-off relationship between "cost" and "flexibility" this difference (and the slightly better initial condition) is maintained during the simulation, which results in a classical "success-to-the-successful" behaviour (Senge, 1990).

Considering the discussion about the competitive advantage provided by flexibility (Gerwin, 1993; De Meyer *et al.*, 1989), it could be argued that flexibility is 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 4 shows, the situation becomes worse when management's attention is concentrated on the flexibility capability. In this case, a counter-intuitive phenomenon happens: only quality reaches a significant level of development; the three other capabilities (including flexibility, which is emphasized by management) show relatively stable or even declining levels resulting in a low-total performance score. The reason for this result lies mainly in the fact that resources, which are given to flexibility, are virtually wasted as long as they

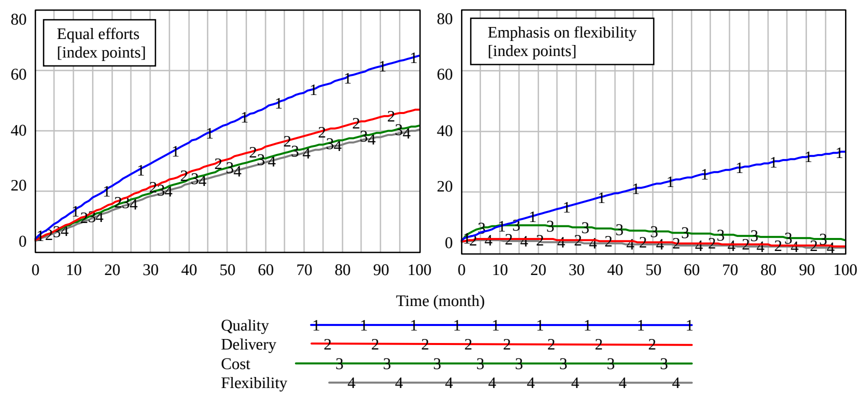

Figure 4.
Simulation results for resource employment policies: equal efforts (left) and emphasis on flexibility (right)

are not supported by strong underlying capabilities. Furthermore, such resources, of course, cannot be used to grow other capabilities.

In Figure 5 two other possibilities are depicted, how management could employ resources (note that 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 resource employment policy followed in this scenario is that capabilities get the more resources 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, both cost and flexibility do not achieve good results in this case because of their position in the hierarchy of capabilities.

The graph on the right-hand side of Figure 5 shows 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's focus is taken away from cost and shifted to the flexibility capability. Because both capabilities are in a trade-off relationship, the cost capability shows unsatisfactory results in this scenario.

Finally, Figure 6 shows the simulation results of a scenario that uses a dynamically changing resource employment policy. In the first third of the simulation, emphasis is on quality as the fundamental capability. After that, management's attention shifts to delivery. In the last third of the simulation period, considerably much resource employment is put on the flexibility capability. With this shifting resource employment policy, not only the highest flexibility level of all scenarios can be achieved. Additionally, overall performance also is slightly higher as in the base run with equal efforts (Figure 4, left). Thus, a dynamic effort policy offers an option for a strategic change and the concentration on an otherwise underdeveloped capability (flexibility) without compromising too much other capabilities or systems performance. As long as the nature and the value of the supportive and inhibiting links between capabilities persist as in the sample from which the model parameters were distilled, the only chance to develop flexibility in a satisfying way above the level as in the base run seems to employ a shifting resource employment policy.

Table I shows the results of all tested scenarios for total performance and the flexibility capability.

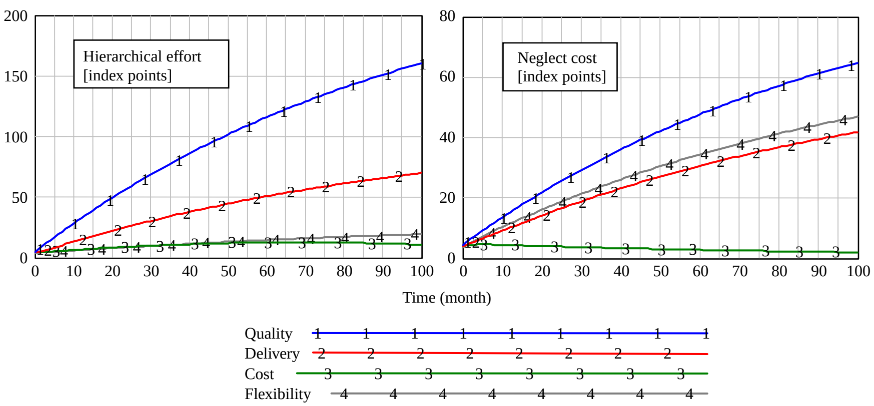

Figure 5.
Simulation results for resource employment policies: hierarchical efforts (left) and neglect of cost (right)

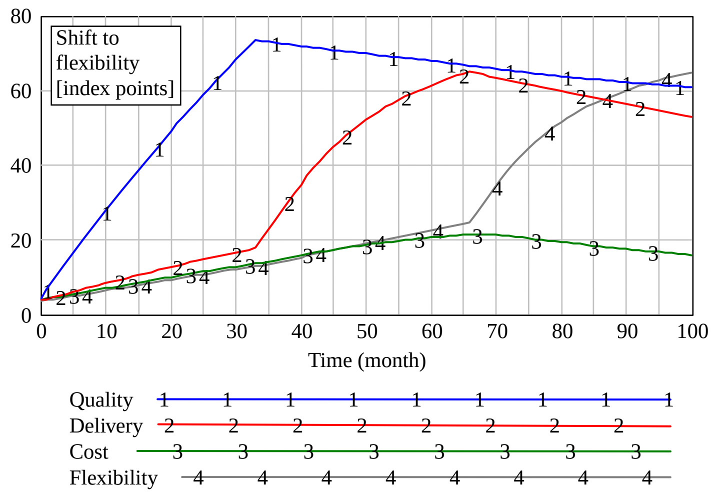

Figure 6.
Simulation result for resource employment policy: dynamic shift to flexibility

Table I.
Results of all tested scenario runs (highest scores are in italic values after 100 simulation periods are reported)

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 it is not shown here, in a deterministic model as the one presented in this paper a true optimal solution can be calculated as well. However, 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.

(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:

- the abstract nature of the concept of strategic capabilities;
- the simplicity of the assumed mathematical relationships between variables in the model;

- the necessarily impreciseness of the empirical data on which the parameterization of the model is based; and
- the degree of precision required in most strategic analyses (Chussil, 2005).

A very 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. 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.

Discussion and further research

The exploratory system dynamics model as shown 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, shortcomings 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 erosion rates.

When 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 also 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 are discussed in the following. However, it has to be noted that it was not the purpose to "improve" the model beyond what is conventional wisdom in operations management literature, in order to keep it as much according to common understanding as possible.

For instance, the original "law of cumulative capabilities" (Schmenner and Swink, 1998) does not discuss 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, for instance 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. However, it is only rarely discussed, how the other direction works. 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 (Sterman, 2000). 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 seems quite reasonable. From a simulation perspective, the empirical measurement of such delays would be beneficial: presumably, different delay times between the capabilities could result in amplified changes and oscillations.

The model in its current version reflects the mechanism of capability accumulation and trade-off. However, similar to the literature in operations management this version of the model yields only limited results regarding 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; Größler and Grübner, 2006; Laugen *et al.*, 2005) as well as the development and conservation of strategic resources. Thus, the system dynamics model might be amended by "digging deeper" into the factors that causally affect the nature of the relationship between capabilities. In addition, the model assumes that the underlying structure and relationship between capabilities remain stable over time. However, it seems quite reasonable that the capabilities' structure changes – at least over a time interval of some years or decades. In order to incorporate this change of structure, either another modelling and simulation technique needs to be used (e.g. agent-based simulation; Bonabeau *et al.*, 1999) or changing structures are represented by shifting loop dominance in a system dynamics model (Ford, 1999; Richardson, 1995).

A possible extension of the model would be to include strategic priorities, which are planned capabilities, into the model (Roth and van der Velde, 1991; Wood *et al.*, 1990). With the help of such a model, a two-stage process could be represented: first, strategic priorities are formulated; second, these priorities and the actions to achieve them result in changes to the strategic capabilities. Interestingly, 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 the content to the process of manufacturing strategy (Ward *et al.*, 1990; Voss, 1992; Swink and Way, 1995; Mills *et al.*, 1995, 1998; 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 can 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. Such differences in the degrees of sustainability might be caused by different erosion rates of capabilities. In order to incorporate the assumed effect of erosion, attrition rates can 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 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.

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Appendix 1

System dynamics model (base run setting; variables in alphabetical order)

```
//autonomous outflow factor from capability stocks
ATTRITION c = 0.01
    Units: 1/Month
ATTRITION d = 0.01
    Units: 1/Month
ATTRITION f = 0.01
    Units: 1/Month
ATTRITION q = 0.01
    Units: 1/Month

//flows from/to cost capability
c decrease = Cost*ATTRITION c
    Units: capability point/Month
c increase = EFFORT c*support dc*tradeoff fc
    Units: capability point/Month
//ratio between cost and delivery capability
"c/d ratio" = ZIDZ(Cost,Delivery)
    Units: Dmnl
```

```
//ratio between cost and flexibility capability
"c/f ratio" = ZIDZ(Cost,Flexibility)
    Units: Dmnl

//cost capability stock
Cost = INTEG (+ c increase-c decrease, INI C)
    Units: capability point

//flows from/to delivery capability
d decrease = Delivery*ATTRITION d
    Units: capability point/Month
d increase = EFFORT d*support qd*tradeoff cd*tradeoff fd
    Units: capability point/Month

//ratio between delivery and quality capability
"d/q ratio" = ZIDZ(Delivery,Quality)
    Units: Dmnl

//delivery capability stock
Delivery = INTEG (+ d increase-d decrease, INI D)
    Units: capability point

//efforts put into the increase of capabilities
EFFORT c = 1
    Units: resource point/Month
EFFORT d = 1
    Units: resource point/Month
EFFORT f = 1
    Units: resource point/Month
EFFORT q = 1
    Units: resource point/Month

//flows from/to flexibility capability
f decrease = Flexibility*ATTRITION f
    Units: capability point/Month
f increase = EFFORT f*support df*tradeoff cf
    Units: capability point/Month

//ratio between flexibility and delivery capability
"f/d ratio" = ZIDZ(Flexibility,Delivery)
    Units: Dmnl

//stop time of simulation
FINAL TIME = 100
    Units: Month

//flexibility capability stock
Flexibility = INTEG (+ f increase-f decrease, INI F)
    Units: capability point
//initial values of capability stocks
INI C = 3.74
    Units: capability point
```

INI D = 3.61
Units: capability point
INI F = 3.31
Units: capability point
INI q = 4.13
Units: capability point

//flows from/to quality capability
q decrease = Quality *ATTRITION q
Units: capability point/Month
q increase = EFFORT q *tradeoff dq
Units: capability point/Month

//quality capability stock
Quality = INTEG (+ q increase-q decrease, INI q)
Units: capability point

//supporting functions from underlying capabilities
support dc = "Table c/d"("c/d ratio")
Units: Dmnl
support df = "Table f/d"("f/d ratio")
Units: Dmnl
support qd = "Table d/q"("d/q ratio")
Units: Dmnl

//table functions determining supporting/inhibiting functions between capabilities
"Table c/d"([(0,0)-(4,2)],(0.52,1.26),(1.04,0.63),(2.08,0))
Units: Dmnl
"Table c/f"([(0,0)-(4,2)],(0.57,0),(1.13,0.92),(2.26,1))
Units: Dmnl
"Table d/c"([(0,0)-(4,1)],(1.04,1),(2.08,0))
Units: Dmnl
"Table d/f"([(0,0)-(2,1)],(0.92,1),(1.84,0))
Units: Dmnl
"Table d/q"([(0,0)-(2,2)],(0.44,1.08),(0.87,0.54),(1.74,0))
Units: Dmnl
"Table f/c"([(0,0)-(4,2)],(0.57,1),(1.13,0.92),(2.26,0))
Units: Dmnl
"Table f/d"([(0,0)-(2,2)],(0.46,1.16),(0.92,0.58),(1.84,0))
Units: Dmnl
"Table q/d"([(0,0)-(2,2)],(0.87,1),(1.74,0))
Units: Dmnl

//calculation of total effort and total performance (as sum of capability stocks)
total effort = EFFORT q + EFFORT d + EFFORT c + EFFORT f
Units: resource point/Month
total performance = Quality + Delivery + Cost + Flexibility
Units: capability point

//inhibiting functions from capabilities "above"
tradeoff cd = "Table d/c"("c/d ratio")
Units: Dmnl

tradeoff cf = “Table f/c”(“c/f ratio”)
Units: Dmnl
tradeoff dq = “Table q/d”(“d/q ratio”)
Units: Dmnl
tradeoff fc = “Table c/f”(“c/f ratio”)
Units: Dmnl
tradeoff fd = “Table d/f”(“f/d ratio”)
Units: Dmnl

Appendix 2. Questionnaire items used in study (IMSS-III)

From the International Manufacturing Strategy Survey (IMSS-3), question A6 was used (which asks for order winning criteria of the respondent’s organization) for initializing the capability stocks. 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, 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 order winners. Initial values might be under-estimated regarding these (lower level) capabilities.

A6. Consider the degree of importance of the following goals to your major customers (please circle all appropriate alternatives). Compared to your competitors, you *win orders* from your customers by aiming to:

	Not important				Very important	Has goal priority changed in last three years?		
Have lower selling prices	1	2	3	4	5	No	Lower	Higher
Offer superior product design and quality	1	2	3	4	5	No	Lower	Higher
Offer superior conformance quality	1	2	3	4	5	No	Lower	Higher
Offer more dependable deliveries	1	2	3	4	5	No	Lower	Higher
Offer faster deliveries	1	2	3	4	5	No	Lower	Higher
Have superior customer service (after-sales and/or technical support)	1	2	3	4	5	No	Lower	Higher
Provide a wider product range	1	2	3	4	5	No	Lower	Higher
Offer newer products more frequently	1	2	3	4	5	No	Lower	Higher
Provide greater order size flexibility	1	2	3	4	5	No	Lower	Higher
Offer evironmentally sound products	1	2	3	4	5	No	Lower	Higher
Other (please specify)________________	1	2	3	4	5	No	Lower	Higher

Table AI.

Question D2 was used from IMSS-3 for identifying the relationship between strategic capabilities. 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 shown 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.

D2. Please indicate the amount of change of the following performance dimensions over *the last three years:*

	Strongly deteriorated		No change		Strongly improved
Manufacturing conformance	1	2	3	4	5
Product quality and reliability	1	2	3	4	5
Product customization ability	1	2	3	4	5
Volume flexibility	1	2	3	4	5
Mix flexibility	1	2	3	4	5
Time to market	1	2	3	4	5
Customer service and support (customer satisfaction)	1	2	3	4	5
Delivery speed	1	2	3	4	5
Delivery reliability	1	2	3	4	5
Manufacturing lead time	1	2	3	4	5
Procurement lead time	1	2	3	4	5
Procurement costs	1	2	3	4	5
Labor productivity	1	2	3	4	5
Inventory turnover	1	2	3	4	5
Capacity utilization	1	2	3	4	5
Overhead costs	1	2	3	4	5
Environmental performance	1	2	3	4	5

Table AII.

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