A system dynamics computer-based learning environment for the formulation of manufacturing strategy

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Abstract

The paper discusses how the calibration and use of a Computer Based Learning Environment (CBLE), which is based on a system dynamics model, can form the basis of strategy formulation processes at the operations level. The rationale behind, the structure and the elements of the SYDMAS CBLE, as well as its embedment in a scenario-driven manufacturing strategy formulation process are presented. Through a use case, it is shown how the CBLE can enhance the manufacturing strategy formulation process by providing a dynamic perspective and by effectively supporting the related social and knowledge processes.

1. Introduction

Over the last three decades, based on the realisation of manufacturing's potential to act as a direct source of competitive advantage (Skinner, 1969; Hayes and Wheelwright, 1984), manufacturing strategy (otherwise synonymous to operations strategy for more service-oriented firms) has emerged as one of the most important constituent parts of corporate strategy. The formalisation of the development and deployment processes of this functional strategy has been of interest to many academics and practitioners. The majority of authors, influenced by the application of the "rationalistic" paradigm of strategy, have proposed tools and procedures for statically assessing the manufacturing's internal and external environment at a particular instance in time, and for identifying the actions needed to achieve fit among them (e.g. Platts and Gregory, 1990; Mills, et al., 1995; Joseph, 1999; Quezada et al., 1999; Hill, 2000; Tan and Platts, 2004). (It should be noted that currently manufacturing strategy is assumed to include all activities along the value chain through which physical objects (raw materials, components, products) are moving.) Nevertheless, given the dynamic and unpredictable nature of environmental changes, as well as the dynamic evolution of the internal resources and capabilities, purely rationalist approaches to manufacturing strategy formulation seem to be insufficient. Manufacturing-related resources and capabilities take time to build and the opportunities identified may disappear, or change to a lesser of greater degree, in the mean time (Hayes et al., 1996).

On a different to the "rationalist' and prescriptive perspective, the emergent/evolutionary strategy paradigm (Mintzberg and Waters, 1985; Mintzberg and Lampel, 1999) emphasizes retrospective sense-making of strategic initiatives but undermines the fact that strategy-making, in one way or another, takes place in anticipation of the future before actions are decided and implemented. Moreover, its basic philosophy disempowers the role of managers and is quite complicated to apply in real situations (Van der Heijden, 1996), especially in manufacturing/operations and other functionally interdependent strategies.

To address the requirements of explicitly taking into account the dynamics of manufacturing system in establishing a reliable formulation process, we have adopted a processualist/learning perspective in strategy making. In this view, the strategy process per se has more, or at least the same, importance as its content and outcome. Towards this end, we have developed and used a novel formulation process which relies on learning technology. Our process diverts from traditional scenario-building exercises (Codet, 1987; Schoemaker, 1995; Van der Heijden, 1996) in that it relies on the use of SYDMAS (System Dynamics in MAnufacturing Strategy), a Computer-Based Learning Environment (CBLE) specific to the manufacturing/operations strategy process. The technology used diverts from traditional decision-support tools for the same task (e.g. TAPS of Tan and Platts (2004a; 2004b)) in that is fully parameterised, operates at the purely strategic level, explicitly considers the dynamics of the manufacturing system, and, more importantly, it does not fully rely on the subjectively-developed "objective" knowledge of the developer. Instead, the calibration of a pre-structured system dynamics simulation model and the execution of simulations constitute learning exercises, where knowledge elicitation from diverse sources and recombination take place. In the long term, this enhances team learning and decision-making capability, and provides the medium for the development of a shared perspective for managers with diverse backgrounds and responsibilities, who are, however, stakeholders of manufacturing strategy. In other words, the model serves as a "transitional object" for mental models (Papert, 1980; Morecroft, 2004).

This paper concentrates on the characteristics of the learning environment (SYDMAS) and its embedment in the overall manufacturing strategy process. We show how a CBLE can support a strategy process which satisfies the requirement for a dynamic perspective in uncertain environments. In addition, we demonstrate the use of SYDMAS and its associated process through an application example of manufacturing strategy formulation in a real company. Finally, we discuss our experiences from this application.

2. Coping with dynamics: A dynamic model of manufacturing strategy

2.1 Conceptual issues

In a dynamic resource-based perspective (Dierickx and Cool, 1989), manufacturing strategy can be thought as a sequence of decisions and actions on the accumulation and combination of manufacturing tangible and intangible assets stocks (resources, capabilities and competences), which are necessary for achieving a sustainable fit of the firm with its environment (Grant, 1991; Slack and Lewis, 2002). Resources are stocks of available factors which are owned or controlled by the firm, and may include production equipment, planning and scheduling software, machine operators, reputation for quality products etc. Capabilities, on the other hand, can be defined as the capacity of a company to deploy resources, or combinations of resources using organisational processes (Amit and Schoemaker, 1993), or routines (Nelson and Winter, 1992). For instance, a company can use its flexible equipment (resources) effectively if it has a capability in complex scheduling. The stock levels of capabilities are accumulated through the execution of organisational activities and influence the rates of resource accumulations (complex scheduling capability facilitates the deployment of flexible machinery). Both capability and resource accumulations may be self reinforcing, e.g., an existing capability in complex scheduling many be easily extended horizontally by training internally new schedulers, or vertically by learning more complex and more efficient methods. In addition, resource building activities influence the rate of capability accumulation (frequent deployment of flexible equipment in production processes increases the capability of developing complex schedules).

The combination/architecture of manufacturing strategic assets and their stock levels define not only the range and the economies of the activities in which the firm can engage at any point in time (Ghemawat et al., 2001), but also plays a decisive role on the choices of the future competitive objectives by determining the difficulty involved in developing the newly required assets. Specific assets, at specific stock levels may augment or limit the decision space of future manufacturing and corporate strategies (path-dependent trade-offs). For instance, a firm that has invested in dedicated capacity can easily adopt cost leadership strategies by exploiting its capacity and by being supported by its infrastructural attributes (e.g. highly specialised automation, untrained personnel, lengthy production schedules etc.) which have been tuned to large-scale operations. In general, however, the same firm will have a difficulty in adopting a mass-customisation strategy after developing structural and infrastructural resources for mass production.

2.2 Manufacturing strategy dynamics

Integrating the above concepts within the production/operations context, we have developed the resource-based model of manufacturing strategy shown in figure 1. Being a complex system, the manufacturing activity-asset architecture exhibits behaviours which are governed by the spatial and temporal interconnections among its elements, that is, the way functional assets and processes (sets of activities) are related over time. To conceptualise the roots of the dynamic behaviour of such a system, we rely on the modelling language of system dynamics. In system dynamics, the accumulation of assets as a result of the execution of specific activities over time can be modelled by stocks, whereas the rates of accumulation (decisions, activities and processes) and erosion/depletion as flows (Morecroft, 1999; Adamides, 2002; Mollona, 2002; Warren, 2002; Groessler, 2005).

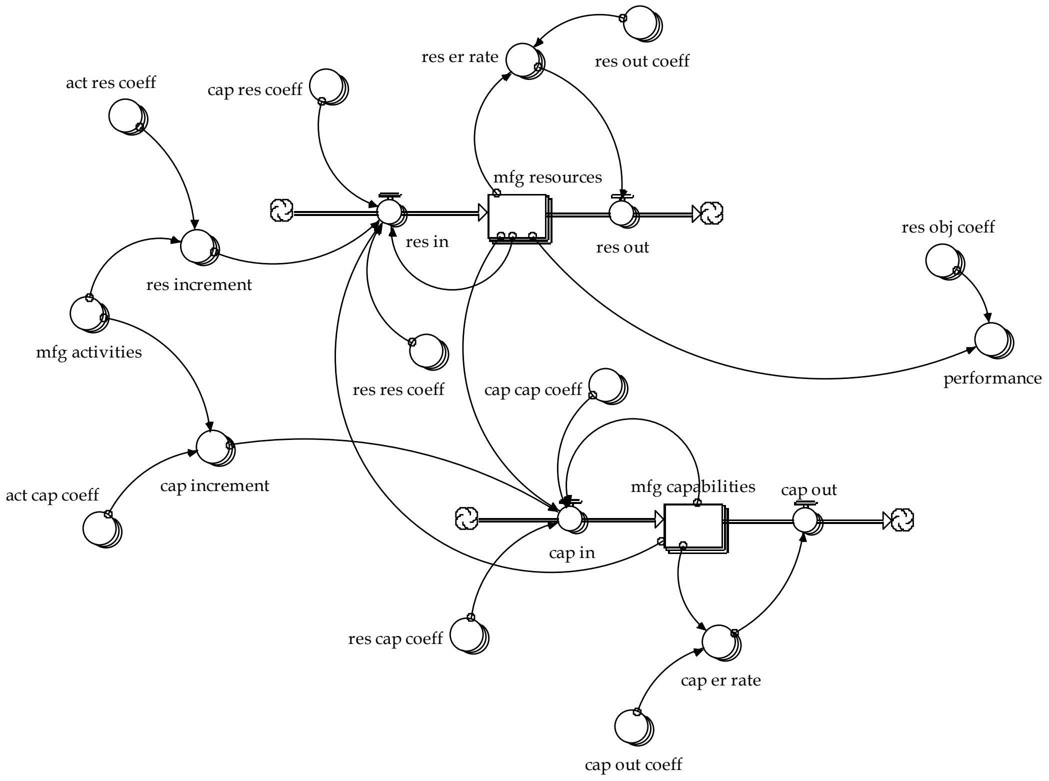


Figure 1 *The system dynamics model of manufacturing strategy*

In the model of figure 1, *mfg_resources* and *mfg_capabilities* are two sets of stocks (array stocks) representing the accumulation of manufacturing-related resources and capabilities, respectively. On the other hand, *res_in* is a set of (array) flows indicating the rate of accumulation of manufacturing resources, whereas *cap_in* is a set of flows representing the rate of accumulation of manufacturing capabilities. Both rates depend on the intensity and frequency of execution of a set of resource and capability building activities (*mfg_activities*) which may belong to specific operational processes (or *routines*), or may be intentional asset development decisions, such as investment in equipment and facilities. The rates of resource and capability erosions are represented by the set of flows *res_out* and *cap_out*, respectively, which depend on the current level of their corresponding stock (*res_out_coeff* and *cap_out_coeff* through the intermediate variables *res_er_rate* and *cap_er_rate*).

The performance of the manufacturing function is measured with respect to the stock levels of its resources. Resource levels correspond to the values of the typical manufacturing performance objectives of cost, flexibility, dependability, quality and speed through a matrix (two-dimensional array) of coefficients *res_obj_coeff*. The links between *mfg_resources* and *cap_in* on the one hand, and *mfg_capabilities* and *res_in* on the other, indicate the mutual dependence of resources and capabilities. How resources and capabilities are linked (whenever specific pairs are linked) is indicated in the converter matrices of coefficients *res_cap_coeff* and *cap_res_coeff* of appropriate dimensions. The matrices of coefficients *act_res_coeff* and *act_cap_coeff* denote the relation (if it exists) of specific activities to the resources and capabilities of the manufacturing function (through the intermediate variables *res_increment* and *cap_increment*, respectively). The mutual effect of the stock levels of resources and capabilities (facilitating or impeding) is indicated by the converter matrices *res_res_coeff* and *cap_cap_coeff* within the corresponding reinforcing loops. They indirectly indicate any trade-offs among resources and among capabilities, that is whether the earlier development of a specific resource hinders the execution of activities towards the development of trade-off manufacturing resources.

Consequently, what constitutes manufacturing strategy in the logic of the above model, is the establishment of the conditions which create reinforcing loops among specific sets of resources and capabilities. This becomes possible by identifying and building distinct manufacturing resources, capabilities and/or linkages among them, and/or by selecting improvement programs which result in faster, or superiorly timed, resource and capability accumulations.

It should be noted that the purpose of the model of figure 1 is to demonstrate the basic elements of the resource-capability system. Clearly, the actual working model used in SYDMAS contains more elements for reasons imposed by the technicalities of the simulation environment, for additional calculations (cost and risk), as well as for implementing the graphical displays.

2.3 SYDMAS – A CBLE for the formulation of manufacturing strategy

Computer Based Learning Environments (CBLE) or Microworlds have been developed and used for enhancing learning in strategic planning and decision making processes (Morecroft, 1988; Issacks and Senge, 1994). CBLEs for strategic management have been associated with system dynamics because at the heart of the majority of CBLEs lies a flexible dynamic simulation model at this level of abstraction (not discrete event) of the issue or the problem to be dealt with. Through user-friendly interfaces, they provide the medium for simulation-supported scenario building, experimentation and evaluation. According to Riis and Smeds (1998), what constitutes a learning environment extends from a simple simulation model and its interface to include the physical and social setting, the facilitation and the debriefing of the simulation. In the manufacturing/operations area, the most frequent use of a CBLE is for training purposes (*learn by doing*) (Smeds, 2003), while their embedment in actual organisational tasks (*do by learning*), is principally associated to discrete event process models for change management (development and re-engineering of administrative and industrial processes, e.g., Taskinen, 2003).

In the manufacturing strategy context, the SYDMAS learning environment allows strategists to address and experiment on questions such as: When the market requirements and the specific manufacturing competence will be aligned? How long will that take? When should the firm increase the effort to achieve this on time? Do current decisions enhance or limit the long-term strategic flexibility of the manufacturing function? What is the emerging performance of the manufacturing competences?

The kernel of the SYDMAS computer-based learning environment is the implementation of the resource-based model of manufacturing strategy of the previous section in the system dynamics simulation environment *ithink Analyst*. Users can calibrate and manipulate the model through friendly interfaces. They can specify the current/initial state of resources and capabilities, as well as the impact/contribution factors and the scaling coefficients of the model. The execution of activities can be specified in two modes: either interactively during the simulation as rates (e.g. monthly), or as commitments of a particular intensity that take place at a specific time period. In the current version of the SYDMAS prototype, up to nine activities with their associated costs and risk factors can be specified. The performance sought can be defined in terms of the performance objectives of cost, flexibility, dependability, quality and speed for up to five manufacturing processes simultaneously which are directly related to products or product groups. Aggregates for more than one product group can also be defined (the default mode of aggregation is by averaging, but other modes can also be specified). Simulations can be executed either by fixing the parameters of the model at the beginning, or interactively in the management flight simulator mode. Absolute or comparative (discrepancies) performance levels with respect to the required ones can be displayed. Total costs, cost profiles and costs per activity, as well as risk estimates are also calculated and displayed. Costs are defined per activity and are accumulated according to the frequency and intensity of activity execution.

In the manufacturing strategy formulation process presented in the following section, the use of SYDMAS serves a two-fold purpose. First, the determination of linkage coefficients to calibrate the model provides the incentive to research, discuss and make sense of the current state of the company's manufacturing operations and strategies. Secondly, the experimentation and evaluation of alternative activity execution schemes and interventions on the linkages among the elements of the model constitute a learning exercise that cannot be accomplished in its absence. In both cases, the model acts a medium to engage managers in a strategic conversation of immense depth and value for the company.

3. Coping with uncertainty: Manufacturing strategy as a learning exercise

3.1 The overall process

The methodology developed is a facilitator-driven process that combines two of the most widely used tools of the procesualist, or learning, school of strategy development: *construction of scenarios* and *group model building and evaluation*. As with other participative approaches to strategy formulation that use information technology for mapping (e.g. the SODA methodology and Group Explorer (Eden and Ackermann, 1998, and the system dynamics approach of Vennix (1996)), the facilitator is responsible for using the mapping, simulation or, as in our case, learning software tool.

The scenario approach aims at overcoming the drawbacks and limitations of forecasting by providing a structured method to speculate about possible futures. The value of scenario planning does not stem from its outcomes but rather from the process of scenario construction itself which stimulates learning. On the other hand, model construction and manipulation, as well as interactive simulation are also widely used tools to enhance learning, so that more educated decisions are made. Furthermore, group model building is a process used to integrate and coordinate mental models and contexts of individual managers participating in strategy formulation (Eden and Ackermann, 1998; Vennix, 1996).,

In the proposed methodology, scenarios are built to speculate about the future trends and competitive forces that shape the external environment and to derive the required manufacturing performance objectives profiles (required performance with respect to time). The instantiation/calibration of the generic system dynamics model template of manufacturing operations, which in effect constitutes a group model-building exercise, and the simulations with the resulting model are used to understand the inherent dynamics of the firm's manufacturing-resource and capability architecture, as well as to evaluate intended improvement programmes. In this sense, system dynamics modelling is accomplished in an "interactive" mode to enhance the social and knowledge processes of strategy formulation (Lane, 1999; Lane, 2000).

In brief, our methodology consists of three learning exercises (L1 to L3) structured into the following stages:

L1. LEARNING THE DYNAMICS OF RESOURCE-BASED MANUFACTURING STRATEGY (CONTEXT INDEPENDENT)

- Exploration of the system dynamics model of manufacturing strategy – Facilitator-driven.
- Understanding the linkages between system elements - Facilitator-driven.

L2. LEARNING THE DYNAMICS OF INTERNAL AND EXTERNAL ENVIRONMENT (CONTEXT SPECIFIC)

A. ASSESSMENT OF EXTERNAL ENVIRONMENT

- Definition of planning horizon – Discussion – Agreement.
- Identification of future market events at-large – Discussion – Agreement.
- Identification of corporate level event s– Discussion – Agreement.
- Identification of product level events – Discussion – Agreement.
- Construction of required performance objectives profiles (RPOP) – Facilitator – Discussion – Agreement.

B. ASSESSMENT OF INTERNAL ENVIRONMENT

- For each product, product group, or business unit, assessment of current manufacturing performance with respect to the manufacturing performance objectives (cost, flexibility, quality, speed, dependability) – Discussion - Agreement.
- Identification of manufacturing-related resources – Discussion – Agreement.

- Determination/estimation of contribution of resources to manufacturing objectives – Discussion – Agreement.
- Identification of manufacturing-related decisions, improvement activities and processes – Discussion – Agreement.
- Determination/estimation of contribution of decisions, improvement activities and processes to resource accumulation – Discussion – Agreement.
- Determination of linkages among resources and capabilities – Discussion – Agreement.
- Calibration of system dynamics model – Facilitator – Discussion – Agreement.

L3. LEARNING FROM THE RESPONSES TO THE ENVIRONMENTAL SETTINGS (CONTEXT SPECIFIC)

C. DEVELOPMENT OF MANUFACTURING STRATEGY

- Establishment of improvement projects as sequences of timed activities – Discussion – Agreement.
- Execution of simulations to construct performance profiles – Facilitator – Discussion.
- Estimation of effort required for achieving these profiles – Discussion – Agreement.
- Comparison of performance objectives profiles with the required ones – Discussion – Agreement.
- Repetition of C for the same scenario or for different scenarios (phase A), if necessary.
- Repetition of C for alternative assessments of internal environment (phase B), if necessary.

The three core phases of the approach are discusses in more detail below.

3.2 Assessment of external environment

In this phase scenarios of the external environment are constructed for the planning horizon, which is typically up to five years. The usual scenario building procedure, which considers events in the economic, social, technical and demographic spheres is used (Schoemaker, 1996). (It is obvious that the presentation of the detailed scenario-construction process is not the purpose of this paper. Thorough insights on this process can be found in Codet (1987), Schwartz (1996) and Van der Heijden (1996).) For each scenario, the strategic objectives necessary for achieving competitive advantage are identified. These are then translated into required timed characteristics for operations associated to product or product group offerings, and expressed in a 1 to 5 scale (1 = very weak, 2 = weak, 3 = average, 4 = strong, 5 = very strong requirement) with respect to the performance objectives of cost, flexibility, quality, dependability and speed.

The SYDMAS learning environment allows required performance objectives profiles to be defined interactively either by specifying ratings for specific periods, at different levels of time detail (week, month, 6-month, etc.), or by drawing patterns of evolution of importance (again within the range of 1 to 5). Figure 2 shows a screen-shot of the related interface and a diagram of the input strategic manufacturing profiles for a specific product group.

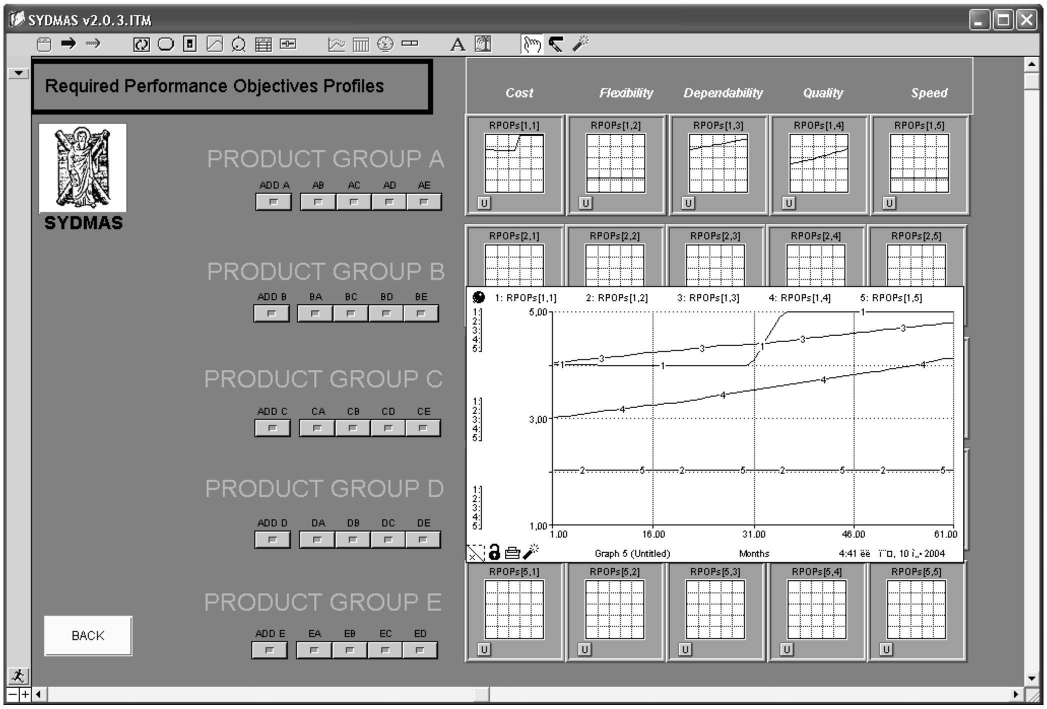


__Figure 2__ The SYDMAS interface for the definition of the required performance objectives profiles.

3.3 Assessment of internal environment

Once a qualitative assessment of the company's current manufacturing performance is accomplished with respect to the performance objectives for the products, product groups or business units under consideration, the assessment of internal environment concentrates on the identification and the assessment of manufacturing related tangible and intangible resources (e.g. packaging machine capacity, workers training level) which play a significant role in achieving the objectives set in the previous phase. These resources are listed with an evaluation mark in the range 1 to 5 to indicate, at the two extremes of the scale, whether they are fully developed strategic resources (given a rating of 5) or resources which are marginally developed (rating = 1).

Then the *res_obj_coeff* matrix is constructed. Each element of the matrix indicates the degree of importance of each resource with respect to each of the five principle performance objectives. Again, the scale of ratings is between 1 and 5 (1 = very small contribution, 2 = limited, 3 = average, 4 = important, 5 = decisive resource in achieving the specific objective).

The next step in this phase involves the identification of the appropriate decision areas (*activities*), and the estimation of the influence that each decision and related action has on each of the previously identified resources (e.g. how the investment on an advanced scheduling system influences the level of the associated complex scheduling capability, or how the upgrading of a packaging machine enhances the packaging capability of the company). Associations between decisions/activities and resources are tabulated in the *act_res_coeff* matrix. The scale of ratings is again from 1 to 5 with the same meaning as for the contribution of resources to performance objectives. The same takes place for capabilities (*act_cap_coeff*). The linkages between resources and capabilities are also discussed and estimated (*res_cap_coeff* and *cap_res_coeff*).

All coefficient matrices are used to calibrate (scale) the system dynamics model in an interactive fashion by taking into account the current state of the internal environment and the observed or calculated performance. The resulting model presents a quantitative estimation of the firm's manufacturing function's current operation at the strategic level. At this stage, the execution of the simulation model provides an estimation of the projected future performance of the manufacturing function with the current set and levels of resources, capabilities and activities/policies. In addition, it provides a picture of the inherent dynamics of the current resource-capability system with no external disturbances in the form of new policies, improvement programs, etc.

3.4 Development of manufacturing strategy

This phase starts with proposals and discussions on the initiatives that must be undertaken for achieving the required performance profiles defined for each scenario. Effectively, it is a process where individual mental models are exposed and accommodated into a single perspective through discussion and argumentation. The use of the learning environment facilitates this task as it allows for the immediate testing of individual assumptions and intuitions. As strategies are formulated, assumptions on the current state of the manufacturing system may be revised.

Strategies, as timed investment and improvement decisions, may be formulated as a whole and then tested using SYDMAS, or alternatively, may be decided "on the fly" as the simulation runs by observing the results of previous decisions. The projected manufacturing performance is assessed with respect to the performance objectives profiles defined in phase A. The total effort (investments) to achieve each profile is calculated automatically based on estimations of activity costs (sum of activity costs). As in the Activity Based Costing system, for each activity, the cost per unit execution has to be estimated, after the activities necessary for strategic initiative are determined. A risk estimate for each strategic initiative is calculated on the basis of certainty factors defined for the relations/contributions among activities, resources, capabilities and performance objectives, as well as for the required performance objectives profiles. Certainty values are collective estimates usually obtained through discussion and voting. The total certainty (risk) is the product of the certainty factors of cascaded associations. Simulations can be executed for different RPOPs (different scenarios of the external environment dynamics), or different internal assessments of all parameter values/assessments, i.e. for decisions, resources and their interrelations, as well as the relations among resources and performance objectives.

In practice, frequently, the manufacturing strategy process is driven by an "end-means" rule, that is, it becomes an attempt to close the gap between current and required performance, which is translated into a quantitative percentage increase (or decrease) of specific performance objective within a pre-specified time period, e.g. increase volume flexibility by 10% in the next six months. To get some directions on how to do this, the manufacturing strategy team, works backwards (returns to previous phases). First, by considering the appropriate performance metrics requirements, finds which resources and capabilities contribute to this performance objective. Then, the amount of change required for each resource to achieve the new performance objective is estimated. The next question that has to be answered is how to achieve this change in resources, i.e. which activities should be executed, and at what rate, for augmenting the resources.

As the relationships among performance objectives, resources and activities are quite complex inducing dynamic effects, it is important to experiment with different decision (activity) combinations and timings to see the effects and the results of each decision setting. As it is shown in the case example provided in the next section, SYDMAS and its associated process can efficiently support this process.

4. The use of the methodology – An example case

Almost twenty years ago, FOODCO S.A. (the real name of the company is disguised for confidentiality) was one of the largest cooperative-owned operations in food processing in Greece producing a relatively constant range of products around two business units with distinct manufacturing facilities: tomato and canned vegetable products (tomato paste, peeled whole and diced tomatoes, ketchup, peas, beans, pickles, peppers, etc.) and potato products (mashed potatoes, frozen fresh fries, etc). After a period of unsuccessful investments in forward (distribution) and backward (development and manufacture of basic food processing equipment) of integration, in the early nineties, the company was in a bad financial and market position. The intervention of the state resulted in the restructuring of the company and the rationalisation of its operations. With a leaner structure the company continued to operate in increasingly competitive domestic and international markets searching continuously for a strategy that will guarantee a sustainable growth and prevent it from eventual financial problems.

Four years ago, the company was a volume producer for the domestic consumer and catering markets with marginal presence in European and Eastern European markets. It also acted as a contract manufacturer for private-label products of major domestic and international supermarket chains. By then, the company operated three business units, after the addition of a frozen vegetables unit to the tomato and potato ones. At that time, FOODCO decided to commit resources on its strategy processes and agreed to adopt (and act as a test-bed for) the methodology and the tool described in this paper for the formulation of its manufacturing strategy. It should be noted that managers of the company had been previously exposed to elements of the methodology and experimented with the basic model in a series of seminars on the use of system dynamics modelling and simulation in the formulation of strategy.

A team of seven managers was assembled, comprising of all business unit and functional managers. The whole process was led by an external facilitator, proficient in the use of the methodology. In a first meeting, the functionalities of SYDMAS were presented to the team giving particular emphasis on the underlying model. Then, six daily sessions of scenario building spread over a period of two months resulted in three concentric sets of scenarios for the external environment. They were distinguished by the extent of their geographic coverage: Scenarios Balkans, Scenarios Europe and Scenarios Globe. Starting from the global level and considering the influence of events to smaller of larger spheres of discourse, for each individual scenario, Required Performance Objective Profiles were constructed. For the shake of presentation, here we select three scenarios, one from each area, namely Large Balkan Markets, Clustering Europe and Open USA. The environmental parameters for the first were summarised in the existence of large low-variety, low-quality markets for tomato and potato products in the near proximity of the company, whereas for the second, the formation of a clustering initiative with other domestic food companies to promote Mediterranean-diet products in the major Western European markets. The third scenario was triggered by the existence of a sweeping consumer trend towards Mediterranean-diet products in the USA.

The determination of RPOPs which involved the quantification of performance objectives proved to be a very time-consuming task as it caused steaming discussions among the members of the group. The role of the facilitator was to turn their attention on estimating RPOPs solely on the basis of the scenarios rather than by considering the current operational and financial state of the company. Discussions and debates resulted in the definition of RPOPs for the three scenarios:

<u>S1: Large Balkan Markets</u>

Increase capacity in the tomato and potato processing units by 20% in 3 years
Reduce operating cost by 20% in 3 years
Keep incremental pace (5-10%, yearly) in quality and dependability
Keep product range and speed of response to current levels

<u>S2: Clustering Europe</u>

Increase vegetable product range by 100% in 5 years
Increase quality by 50% in 2 years
Increase dependability by 20% in 3 years
Increase speed by 30% in 2 years
Keep annual increase in operating costs below 15%

<u>S3: Open USA</u>

Increase capacity in all units by 20% in 3 years
Reduce operating cost by 10% in 3 years
Increase product range by 40% in 2 years
Increase quality by 30% in 2 years
Increase dependability and speed by 20% in 2 years

Moving into phase B of the methodology, facilitated discussion among the company's managers resulted in the identification of three core resources (dedicated high-speed equipment (R1), flexible equipment (R2), trained operators (R3)) and three basic capabilities (fast changeover capability (C1), scheduling capability (C2) and special relationships with suppliers (C3) (in fact, raw material suppliers (small farmers) worked in the factory for an extra income and are equity holders). Additional resources and capabilities belonging to the above macro-resources and macro-capabilities were considered but are not included in the presentation for the shake of simplicity and comprehensiveness. The current state of the company's manufacturing assets was estimated as:

Total capacity:	1 500 000 units

Product range: 32
Assessment of scheduling software: 1 (in a 1 to 5 scale)
Percentage of trained workers: 20%
Changeover capability: 1 (in a 1 to 5 scale)
Scheduling capability: 1 (in a 1 to 5 scale)

The importance factors (contributions) given to the above resources with respect to the performance objectives were

	C	*F*	*D*	*Q*	*S*
R1	5	1	5	3	4
R2	1	5	3	4	2
R3	1	5	5	5	2

The main activities that influence the above resources' and capabilities' accumulation were identified to be
A1: Increase of capacity
A2: New product introduction
A3: Training of operators
A4: Installation of flexible machinery
A5: Installation of scheduling software

The contribution of each activity on the accumulation of every resource was estimated as in the following matrix

	A1	*A2*	*A3*	*A4*	*A5*
R1	5	1	1	1	1
R2	1	5	4	5	5
R3	1	4	5	4	3

Similarly, the contribution of each activity on the accumulation of every capability was estimated as

	A1	*A2*	*A3*	*A4*	*A5*
C1	1	3	5	4	4
C2	1	2	5	3	5
C3	4	1	1	1	1

The resource-capability matrix was formed as

	R1	*R2*	*R3*
C1	-2	5	5
C2	-3	4	3
C3	5	0	-3

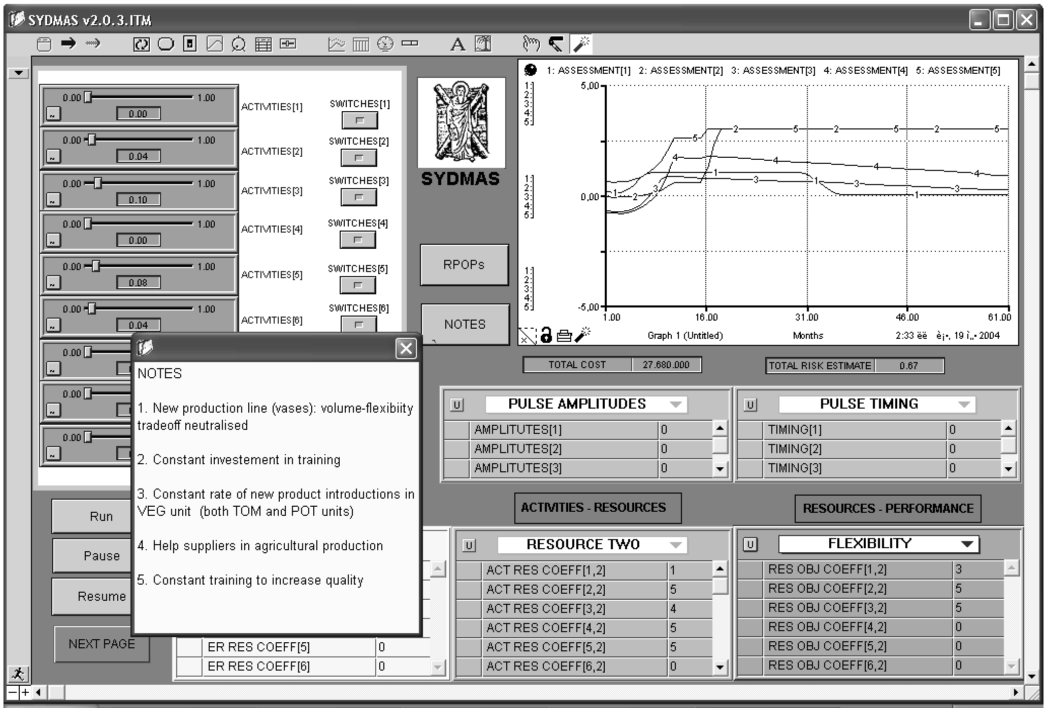
The estimations for the performance of the FOODCO's current manufacturing system were, in an 1-5 scale, Cost = 3, Flexibility = 2, Dependability = 4, Quality = 3, and Speed = 3. The assessments for the company's resource levels were: R1 = 4, R2 = 1, and R3 = 2. For capabilities, C1 = 1, C2 = 1, and C3 = 5. Based on these values, the model's scaling coefficients were calculated. The model was calibrated using these coefficients.

In phase C, in examining how to deal with scenario Large Balkan Markets, the initial assumption of the team was that a new manufacturing site in a Balkan country would be necessary for addressing effectively the required performance objectives profiles. This could very well support the requirement for increased capacity and low cost, but simulations showed that even with the most optimistic estimates this would take at least three years to ramp up (mainly to develop a reliable raw materials supply) with a very high risk (a risk factor of 0.89), especially in terms of achieving the required performance in quality and dependability. The cost of this effort was estimated in the region of 2 500 000 Euros. The actual risk of this scenario was even higher since commitments had to be made at the earliest time possible.

Alternatively, an extension of the existing facilities to accommodate the requirement of additional capacity seemed more promising with a lower cost. This scenario exploited the existing capabilities of FOODCO and the already existing inherent dynamics of the firms manufacturing assets architecture. Different investment and improvement programs were evaluated. The best program found assumed a commitment for the extension of capacity, to be made, at the latest, in about 18 months, accompanied by a parallel introduction of a quality improvement program with emphasis on employee development (to be started at the earliest possible). The cost of this effort, which satisfied the 20% cost decrease objective, was estimated to be around 1 500 000 Euros, with a risk factor of 0.27.

The second alternative strategy was then chosen as a starting point for assessing an eventual change in the focus of importance towards the objectives defined for the scenario Clustering Europe. The internal structure and performance obtained for the scenario Large Balkan Markets were used as the departure point for assessing further strategic moves. The simulations showed that the objectives of scenario S2 could not be achieved with the same operational architecture. Looking into what caused the strategic inertia, the team started to discuss the linkages between resources and capabilities, which obviously governed the dynamic behaviour of the system. Improvement and investment programs that address the requirements of both scenarios simultaneously were put on the table. In dealing with these scenarios, the trade-off relationships among resources and capabilities were examined and redefined to see their effects in SYDMAS. As scenario S2 implied products which required more flexible and complex handling in all manufacturing activities, to test the decision of building a new production line for sauces it was assumed that even the traditional products were treated the same and packaged in plastic vases. This implied the development of resources and capabilities for storing intermediates. A new resource, capability and activity were input into SYDMAS and their contribution and scaling factors were set. In addition, for increasing quality the team examined the possibility of gradually shifting the incentives to suppliers towards advanced training for some of them, and additional support in their agricultural activities for the others. Simulations showed that although this initiative resulted in an initial increase in costs, the combined objectives of the two scenarios could be well satisfied.

The same process was followed in considering scenario S3, and the team ended up with a flexible manufacturing strategy as a set of scalable structural relations, investment activities and operating procedures that can address the requirements of all three scenarios, if necessary. The main constituent parts of this strategy were: early development of a new production process that relaxes the current volume-flexibility trade-off, gradual but consistent redefinition of company's relations with its suppliers and establishment of different HR policies. The main SYDMAS interface indicating the comparative performance assessment of this strategy (for the five performance objectives) is shown in figure 3. On the left of the screen are sliders and buttons through which the intensity and frequency of activity execution were set. On the bottom of the interface are the tables through which the parameters of the model were input. Buttons were used to navigate to different interfaces, to control the simulations and to write and display notes on the scenario being executed.



0.00 – 1.00 ACTIVITIES[1] 0.00
0.00 – 1.00 ACTIVITIES[2] 0.04
0.00 – 1.00 ACTIVITIES[3] 0.10
0.00 – 1.00 ACTIVITIES[4] 0.00
0.00 – 1.00 ACTIVITIES[5] 0.08
0.00 – 1.00 ACTIVITIES[6] 0.04

NOTES

1. New production line (vases): volume-flexibiity tradeoff neutralised

2. Constant investement in training

3. Constant rate of new product introductions in VEG unit (both TOM and POT units)

4. Help suppliers in agricultural production

5. Constant training to increase quality

TOTAL COST 27.680.000

TOTAL RISK ESTIMATE 0.67

PULSE AMPLITUDES	
AMPLITUTES[1]	0
AMPLITUTES[2]	0
AMPLITUTES[3]	0

PULSE TIMING	
TIMING[1]	0
TIMING[2]	0
TIMING[3]	0

ER RES COEFF[5]	0
ER RES COEFF[6]	0

RESOURCE TWO	
ACT RES COEFF[1,2]	1
ACT RES COEFF[2,2]	5
ACT RES COEFF[3,2]	4
ACT RES COEFF[4,2]	5
ACT RES COEFF[5,2]	5
ACT RES COEFF[6,2]	0

FLEXIBILITY	
RES OBJ COEFF[1,2]	3
RES OBJ COEFF[2,2]	5
RES OBJ COEFF[3,2]	5
RES OBJ COEFF[4,2]	0
RES OBJ COEFF[5,2]	0
RES OBJ COEFF[6,2]	0

Figure 3 *The main interface of SYDMAS*

In reality, the whole manufacturing formulation process took seven months. During this period, three facilitators were engaged and five scenarios were considered in detail. The whole process helped the managers of the company to realize what was possible and what was not possible and to acquire new knowledge in terms of market potential and different technical and operational systems. Although the company started to implement with promising success a strategy focusing on the requirements of the first scenario (Balkan markets), its managers have formed a picture of what will look like the markets and the firm's operating environment when similar conditions to those defined for the other scenarios will arise. In addition, it seems that FOODCO's current strategy has the intrinsic flexibility of addressing the requirements of the other scenarios effectively. More importantly, the use of the learning environment helped the decision makers of the company to understand, in a holistic way, the dynamics of the system of which they are part of.

5. Conclusions

In this paper we have presented a novel manufacturing strategy formulation process that relies on the use of scenarios and system dynamics modelling. We have presented the logic of the methodology and the structure of the computer based learning environment that forms its kernel. The use of the methodology and the associated CBLE has indicated that both can enhance the formulation process addressing and overcoming drawbacks of other approaches by providing

- a means to represent, understand and take into account the structures responsible for the dynamics of the manufacturing function's asset system
- a platform for discussion, argumentation and, consequently, knowledge elicitation and recombination by exposing diverse mental models and assumptions of stakeholders
- a platform to "visit" diverse future settings of the internal and external environment of the company.

Although the case presented concerns a company in a relatively mature sector, the methodology and the tool can be (and have been) easily tailored for more dynamic sectors where the potential benefits from their use may be higher. Our current efforts are towards embedding SYDMAS to a collaboration-supporting information system (Adamides and Karacapilidis, 2005; Karacapilidis and Adamides, 2003) that explicitly addresses the requirement for IS support of the social dynamics of the strategy process. Through the implementation of a formal argumentation schema, this will increase the quality and usefulness of simulations by using the collective knowledge of all stakeholders of manufacturing strategy in a more complete and efficient manner.

References

Adamides, E.D., 2002, The use of fitness landscape theory and systems dynamics for the development of manufacturing strategy, In: G. Frizelle and H. Richards, eds., Proceedings of the 2002 Conference of the Manufacturing Complexity Network, Institute for Manufacturing, University of Cambridge, 53-62.

Adamides, E.D. and N. Karacapilidis, 2005, Knowledge management and collaborative model building in the strategy development process, Knowledge and Process Management, 12(2), 77-88.

Amit, R. and P.J. Schoemaker, 1993, Strategic assets and organizational rent, Strategic Management Journal 14, 33-46.

Codet, M., 1987, Scenarios and Strategic Management (Butterworth, London).

Dierickx, I. and K. Cool, 1989, Asset stock accumulation and the sustainability of competitive advantage, Management Science 35, 1504-1511.

Eden C. and F. Ackermann, 1998, Making Strategy: The Journey of Strategic Management (Sage, London).

Ghemawat, P., D.J. Collins, G.P. Pisano and J.W. Rivkin, 2001, Strategy and the Business Landscape: Core Concepts (Prentice Hall, Upper Saddle River, NJ).

Grant, R.M. 1991, The resource-based theory of competitive advantage: Implications for strategy formulation, California Management Review, Spring 33(2), 114-135.

Groessler, A., 2005, An exploratory system dynamics model of strategic manufacturing capabilities, Proceedings of the 23rd International Conference of the System Dynamics Society (CD-ROM version).

Hayes, R.H. and S.C. Wheelwright, 1984, Restoring Our Competitive Edge: Competing through Manufacturing (Wiley, New York).

Hayes, R.H., G.P. Pisano and D.M. Upton, 1996, Strategic Operations: Competing Through Capabilities (The Free Press, New York).

Hill, T., 2000, Manufacturing Strategy: Text and Cases (2nd edition) (Palgrave, New York).

Isaacks, W. and P.M. Senge, 1994, Overcoming limits to learning in computer-based learning environments, In: J.D.W. Morecroft, and J.D. Sterman, eds., Modeling for Learning Organizations (Productivity Press, Portland, OR) 267-287.

Joseph, A.T., 1999, Formulation of manufacturing strategy, International Journal of Advanced Manufacturing Technology 15, 522-535.

Karacapilidis, N. and E. Adamides, 2003, Integrating Simulation and Argumentation in Organizational Decision Making. In V. Palade, R.J. Howlett and L. Jain, eds., Knowledge-Based Intelligent Information and Engineering Systems, Proceedings of the 7th International Conference on Knowledge-Based Intelligent Information and Engineering Systems (KES 2003), Oxford, Lecture Notes in AI, Vol. 2774, (Springer-Verlag, Berlin) 107-114.

Lane, D.C., 1999, Social theory and systems dynamics practice, European Journal of Operational Research, 113, 501-527.

Lane, D.C., 2000, Should system dynamics be described as a "hard" or "deterministic" systems approach?, Systems Research and Behavioral Science, 17, 3-22.

Mills, J., K. Platts, and M. Gregory, 1995, A framework for the design of manufacturing strategy processes, International Journal of Production and Operations Management 15, 17-49.

Mintzberg, H. and J.A. Waters, 1985, Of strategies deliberate and emergent, Strategic Management Journal 6, 257-272.

Mintzberg, H. and J. Lampel, 1999, Reflecting on the strategy process, Sloan Management Review 40 (Spring), 21-30.

Mollona E., 2002, A competence view of firms and resource accumulation systems: A synthesis of resource-based and evolutionary models of strategy-making, In: J.

Morecroft, , R. Sanchez and A. Heene, eds., Systems Perspectives on Resources, Capabilities, and Management Processes (Elsevier Science, Oxford) 93-125.

Morecroft, J., 1988, System dynamics and microworlds for policy makers, European Journal of Operational Research 35, 301-320.

Morecroft, J., 1999, Management attitudes, learning and scale in successful diversification: A dynamic and behavioural resource system view, Journal of the Operational Research Society 50, 315-336.

Morecroft, J., 2004, Mental models and learning in system dynamics practice, in: Pidd, M., ed., Systems Modelling: Theory and Practice, (John Wiley and Sons, Chichester, UK), 101-126.

Nelson, R.R. and S.G. Winter, 1982, An Evolutionary Theory of Economic Change (Harvard University Press, Cambridge, MA).

Papert, S., 1980, Mindstorms: Children, Computers, and Powerful Ideas, (Basic Books, New York).

Platts, K.W. and M.J. Gregory, 1990, Manufacturing audit in the process of strategy formulation, International Journal of Operations and Production Management 10, 5-26.

Quezada, L.E., F.M. Cordova, S. Widmer and C. O'Brien, 1999, A methodology for formulating business strategy in manufacturing firms, International Journal of Production Economics 60-61, 87-94.

Riis, J. and Smeds, R., 1998, The future of simulation games: issues and challenges, in: R. Smeds and J.O. Riis, eds., Experimental learning in production management. The effects of using simulation games in universities and industry (Chapman and Hall, London) 157-164.

Schoemaker, P. J. H., 1995, Scenario planning: A tool for strategic thinking, Sloan Management Review 36 (Winter), 25-40.

Schwartz, P. 1996, The Art of the Long View: Planning for the Future in an Uncertain World (Currency, New York).

Skinner, W., 1969, Manufacturing: Missing link in corporate strategy, Harvard Business Review 47, 136-145.

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

Smeds, R., 2003, Simulation for accelerated learning and development in industrial management (Guest editorial), Production Planning and Control 14, 107-110.

Tan, K.H. and K. Platts, 2004a, Connectance model revisited: A tool for manufacturing objective deployment, Journal of Manufacturing Technology Management 15, 131-143.

Tan, K.H. and K. Platts, 2004b, Operationalising strategy: Mapping manufacturing variables, International Journal of Production Economics 89, 379-393.

Taskinen, T., 2003, Improving change management capabilities in manufacturing: from theory to practice, Production Planning and Control 14, 201-211.

Van der Heijden, K., 1996, Scenarios: The Art of Strategic Conversation (Wiley, Chichester, UK).

Vennix, J.A.M., 1996, Group Model Building: Facilitating Team Learning Using System Dynamics (Wiley, Chichester, UK).

Warren, K., 2002, Competitive Strategy Dynamics (Wiley, Chichester, UK).