Chapter 2

A DSS FOR STRATEGIC PLANNING

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Abstract This chapter presents an innovative approach for assisting entrepreneurs in making long term capacity decisions in Advanced Manufacturing Systems (AMSs). AMSs require high investment costs in manufacturing equipments, human resources and technology knowledge. Such high investments together with the wideness and the variability of the competition scenario contribute to increase the perception of the risk for industrial entrepreneurs especially in SMEs. This problem could be approached by providing the entrepreneur with a Decision Support System (DSS) able to assist her/him in making long term capacity decision in AMS. The DSS proposed in this chapter allows the entrepreneur to plan its production strategy starting from company business strategy, market strategy, competition scenario and outsourcing scenario. Starting from such information, a Fuzzy Expert Systems allows defining the kind of strategic flexibility the company needs and how the company should compose its production mix between internal production and outsourced one. This strategic information represents the input of a Long Term Capacity Planning Model based on economy of scope models that constitutes the economic and financial hearth of the DSS.

Keywords: Advanced Manufacturing Systems, long-term capacity planning, fuzzy systems, economy of scope.

Introduction

This chapter is about the investigation of the major phases of a strategic planning process in advanced manufacturing systems (AMSs). These systems represent manufacturing technologies that embody all the advantages springing from industrial automation (Numerical Control, Robot, AGVs), integrated and computerized control (Industrial Local Area Network), distributed architecture (agents and holonic manufacturing) and distributed artificial intelligence techniques.

From a global competition point of view, especially if we refer to small and medium enterprises (SMEs) operating in highly dynamic and competitive industries, AMSs enable enterprises to acquire flexibility, i.e. the ability to react fast and with low costs to market changes (Agile Manufacturing).

This is the reason why both industrials and academics agree in assuming a strategic approach to evaluate AMSs investments (Naik et al., 1992). On the other hand, every decision making process related to manufacturing investments involves considerations regarding: risk evaluation, uncertainty estimation, investment planning and timing. In case of AMS investment, these factors heavily impact the final decision because: a) the enterprise perceives a risk that is higher if compared with other manufacturing investments; b) AMSs embody an high flexibility degree that enlarges the investment scenario making higher the investment uncertainty; c) the competitive scenario evolution needs to be also evaluated in order to carry out a correct investment planning and timing.

For such reasons, AMSs investment decisions are perceived, especially from SMEs, as high risk decisions in a very uncertain and complex environment. Many entrepreneurs and researchers have highlighted that this complexity and the related risk do not encourage the adoption of AMSs causing a looseness of competitiveness for SMEs; at the same time, it has been also stressed how the availability of proper Decision Support Systems (DDSs) able to assist enterprises in making decisions about AMSs investments, could reduce the risk and the complexity perception making SMEs more competitive and profitable (Price, et al., 1998). It should be known that AMS design is a complex process that can be hierarchically divided into three phases: a) strategic design, b) production system configuration, c) detailed design. The strategic design phase aims at providing suggestions and indications about AMS strategic variables such as flexibility forms (mix flexibility, technological flexibility, volume flexibility, expansion flexibility and so forth), competitive policies (production mix and volumes etc.), make or buy strategies, and of course, an estimation about the long term capacity to be installed in a time horizon equal to the AMS life cycle. The set of the above decisions puts some important architectural constraints that need to be considered in the following, and more detailed, design phases.

During the last decades, several researches focused on supporting the entrepreneurs in making right decisions, at strategic level, about AMSs investments. The result is a very rich and articulated literature. A detailed analysis of the literature concerning the AMSs strategic issues reveals a predominance of qualitative studies whose main objective is to stress the strategic impact of AMSs; in particular, it has been pointed out how important is to conceive a proper manufacturing strategy aligned with the market (Berry et al., 1999) and in the meantime, able to take into account for the influence of new technologies such as AMSs (Banerjee, 2000; Wu et al., 2000). From a more specific manufacturing point of view, several researchers have pointed out the strategic impact of manufacturing flexibility in changing times (Frazelle, 1986; De Meyer et al., 1989; Tombak, 1990), in order to improve the company ability in creating new markets, reacting faster to market changes, reducing time to market for new product developing.

On the other hand, quantitative studies at strategic level have principally focused on flexibility evaluation and measurement (Feurstein et al., 2000; Parker et al., 1999; Shewchuk, 1999; Bateman et al., 1999), strategic evaluation of AMS installation (Sarkis et al., 1999; Elango et al., 1994; Sheng et al., 1995), economic and financial justification of AMSs (Albayrakoglu, 1996; Mohanty, 1993; Parsei et al., 1989), design approaches at strategic levels (Chan et al., 2000; Babic, 1999; Perrone et al., 1999-a), optimal capacity models for flexible manufacturing systems (Fine et al., 1990) under constraints situations (Lim et al., 1998) and several market conditions (Chung et al., 1998), and finally, the analysis of uncertain impact on AMSs investments decisions (Dangl, 1999; Harrison et al., 1999).

However, from the analysis of the literature three paths that should be deeply investigated emerge: a) the formulation of a set of theoretical models able to highlight the real competitive advantage that several forms of AMSs can lead to a company; b) a deep analysis of the impact of the scenario uncertainty and vagueness on AMSs strategic design decisions; c) the development of an integrated and comprehensive support system able to assist the entrepreneur in all the aspects concerning the definition of AMSs investment decisions (Price et al., 1998). Investment decisions mainly concern the production strategy and the long-term capacity planning, and include decisions regarding the typologies of manufacturing systems to purchase throughout the planning horizon, eventually a mix of typologies such as dedicated manufacturing lines or flexible manufacturing systems. The development of an integrated decision support environment that puts into operation such features, cannot be obtained independently from the development of a theoretical framework and from a deep understanding about how scenario uncertainty can impact such decisions (Perrone et al., 1999-b).

The research presented here follows these directions, specifically, focusing on the development of a theoretical framework able to provide a general understanding of what are the market and competition conditions that have a critical impact on the strategic planning of manufacturing capacity. Then, a decision support system which implements this theoretical framework and suitable for assisting entrepreneurs in making the right strategic decision for manufacturing system design and planning, is presented.

1. The strategic planning process

The activity “A1 Planning at strategic level” of the IDEF0 context diagram, reported in Figure 1.6 of Chapter 1, can be decomposed in two macro-activities: production strategy planning and long-term capacity planning. Figure 2.1 shows the IDEF0 diagram of these activities.

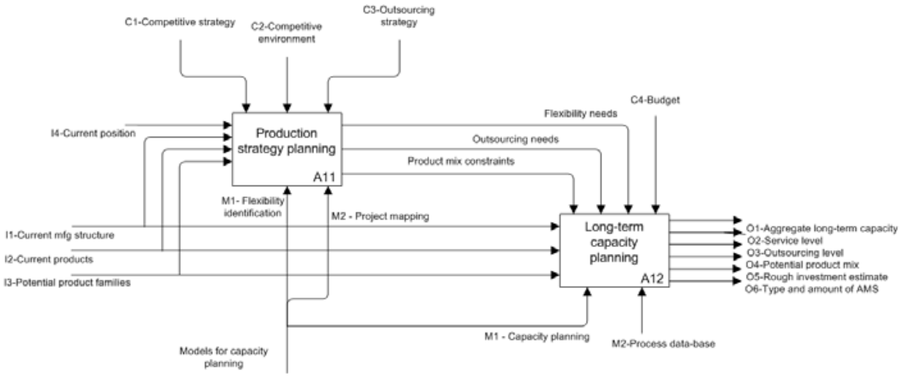


Figure 2.1. A1 level diagram: the strategic planning process.

According to the IDEF0 graphical notation, the inputs, outputs, constraints, and models reported in Figure 2.1, are fully explained in the following.

1.1 [A1-1] Production Strategy Planning

This activity aims at the identification of the enterprise production strategy. The production strategy involves three main decisions: the flexibility types to adopt (product, routing, expansion, and reconfiguration flexibility), the product mix constraints, and the outsourcing policy constraints.

Input

- [A1-1]-I1 **Current manufacturing structure**: such input concerns information regarding the production systems and manufacturing equipments that are currently used to manufacture the current products.
- [A1-1]-I2 **Current products**: the set of products the enterprise currently produces.
- [A1-1]-I3 **Potential products**: the set of the products the enterprise is going to produce in the future.
- [A1-1]-I4 **Current position**: this input describes the current market positioning of the enterprise.

Output

- [A1-1]-O1 **Flexibility types**: this output indicates which flexibility types (product, routing, expansion, and reconfiguration flexibility) are necessary for producing the potential product mix. The output is expressed by a linguistic term associated to each flexibility type, e.g. “the routing flexibility is very important”.
- [A1-1]-O2 **Outsourcing constraints**: this output summarizes the outsourcing policies related to every product and it is expressed by means of a linguistic term, which represents the level of suitability of outsourcing a given product, e.g. “the product AA1 should be strongly outsourced”.
- [A1-1]-O3 **Product mix constraints**: this output gives information regarding the competitive constraints that should be applied to the mix of products. In particular, the output is expressed by means of a linguistic term, which represents the product mix policy to be adopted, e.g. “the product mix should be amplified”.

Constraints

- [A1-1]-C1 **Competitive strategies**: this constraint indicates the business strategy the enterprise wants to pursue. The constraint is expressed by a linguistic term that synthesizes the business strategy itself, e.g. "the business strategy is oriented to the product differentiation".
- [A1-1]-C2 **Competitive environment**: this constraint includes information on the market scenario where the enterprise wants to compete, for example information on the uncertainty level, competition level, and innovation rate. The constraint is expressed by a linguistic term, which represents the competitive scenario, e.g. "the competitive scenario is strongly dynamic".
- [A1-1]-C3 **Outsourcing strategy**: such constraint concerns the market conditions related to a potential outsourcing activity of some products or components. This constraint includes a preliminary analysis of the suppliers of the products and components to be outsourced, in view of their availability, their reliability, and the outsourcing costs. The constraint is expressed in terms of a linguistic term related to the suitability of the outsourcing activity of a given product, e.g. "the cost of outsourcing product AA1 is low".

Models

- [A1-1]-M1 **Models for flexibility identification**: these models are based on expert systems, specifically fuzzy systems, that determine which flexibility types (product, routing, expansion, and reconfiguration flexibility) are strategic for the enterprise, as a result of considerations on current products, potential products, business strategy, and competitive scenario.
- [A1-1]-M2 **Models for project mapping**: these models are based on fuzzy systems that identify which outsourcing constraints and product mix constraints are strategic for the enterprise, as a result of considerations on current products, potential products, business strategy, and competitive scenario.

1.2 [A1-2] Long-term Capacity Planning

This activity involves the determination of the manufacturing resource mix (composition of the manufacturing system as a mix of dedicated, flexible, and reconfigurable resources) and the relative manufacturing capacity.

Input

- [A1-2]-I2 **Current products**: the set of products the enterprise currently produces.
- [A1-2]-I3 **Potential products**: the set of the products the enterprise is going to produce in the future.

Output

- [A1-2]-O1 **Aggregate long-term capacity**: this output indicates the number of manufacturing system for each type, which should be added to the current manufacturing system configuration.
- [A1-2]-O2 **Service level**: this output gives information about the level of demand fulfillment for every product and for every time bucket (2 years).
- [A1-2]-O3 **Outsourcing level**: this outputs indicates, for each product, the total volume percentage, which should be, outsourced.
- [A1-2]-O4 **Potential production mix**: this output indicates the products that should be part of the new product mix.
- [A1-2]-O5 **Rough investment estimates**: this output gives a preliminary estimates on the investment cost that is necessary to acquire additional capacity.
- [A1-2]-O6 **Types and amount of AMS**: this output defines the manufacturing system composition in terms of the all possible manufacturing system types (dedicated, flexible, or reconfigurable system).

Constraints

- [A1-2]-C1 **Flexibility types**: this constraint originates from the output [A1-1]-O1 and indicates which flexibility types (product, routing, expansion, and reconfiguration flexibility) are necessary for producing the potential product mix. It is expressed by a linguistic term associated to each flexibility type, e.g. “the routing flexibility is very important”.
- [A1-2]-C2 **Outsourcing**: this constraint originates from the output [A1-1]-O2 and summarizes the outsourcing policies related to every product. It is expressed by means of a linguistic term, which represents the level of suitability of outsourcing a given product, e.g. “the product AA1 should be strongly outsourced”.

- [A1-2]-C3 **Product mix**: this constraint originates from the output [A1-1]-O3 and gives information regarding the competitive constraints that should be applied to the mix of products. In particular, it is expressed by means of a linguistic term, which represents the product mix policy to be adopted, e.g. "the product mix should be amplified".

- [A1-2]-C4 **Budget**: this constraint defines the budget which is available for investments in AMSs in the long term. This constraint is decided at the corporate level because it involves the analysis of the firm financial position.

Models

- [A1-2]-M1 **Models for capacity planning**: these models are based on mathematical programming algorithms that, by elaborating fuzzy information from the prior production strategy planning activities, identify the strategic mix of manufacturing systems and manufacturing capacity.

2. Models for Production Strategy Planning

As already mentioned in the previous section, the first level of the strategic planning process concerns the process of determining the production strategy. The production strategy, in few words, consists on making three main decisions:

1 Decisions related to the type of flexibility to be implemented by the manufacturing system in order to be able to manufacture all the parts within the product mix. Product, routing, expansion, and reconfiguration flexibilities are example of flexibility types.

2 Decisions related to the outsourcing policy to be implemented, i.e. the identification of constraints which lead the policy of outsourcing of some manufacturing activities.

3 Decisions related to the competitive constraints, i.e. the constraints of the competitive strategy that influences the design of the production system. Concerning the first kind of decisions, the models for flexibility identification ([A1-1]-M1) have been developed, while regarding the second and third kinds of decisions, the so called models for project mapping ([A1-1]-M2) have been developed.

Concerning the first kind of decisions, the models for flexibility identification ([A1-1]-M1) have been developed, while regarding the second and third kinds of decisions, the so called models for project mapping ([A1-1]-M2) have been developed.

2.1 Models for flexibility identification

The four models for the identification of the flexibility type, one for each flexibility type, are based on expert systems, specifically fuzzy systems. These models are represented in Figure 2.2 where the input and output variables, according to the main IDEF0 diagram are shown.

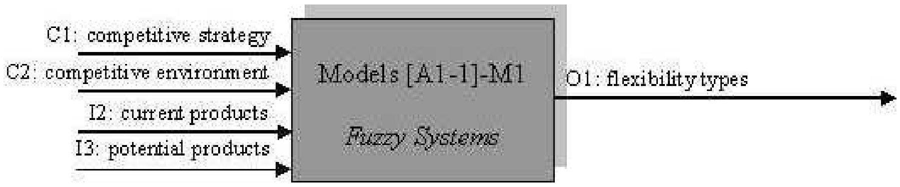


Figure 2.2. Inputs and outputs of the model [A1-1]-M1.

The production system flexibility can be defined as the system ability to rapidly and cost-effectively adapt to market (external) change requirements or enterprise (internal) change requirements. The flexibility types considered by the fuzzy systems are:

- Product (mix- change) flexibility. This is the ability to change the current mix of products by adding new products or substituting the existing ones.
- Routing flexibility. This is the ability to manufacture a product by different alternative process routings throughout the system.
- Expansion flexibility. This is the ability to expand the manufacturing capacity, by means of modular system architectures.
- Reconfiguration Flexibility. This is the ability to change the system configuration when necessary to face market changes for new models of the same product.

As already mentioned four fuzzy systems have been developed, one for each type of flexibility, and each of them uses the business strategy, the competitive scenario constraints, the current products, and potential products input as input variables depending on the considered flexibility type. As output, the fuzzy systems give the importance of each flexibility type. Moreover, these input and output are all linguistic variables (fuzzy variables) that can take the values "low", "medium", and "high"; thus, the term set *T(x)* associated to each variable *x* is *T(x)* = [*Low, Medium, High*], where each term is characterized by a fuzzy set in U=[0 , 1]. The membership functions of the three linguistic values related to every linguistic variable are shown in Figure 2.3.

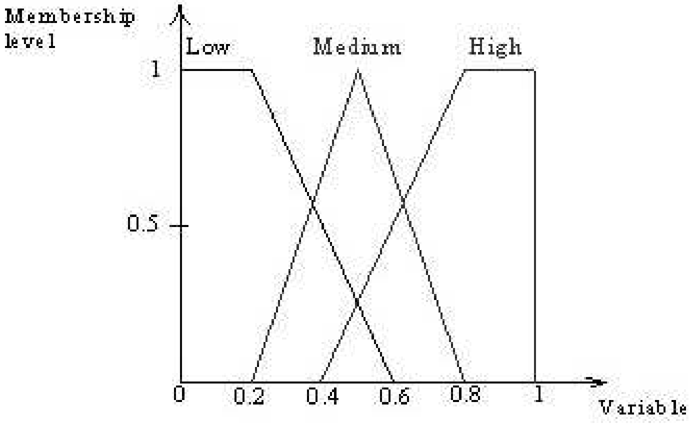


Figure 2.3. Membership functions for the values "low", "medium", and "high".

In Figure 2.4, the input and output specific to the four fuzzy systems are graphically reported. As the reader can notice in Figure 2.4, the fuzzy systems take as input some variables related to the company business strategy and the competitive scenario. In particular, the decision maker should evaluate by means of a linguistic statement the importance of the following input variables:

- reactiveness to internal and external changes
- set-up cost and time reduction
- demand variation
- product life cycle reduction
- reactiveness to internal changes
- product variety

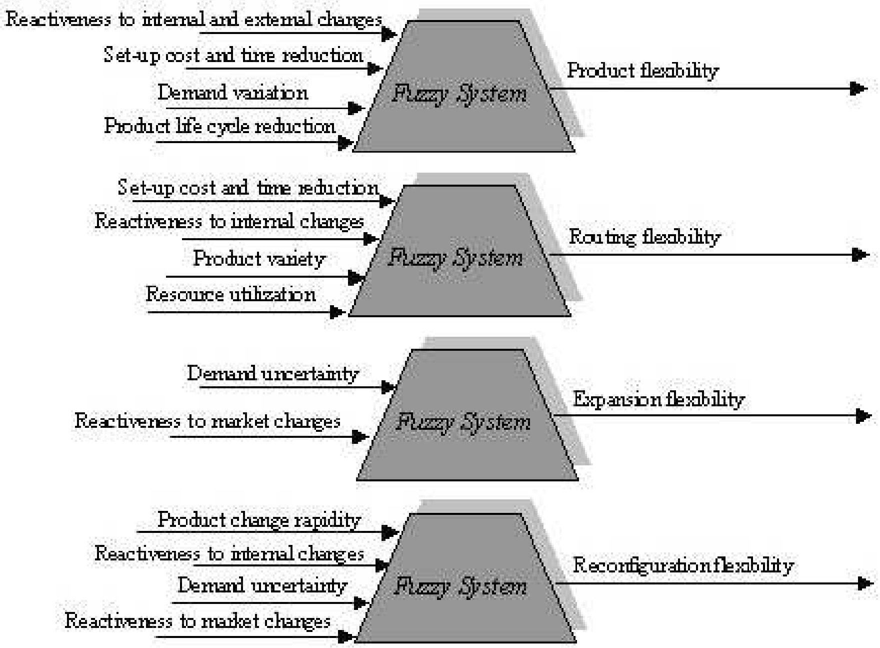


Figure 2.4. Inputs and outputs of the four fuzzy systems of the model [A1-1]-M1.

- resource utilization
- demand uncertainty
- reactiveness to market change
- product change rapidity.

The fuzzy system, by using a knowledge base which consists of a set of fuzzy rules, determines the linguistic values associated with the importance of the output variable of the fuzzy system itself, e.g. the importance of implementing product flexibility. If A_i is the i-th input strategic variable and $L_k(A_i)$ the linguistic value given by the decision maker for the importance of variable A_i, the fuzzy rule $R_{i,f}$, associated with the input variable i and the flexibility type f results:

$$R_{i,f} : \text{IF } A_i \text{ is } L_k(A_i) \text{ THEN } f \text{ is } V_s(f)$$

where $V_s(f)$ is the linguistic variable that expresses the importance associated with the flexibility type *f*.

2.2 Models for project mapping

The models for project mapping are depicted in Figure 2.5 and consist of two fuzzy systems. The former is used to determine the outsourcing conditions and the latter to identify the product mix constraints, as already described in Section 1.

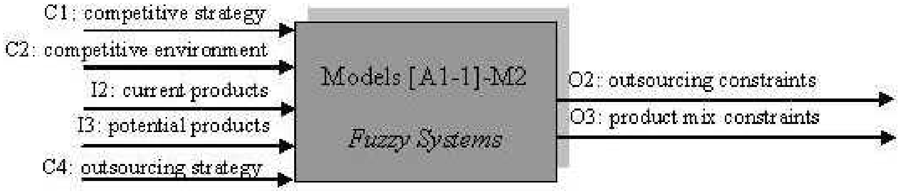


Figure 2.5. Inputs and outputs of the models [A1-1]-M2.

Specifically, Figure 2.6 reports the input and output variables of the two fuzzy systems.

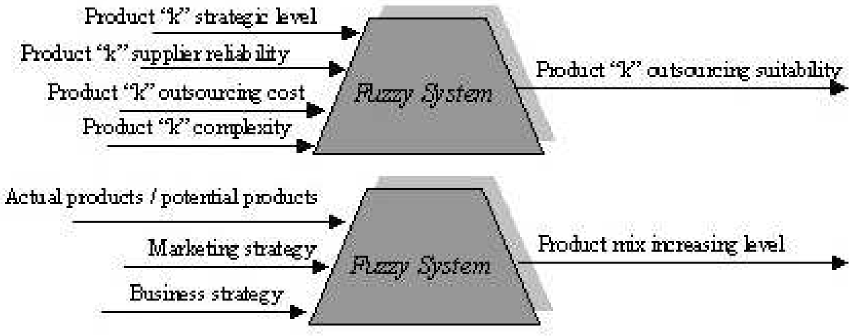


Figure 2.6. Inputs and outputs of the two fuzzy systems of the model [A1-1]-M2.

Specifically, the first fuzzy system, by inferring four linguistic variables describing the strategic level of a specific product "k", i.e. its "strategic level", its "supplier reliability", its "outsourcing cost", and its "complexity", gives as output its "outsourcing suitability". On the other hand, the second fuzzy system, by inferring three linguistic variables describing the business strategies, i.e. the ratio "actual products/potential products", the "marketing strategy", and the "business strategy", gives as output the "product mix increasing level".

3. Models for Long-term Capacity Planning

This model is intended for the identification of the manufacturing system composition in terms of which number of dedicated manufacturing lines (DML), flexible manufacturing systems (FMS), and reconfigurable manufacturing systems (RMS) need to be part of the manufacturing system itself. In other words, the model is able to determine the long term manufacturing capacity for each manufacturing system kind which is implemented. The model runs optimization algorithms based on mathematical programming, capable to deal with fuzzy information. From models [A1-1]-M1 e [A1-1]-M2, it is possible to determine the enterprise production strategy. The production strategy, as it has been defined, means specific choices on the flexibility type to adopt and on the product mix and outsourcing activity constraints to fit. In other words, the output of models [A1-1]-M1 e [A1-1]-M2 represents the input of the model [A1-2]-M1. Such a model is utilized in order to analyze, from an economic perspective, the suitability of a specific manufacturing system configuration (manufacturing mix and capacity) for a given market demand scenario. The next sub-sections present, first, the optimization model in which only the traditional manufacturing system types (dedicated lines and flexible manufacturing systems) are considered. Then, an innovative model, which also takes into consideration the new reconfigurable manufacturing system paradigm, is presented.

3.1 DML and FMS model

Notation:

i	product index, $i= 1, \ldots I$;
j	time bucket index, $j= 1, \ldots J$;
r	cost of capital;
A_j	time availability in j;
D_{ij}	market demand for product i in j;
m_{ij}	contribution margin for product i in j;
V_{ij}^{DML}	volume of product i to manufacture in j by DML;
V_{ij}^{FMS}	volume of product i to manufacture in j by FMS;

V_{ij}^{EST}	volume of product i to outsource in j;
V_{ij}^{TOT}	total volume of product i in j;
DML_i	Dedicate manufacturing line producing product i;
O_i	number of technological operations for product i;
o	technological operation index, $o= 1, ...O_i$ for product i;
t_{io}	processing time of operation o for product i;
BT_i	processing time of the bottleneck machine of DML_i;
CP_i^{DML}	total volume of product i in j;
C_i^{DML}	investment cost for DML_i;
L_{ij}^{DML}	number of DML_i to purchase in j;
FT_i	total processing time for manufacturing product i;
L_j^{FMS}	number of FMS to purchase in j;
WL_j^{FMS}	FMS workload for manufacturing I in j;
C_{FMS}	investment cost for purchasing the FMS;

By denoting with α^{FMS} and β^{FMS} the economy of scope parameters that put into relation DML and FMS, the FMS workload and its investment cost can be calculated respectively as in expressions (2.1) and (2.2):

$$WL_j^{FMS} = \sum_{i=1}^{I} \alpha^{FMS} \times FT_i \times V_{ij}^{DML} \tag{2.1}$$

$$C^{FMS} = \beta^{FMS} \times \sum_{i=1}^{I} DML_i \tag{2.2}$$

The economy of scope technological coefficient, α^{FMS}, takes into account that a flexible system takes less time to fulfill a set of operations than a dedicated line. For this reason α^{FMS} satisfies the condition expressed in equation (2.3):

$$BT_i \leq \alpha^{FMS} \times FT_i \leq FT_i \Leftrightarrow \frac{BT_i}{FT_1} \leq \alpha^{FMS} \leq 1 \tag{2.3}$$

On the other hand, the economy of scope cost coefficient, β^{FMS}, takes into consideration that a flexible system which processes a set of parts is less expensive than the set of dedicated lines needed for processing the same set of parts, although the flexible system is more expensive than each of the dedicated lines. For this reason β^{FMS} must satisfy the condition (2.4):

$$\max_i C_i^{DML} \leq C^{FMS} \leq \sum_i C_i^{DML} \Leftrightarrow \frac{\max_i C_i^{DML}}{\sum_i C_i^{DML}} \leq \beta^{FMS} \leq 1 \tag{2.4}$$

In order to set the optimal investment for DML and FMS, an optimization non-linear constrained programming model has been proposed. Such a model maximizes the return on investment (ROI) calculated as in expression (2.5) for what concerns the DML system and expression (2.6) for the FMS.

$$ROI(DML) = \frac{\sum_j \sum_i m_{ij} \times V_{ij}^{DML} \times (1+r)^{1-j}}{\sum_j \sum_i L_{ij}^{DML} \times C_i^{DML} \times (1+r)^{1-j}} \tag{2.5}$$

$$ROI(FMS) = \frac{\sum_j \sum_i m_{ij} \times V_{ij}^{FMS} \times (1+r)^{1-j}}{\sum_j \sum_i L_{ij}^{FMS} \times C_i^{FMS} \times (1+r)^{1-j}} \tag{2.6}$$

By defining the following functions which map the ROI measures into [0 , 1], both the ROI indexes can be taken into consideration in a single objective function. These mapping functions are reported in expressions (2.7) and (2.8):

$$\mu_{ROI(DML)} = \max\left[0, \min\left[1, \frac{ROI(DML) - ROI_{MIN}}{ROI_{MAX} - ROI_{MIN}}\right]\right] \tag{2.7}$$

$$\mu_{ROI(FMS)} = \max\left[0, \min\left[1, \frac{ROI(FMS) - ROI_{MIN}}{ROI_{MAX} - ROI_{MIN}}\right]\right] \tag{2.8}$$

where ROI_{MIN} and ROI_{MAX} are the minimum and the maximum that the decision maker expects to gain for the two economic variables. The following constraints need to be considered.

Model Constraints

1 *Volume composition constraint.* This constraint implies that the total volume needed for product i in the bucket j is given by the sum of the volume of the same product by producing it in the DML and in the FMS and by outsourcing the volume V_{ij}^{EST} as expressed by equation (2.9).

$$V_{ij}^{TOT} = V_{ij}^{DML} + V_{ij}^{FMS} + V_{ij}^{EST} \tag{2.9}$$

2 *Demand fulfillment constraint.* Condition (2.10) guarantees that the total volume of product i in j must be less than the demand of the same product in the same time bucket and greater than a minimum level depending on the strategic level of the product i itself, expressed through a variable $x_i \in [0;1]$.

$$x_i \times D_{ij} \leq V_{ij}^{TOT} \leq D_{ij} \tag{2.10}$$

3 *Outsourcing strategy constraint.* Relation (2.11) expresses that the volume of product i to outsource in the time bucket j depends on the total volume by means of the variable z_{ij} which, in this way, represents the total volume percentage to outsource. Such a variable, takes into account the information from models [A1-1]-M2, concerning the generic product "k" outsourcing suitability.

$$V_{ij}^{EST} = z_{ij} \times V_{ij}^{TOT} \tag{2.11}$$

In particular, as the output coming out from the model [A1-1]-M2 is a linguistic term like "the outsourcing level of product i is VARling" (where VARling can be "high" - H, "medium" - M, or "low" - L), the outsourcing constraint is expressed by the objective function (2.12):

$$\mu(V_{ij}^{EST}) = \max[0; \gamma_L \times \min[0; (1 - z_{ij})]; \gamma_M \times \tag{2.12}$$

$$\times \min\left[0; \tfrac{z_{ij}-0.5}{0.5}; \tfrac{0.5-z_{ij}}{0.5}\right]; \gamma_H \times \min[0; z_{ij}]]$$

where $\gamma_k = 1$, if $k =$ VARling, 0 otherwise ($k =$ L, M, H).

4 *Manufacturing capacity constraint.* This constraint guarantees that the workloads on the DML and FMS are less than the respective system capacities and is expressed in equations (2.13) and (2.14).

$$V_{ij}^{DML} \leq \sum_{k=1}^{j} L_{ij}^{DML} \times Cp^{DML} \quad \forall i, j \tag{2.13}$$

$$WL_j^{FMS} \leq \sum_{k=1}^{j} L_j^{FMS} \times A_k \quad \forall i, j \tag{2.14}$$

5 *Product mix constraint.* The product mix can be defined by introducing the binary variable y_i which is equal to 0 if product i is internally produced, and 0 otherwise. Of course, condition (2.15) must be satisfied.

$$MIX = \sum_i y_i \tag{2.15}$$

As it has been seen in the previous sections, the output of the model [A1-1]-M2 is a linguistic term representing the increasing level of the product mix (increasing, constant, or decreasing). As for the *Outsourcing strategy constraint*, the constraint on the product mix is translated into the objective function (2.16).

$$\mu_{MIX} = max\left[0; min\left[\frac{\sum_i y_i - a}{\frac{b-a}{2}}; \frac{b - \sum_i y_i}{\frac{b-a}{2}}\right]\right] \tag{2.16}$$

The coefficients a and b can be calculated as in expressions (2.17) and (2.18), given the current mix MIX_{curr}, and m, n the percentage values of the minimum and maximum values of the linguistic terms coming out from the model [A1-1]-M2.

$$a = (1 + m) \times MIX_{curr} \tag{2.17}$$

$$b = (1 + n) \times MIX_{curr} \tag{2.18}$$

Notice that, in the formulation of this model, the budget constraint (C4 in Figure 2.1) and the current manufacturing structure input (I1 in Figure 2.1) have not been considered.

Model Objective Function

After having translated some constraints into single objective functions, the final multi-objective function becomes the one represented in expression (2.19).

$$max[g_1[\frac{1}{I}\sum_i y_i \times \frac{1}{J}\sum_j \mu_{ij}^{EST}]+ \tag{2.19}$$

$$+g_2[k_F \times \mu_{ROI(FMS)} + (1 - k_F) \times \mu_{ROI(DML)}] + g_3[\mu_{MIX}]]$$

Where:

- g_1, g_2 e g_3 are the weights of the three main factors of the objective function and can be chosen by the manager for a specific case during the optimization phase;
- k_F is a flexibility parameter. Its value is obtained from model [A1-1]-M1, by giving proper weights to the crisp values of the *Product Flexibility*, *Routing Flexibility*, and *Expansion Flexibility*.

3.2 DML, FMS and RMS model

Taking into account RMS increases the complexity of the above described investment decision problem. Indeed, it gives even more manufacturing solutions to consider and, also, increases both the uncertainty and risk levels. Let's consider the objective function (2.20) determined in the already presented model by including the reconfigurable manufacturing system option.

$$max[g_1[\frac{1}{I}\sum_i y_i \times \frac{1}{J}\sum_j \mu_{ij}^{EST}]+ \tag{2.20}$$

$$+g_2[k_F \times \mu_{ROI(FMS)} + k_R \times \mu_{ROI(RMS)}+$$

$$+(1-k_F-k_R) \times \mu_{ROI(DML)}] + g_3[\mu_{MIX}]]$$

The objective function presents a new factor $\mu_{ROI(RMS)}$ (once again, the ROI mapping function which can be achieved by producing in the RMS) which is weighted by a flexibility parameter k_R gained by the crisp value of the Reconfiguration flexibility linguistic output from model [A1-1]-M1. Concerning the relationships among RMS with DML, the same considerations that have been exposed for FMS/DML can be formulated. Indeed, although RMS and FMS are two different manufacturing solutions in terms of hardware and software architecture, from an operation management perspective, they present the same feature with respect to DML. Thus, the workload of an RMS that produces all product I in j can be calculated as in equation (2.21), while the investment cost for purchasing the RMS as in equation (2.22).

$$WL_j^{RMS} = \alpha^{RMS} \times \sum_i (FT_i \times V_{ij}^{RMS}) \tag{2.21}$$

$$C^{RMS} = \beta^{RMS} \times \sum_i C_i^{DML} \tag{2.22}$$

Moreover, the conditions (2.23) and (2.24), analogous to (2.3) and (2.4) are still valid.

$$BT_i \leq \alpha^{RMS} \times FT_i \leq FT_i \Leftrightarrow \frac{BT_i}{FT_1} \leq \alpha^{RMS} \leq 1 \tag{2.23}$$

$$\max_i C_i^{DML} \leq C^{RMS} \leq \sum_i C_i^{DML} \Leftrightarrow \frac{\max_i C_i^{DML}}{\sum_i C_i^{DML}} \leq \beta^{RMS} \leq 1 \tag{2.24}$$

When it comes to the relationships among FMS and RMS, some more considerations need to be pointed out. If we think at the RMS as a system made up of a base structure where a number of different modules (each necessary for processing a part type) can be added and removed, then the reconfiguration time (the time to remove a module and add a new one) can be thought of as the FMS set-up time, even though it is surely greater. Then, condition (2.25) holds.

$$\frac{BT_i}{FT_i} \leq \alpha^{FMS} \leq \alpha^{RMS} \leq 1 \tag{2.25}$$

Regarding the investment costs, it can be stated the cost for purchasing an RMS is minor then the one for purchasing an FMS. This because of the different design, structure, and technological levels associated to the two manufacturing systems solutions. For this reason, from relations (2.4) and (2.24), condition (2.26) derives.

$$\frac{\max_i C_i^{DML}}{\sum_i C_i^{DML}} \leq \beta^{RMS} \leq \beta^{FMS} \leq 1 \tag{2.26}$$

4. DSS description

The Decision Support System (DSS), including the fuzzy systems and the interface forms, has been developed into the Visual Basic platform, while the optimization algorithms of the model [A1-2]-M1 has been implemented into LINGO optimization software. The initial menu form of the DSS (Figure 2.7) presents to the user three buttons, each activating the possible use cases. “Insert Data”, from which the user can insert data about the specific problem; “Models for flexibility identification”, by which the user can enter into the models [A1-1]-M1, “Models for project mapping”, by which the user can activate the models [A1-1]-M2.

By clicking the “Models for project mapping” button, the user enter the form represented in Figure 2.8 and can determinate the impact of the input variables *business strategies*, *competitive scenario*, *current products*, *potential products*, and *outsourcing conditions* on the output variables *outsourcing constraints* and *product mix constraints*. The form and its sub-forms (e.g. Figure 2.9), indeed are connected to the fuzzy systems discussed in Section 2. As the reader can notice in Figure 2.8, in order to have the output “outsourcing constraints”, the user needs to select the product, insert a linguistic evaluation on the input parameters, and to run the fuzzy engine by clicking on the button “Results”. It is also possible to visualize the externalization coefficients which will be used as input of the models [A1-2]-M2, i.e. “Long term capacity planning”. When it comes to the strategic evaluation of the flexibility types, by clicking the button “Models for flexibility identification” of the main menu, the form depicted in Figure 2.10 will appear. This form allows selecting a flexibility type among product flexibility, routing flexibility, expansion flexibility, reconfiguration flexibility and to enter the respec-

Figure 2.7. The initial menu form.

tive fuzzy model. For example, Figure 2.11 reports the form for product flexibility. The user expresses the importance level of the input variables and runs the fuzzy engine in order to obtain the evaluation of the importance level of the considered flexibility type. At this point, directly from the form of Figure 2.10, the user can access the models [A1-2]-M1, i.e. “Long term capacity planning” as showed in Figure 2.12 At this point, the user is required to insert the investment costs for purchasing the DML_i and the coefficients α and β which are necessary to run the optimization model. Also, the user must specify the minimum and maximum expected values of ROI and the weights g_1, g_2, g_3 of the objective function. Then for each product and time bucket, processing times and contribution margins, the expected demand, and the strategic level x_i of the particular product i. As soon as all these input are inserted, the user can run the optimization algorithm, automatically performed by the LINGO solver, just clicking the button “Solve”. The optimization results are reported in a new form represented in figure 2.13. As it can be observed, from such a form the following information comes out.

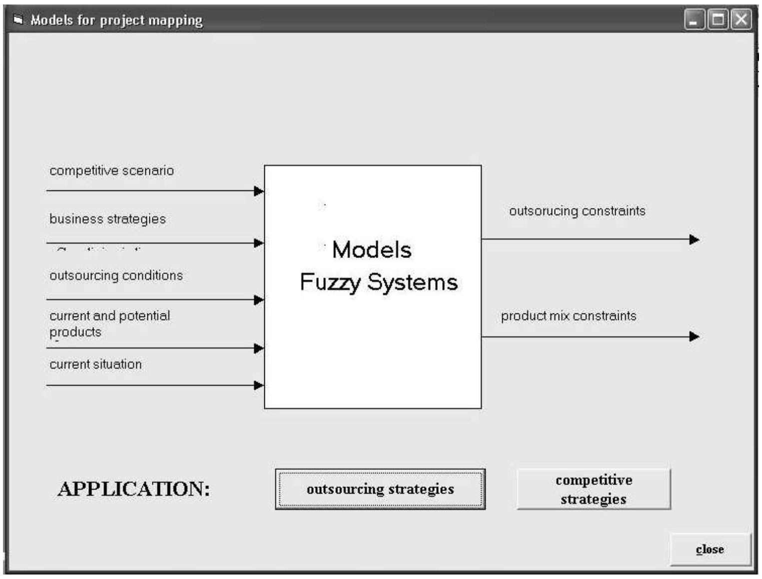
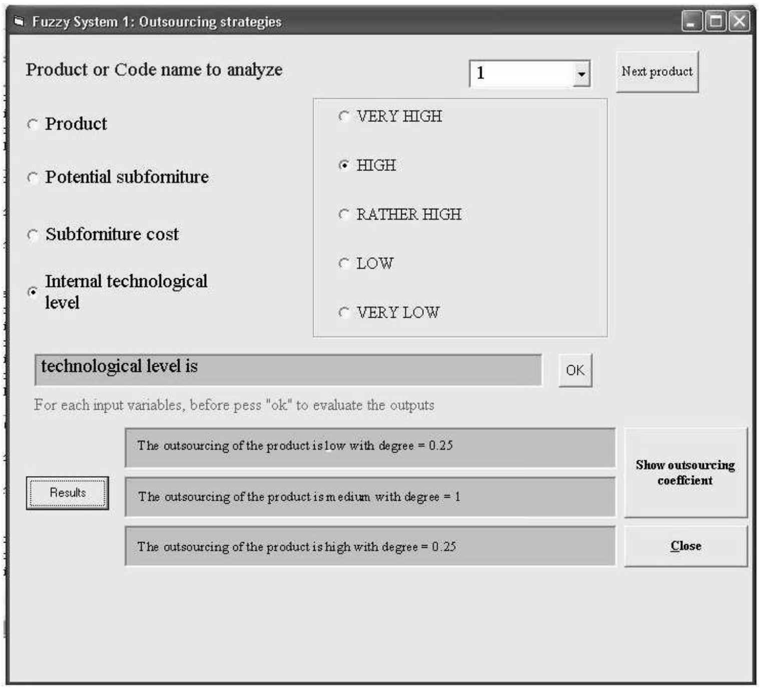


Figure 2.8. The form Models for project mapping.

- The number L_{ij}^{DML} of dedicated lines to purchase in the time bucket j for manufacturing product i;
- The number Lj^{FMS} of flexible manufacturing system to buy in the bucket j;
- The volumes V_{ij} of product i that have to be manufactured in the DML or FMS in the time bucket j;
- The total volume percentage to outsource for each product and time bucket.

4.1 DSS integration in the Strategic Planning DSS platform

One of the main requirements in the DSS design has been its easy integration with other software systems which support the entire process of strategic planning by implementing all the other planning models as described in the first chapter of this book. For this reason, the DSS, besides displaying the results in a Visual Basic form, generates an output



Fuzzy System 1: Outsourcing strategies

Product or Code name to analyze: 1

○ Product
○ Potential subforniture
○ Subforniture cost
● Internal technological level

○ VERY HIGH
● HIGH
○ RATHER HIGH
○ LOW
○ VERY LOW

technological level is

For each input variables, before pess "ok" to evaluate the outputs

The outsourcing of the product is low with degree = 0.25

The outsourcing of the product is medium with degree = 1

The outsourcing of the product is high with degree = 0.25

Figure 2.9. The form for outsourcing constraint determination.

file (a *txt* file) with the same data as in the optimization results form. Such a file can be automatically read by the other software systems that take such a data as input of their models. Figure 2.14 shows a sketch of this *txt* file.

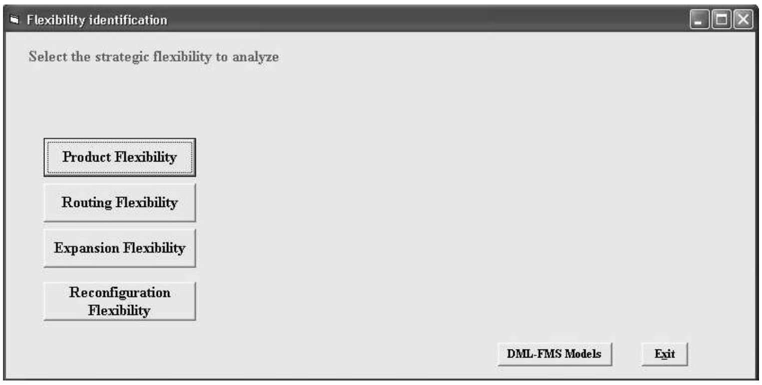
5. Tests and results

In order to test the proposed methodologies, the developed DSS has been applied to the case study presented in Section **??** of Chapter 1. Specifically the DSS has been run in two different scenarios.

5.1 Scenario 1

Input

- Product 1



Select the strategic flexibility to analyze

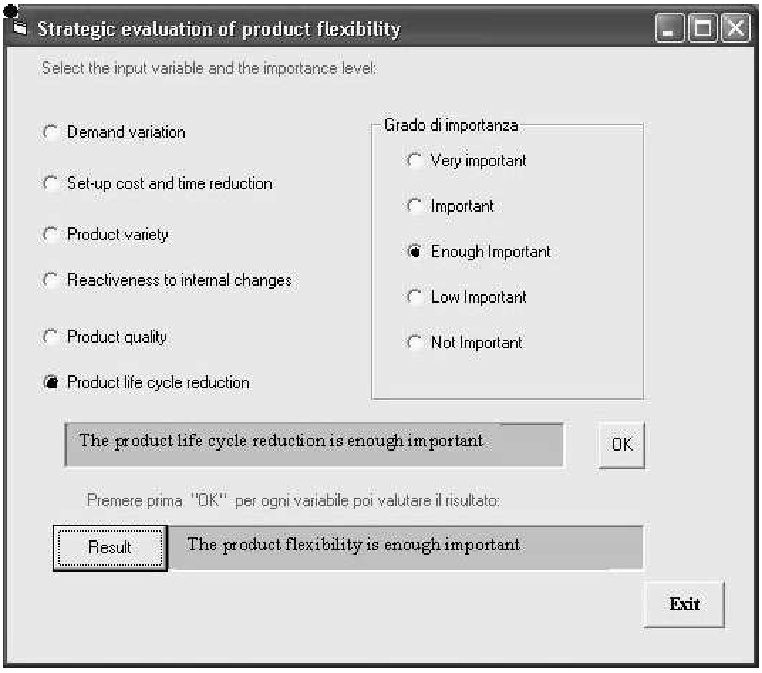
Figure 2.10. The form for flexibility identification.

  - Strategic level: very strategic;
  - Potential supplier: not very reliable;
  - Outsourcing cost: not very suitable;
  - Technological level: rather high;

- Product 2
  - Strategic level: strategic;
  - Potential supplier: not very reliable;
  - Outsourcing cost: not very suitable;
  - Technological level: high;

- Product 3
  - Strategic level: strategic;
  - Potential supplier: rather reliable;
  - Outsourcing cost: not very suitable;
  - Technological level: high;

- Product 4
  - Strategic level: not very strategic;
  - Potential supplier: reliable;
  - Outsourcing cost: suitable;


Strategic evaluation of product flexibility

Select the input variable and the importance level:

○ Demand variation
○ Set-up cost and time reduction
○ Product variety
○ Reactiveness to internal changes
○ Product quality
● Product life cycle reduction

Grado di importanza
○ Very important
○ Important
● Enough Important
○ Low Important
○ Not Important

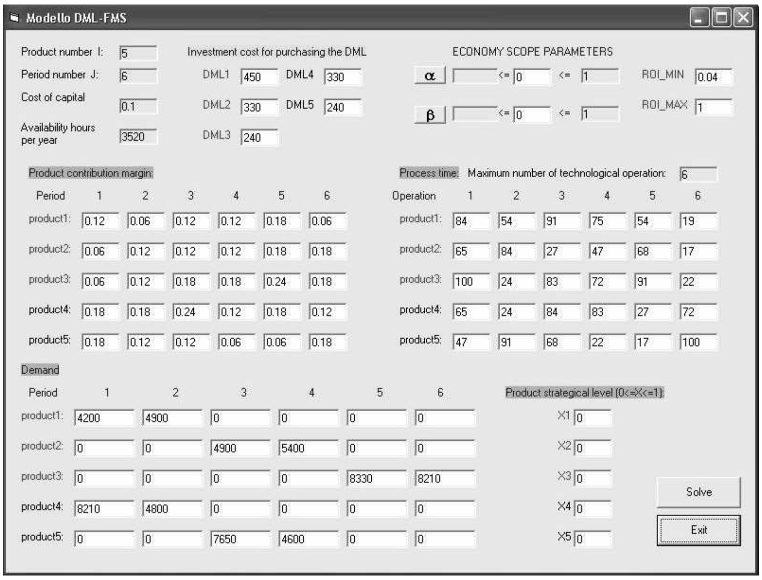
The product life cycle reduction is enough important

Premere prima "OK" per ogni variabile poi valutare il risultato:

The product flexibility is enough important

Figure 2.11. The form for the strategic evaluation of *product flexibility.*

  - Technological level: not very high;
- Product 5
  - Strategic level: very strategic;
  - Potential supplier: not very reliable;
  - Outsourcing cost: suitable;
  - Technological level: high;
- Current products/potential products: very high;
- Marketing strategy: market penetration;
- Business strategy: differentiation;
- Product flexibility
  - Reactiveness to internal and external changes: very important;



Product number I: 5
Period number J: 6
Cost of capital 0.1
Availability hours per year 3520

Investment cost for purchasing the DML
DML1 450
DML2 330
DML3 240
DML4 330
DML5 240

ECONOMY SCOPE PARAMETERS
α <= 0 <= 1
β <= 0 <= 1
ROI_MIN 0.04
ROI_MAX 1

Product contribution margin:

Period	1	2	3	4	5	6
product1:	0.12	0.06	0.12	0.12	0.18	0.06
product2:	0.06	0.12	0.12	0.12	0.18	0.18
product3:	0.06	0.12	0.18	0.18	0.24	0.18
product4:	0.18	0.18	0.24	0.12	0.18	0.12
product5:	0.18	0.12	0.12	0.06	0.06	0.18

Process time: Maximum number of technological operation: 6

Operation	1	2	3	4	5	6
product1:	84	54	91	75	54	19
product2:	65	84	27	47	68	17
product3:	100	24	83	72	91	22
product4:	65	24	84	83	27	72
product5:	47	91	68	22	17	100

Demand

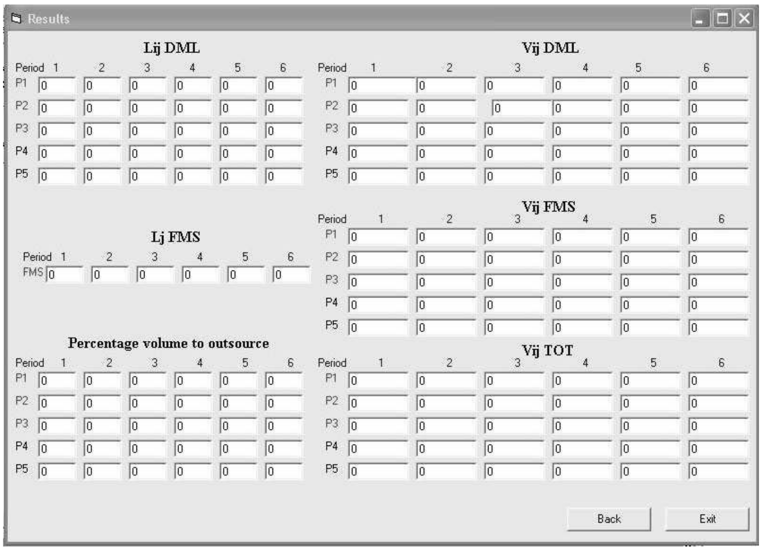
Period	1	2	3	4	5	6
product1:	4200	4900	0	0	0	0
product2:	0	0	4900	5400	0	0
product3:	0	0	0	0	8330	8210
product4:	8210	4800	0	0	0	0
product5:	0	0	7650	4600	0	0

Product strategical level (0<=X<=1):
X1 0
X2 0
X3 0
X4 0
X5 0

Figure 2.12. Form for the strategic evaluation of the manufacturing capacity.

  - Set-up cost and time reduction: not important;
  - Demand variation: rather important;
  - Product life cycle reduction: not important;

- Routing flexibility
  - Set-up cost and time reduction: not very important;
  - Product variety: not important;
  - Reactiveness to internal changes: rather important;
  - Resource utilization: important;
- Expansion flexibility
  - Reactiveness to market changes: very important;
  - Demand uncertainty: not important;
- Reconfiguration flexibility
  - Product change rapidity: important;
  - Reactiveness to internal changes: very important;



Lij DML

Period	1	2	3	4	5	6
P1	0	0	0	0	0	0
P2	0	0	0	0	0	0
P3	0	0	0	0	0	0
P4	0	0	0	0	0	0
P5	0	0	0	0	0	0

Vij DML

Period	1	2	3	4	5	6
P1	0	0	0	0	0	0
P2	0	0	0	0	0	0
P3	0	0	0	0	0	0
P4	0	0	0	0	0	0
P5	0	0	0	0	0	0

Lj FMS

Period	1	2	3	4	5	6
FMS	0	0	0	0	0	0

Vij FMS

Period	1	2	3	4	5	6
P1	0	0	0	0	0	0
P2	0	0	0	0	0	0
P3	0	0	0	0	0	0
P4	0	0	0	0	0	0
P5	0	0	0	0	0	0

Percentage volume to outsource

Period	1	2	3	4	5	6
P1	0	0	0	0	0	0
P2	0	0	0	0	0	0
P3	0	0	0	0	0	0
P4	0	0	0	0	0	0
P5	0	0	0	0	0	0

Vij TOT

Period	1	2	3	4	5	6
P1	0	0	0	0	0	0
P2	0	0	0	0	0	0
P3	0	0	0	0	0	0
P4	0	0	0	0	0	0
P5	0	0	0	0	0	0

Figure 2.13. The form of the optimization results.

  - Demand uncertainty: rather important;
  - Reactiveness to market changes: not very important;
- Economy of scope coefficients
  - coefficient $\alpha = 0.4$
  - coefficient $\beta = 0.35$

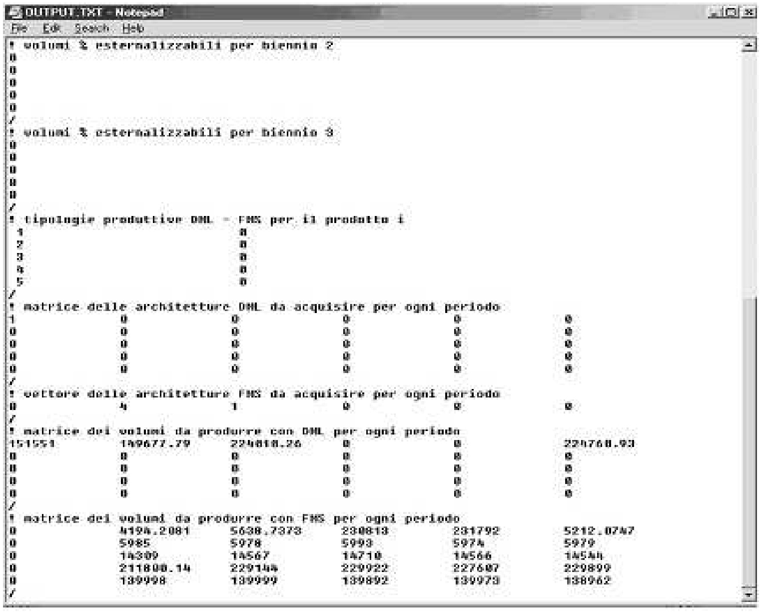
Output

The input data relative to the number of products to manufacture, product costs, contribution margins, outsourcing costs, DMLs costs and throughput, are reported in Figure 2.15. In the same figure the output results of the Scenario 1 are presented.

5.2 Scenario 2

Input

- Product 1
  - Strategic level: very strategic;



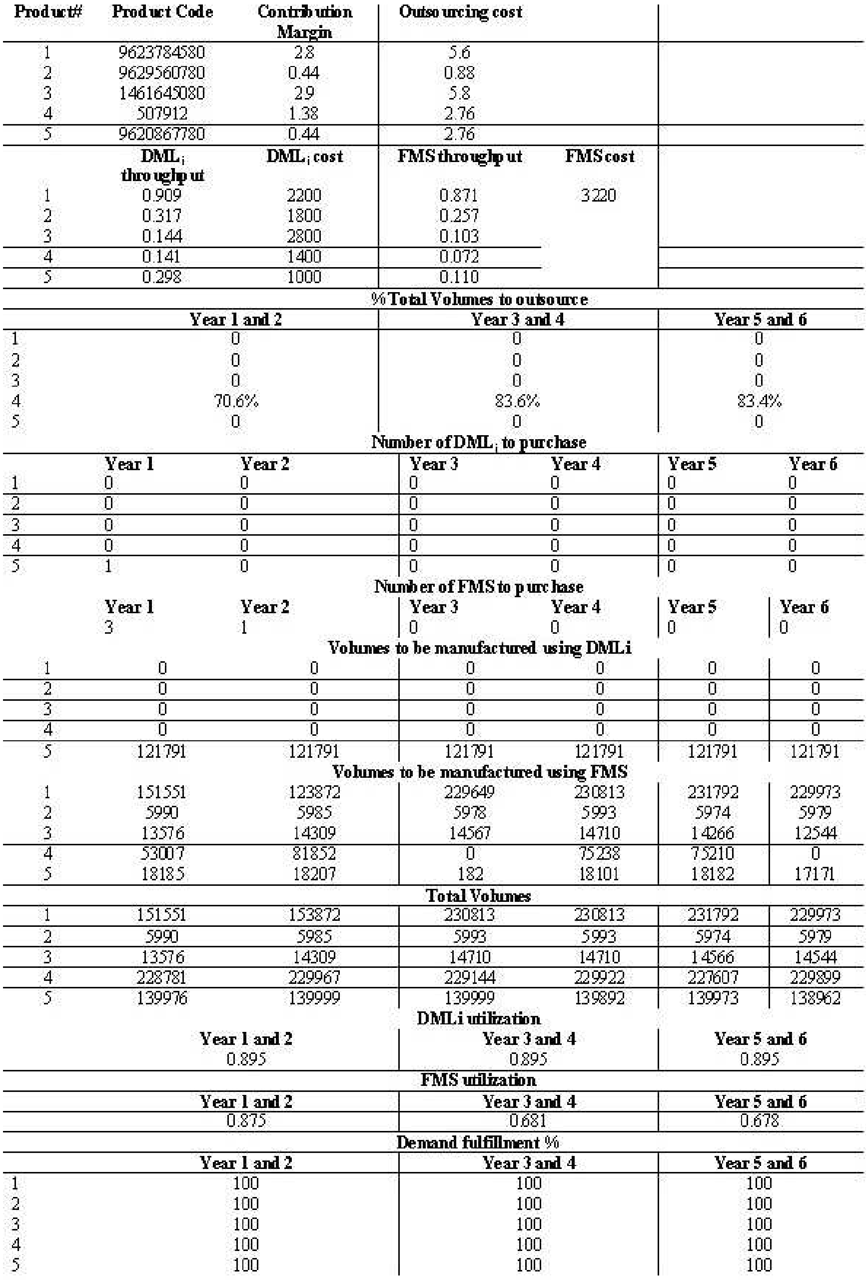
```
! volumi % esternalizzabili per biennio 2
0
0
0
0
0
/
! volumi % esternalizzabili per biennio 3
0
0
0
0
0
/
! tipologie produttive DML - FMS per il prodotto i
 1                              0
 2                              0
 3                              0
 4                              0
 5                              0
/
! matrice delle architetture DML da acquisire per ogni periodo
1               0               0               0               0               0
0               0               0               0               0               0
0               0               0               0               0               0
0               0               0               0               0               0
0               0               0               0               0               0
/
! vettore delle architetture FMS da acquisire per ogni periodo
0               4               1               0               0               0
/
! matrice dei volumi da produrre con DML per ogni periodo
151551          149677.79       224810.26       0               0               224760.93
0               0               0               0               0               0
0               0               0               0               0               0
0               0               0               0               0               0
0               0               0               0               0               0
/
! matrice dei volumi da produrre con FMS per ogni periodo
0               4194.2081       5638.7373       230813          231792          5212.0747
0               5985            5978            5993            5974            5979
0               14309           14567           14710           14566           14544
0               211800.14       229144          229922          227607          229899
0               139998          139999          139892          139973          138962
/
```

Figure 2.14. A sketch of the output *txt* file.

  - Potential supplier: not very reliable;
  - Outsourcing cost: not very suitable;
  - Technological level: rather high;

- Product 2
  - Strategic level: strategic;
  - Potential supplier: reliable;
  - Outsourcing cost: suitable;
  - Technological level: high;

- Product 3
  - Strategic level: not very strategic;
  - Potential supplier: rather reliable;
  - Outsourcing cost: suitable;
  - Technological level: not very high;



Product#	Product Code	Contribution Margin	Outsourcing cost
1	9623784580	2.8	5.6
2	9629560780	0.44	0.88
3	1461645080	2.9	5.8
4	507912	1.38	2.76
5	9620867780	0.44	2.76

	DML$_i$ throughput	DML$_i$ cost	FMS throughput	FMS cost
1	0.909	2200	0.871	3220
2	0.317	1800	0.257	
3	0.144	2800	0.103	
4	0.141	1400	0.072	
5	0.298	1000	0.110	

%Total Volumes to outsource

	Year 1 and 2	Year 3 and 4	Year 5 and 6
1	0	0	0
2	0	0	0
3	0	0	0
4	70.6%	83.6%	83.4%
5	0	0	0

Number of DML$_i$ to purchase

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	1	0	0	0	0	0

Number of FMS to purchase

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
3	1	0	0	0	0

Volumes to be manufactured using DMLi

1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	121791	121791	121791	121791	121791	121791

Volumes to be manufactured using FMS

1	151551	123872	229649	230813	231792	229973
2	5990	5985	5978	5993	5974	5979
3	13576	14309	14567	14710	14266	12544
4	53007	81852	0	75238	75210	0
5	18185	18207	182	18101	18182	17171

Total Volumes

1	151551	153872	230813	230813	231792	229973
2	5990	5985	5993	5993	5974	5979
3	13576	14309	14710	14710	14566	14544
4	228781	229967	229144	229922	227607	229899
5	139976	139999	139999	139892	139973	138962

DMLi utilization

Year 1 and 2	Year 3 and 4	Year 5 and 6
0.895	0.895	0.895

FMS utilization

Year 1 and 2	Year 3 and 4	Year 5 and 6
0.875	0.681	0.678

Demand fulfillment %

	Year 1 and 2	Year 3 and 4	Year 5 and 6
1	100	100	100
2	100	100	100
3	100	100	100
4	100	100	100
5	100	100	100

Figure 2.15. Scenario 1 Output.

- Product 4
  - Strategic level: not very strategic;
  - Potential supplier: not very reliable;
  - Outsourcing cost: not suitable;
  - Technological level: not very high;
- Product 5
  - Strategic level: not strategic;
  - Potential supplier: very reliable;
  - Outsourcing cost: suitable;
  - Technological level: not high;
- Current products/potential products: very high;
- Marketing strategy: market penetration;
- Business strategy: differentiation;
- Product flexibility
  - Reactiveness to internal and external changes: very important;
  - Set-up cost and time reduction: not very important;
  - Demand variation: rather important;
  - Product life cycle reduction: not important;
- Routing flexibility
  - Set-up cost and time reduction: not very important;
  - Product variety: not important;
  - Reactiveness to internal changes: rather important;
  - Resource utilization: important;
- Expansion flexibility
  - Reactiveness to market changes: very important;
  - Demand uncertainty: not important;
- Reconfiguration flexibility
  - Product change rapidity: important;
  - Reactiveness to internal changes: very important;

  - Demand uncertainty: rather important;
  - Reactiveness to market changes: not very important;

- Economy of scope coefficients
  - coefficient $\alpha = 0.6$
  - coefficient $\beta = 0.5$

Output
The input data relative to the number of products to manufacture, product costs, contribution margins, outsourcing costs, DMLs costs and throughput, are reported in Figure 2.16. In the same figure the output results of the Scenario 2 are presented.

5.3 Test results

The main comments related to the test phase of the developed DSS on the case study data can be summarized as follows for the two supposed scenarios:

- Scenario 1: the DSS suggests outsourcing a great percentage of the production of product 4. This is pretty reasonable considered that such a product is not very strategic, its potential supplier is reliable and its outsourcing cost is suitable. None of the other products has these outsourcing fitting conditions and indeed the system suggests not outsourcing any of them. Also, the only DML that needs to be bought is DML5. This result was also expectable, given that DML5 has the minimum investment cost such as DML3. But, DML3 is not suggested for product 3 which is on the contrary produced by FMS. This can be explained by looking at the product demand configuration. Indeed, product 3 is required on periods 5 and 6, i.e. when the already purchased FMS are not busy for producing all of the other products. So, product 3 will be produced on the FMS which is, during those time buckets, idle. On the contrary, for the production of product 5, which is required on periods 3 and 4, the FMS already available cannot be used because busy due to the other products.

- Scenario 2: the DSS suggests outsourcing almost the total production of product 4 and 5, and a great part of the production of product 2. A quick view at the strategic and outsourcing conditions of these products makes clearer such a result. Of course the total number of FMS and DML purchased is minor of that in scenario 1 due to the more substantial outsourcing volume. Also, product 1 will be produced using DML and this probably because of product 1 high volume respect to product 2 and product 3 (this will be outsourced for more than 50 percent).

6. Conclusions

This chapter presents an innovative approach for assisting entrepreneurs in making long term capacity decisions in Advanced Manufacturing Systems (AMS). Indeed, concepts as flexibility and reconfigurability have introduced important strategic and risk issues in making long term capacity decisions when dealing with AMSs. Indeed, AMS allows reactions to internal and external changes making the company more reactive and this is a basic strategic issue in nowadays global competition. On the other hand, such AMS requires high investment in manufacturing equipments, human resources and technology knowledge. Such high investments together with the wideness and the variability of the competition scenario contribute to increase the perception of the risk for industrial entrepreneurs. This is especially true in SME, where the risk perception reduces the propensity to invest in AMS, and this contributes to increase the technological and competition gap in some manufacturing SMEs.

This problem could be approached by providing the entrepreneur with a Decision Support System able to assist her/him in making long term capacity decision in AMS. As often suggested in the scientific and industrial literature, such a DSS should be able to address both strategic and economical-financial issues of AMS such as flexible manufacturing systems (FMS) and Reconfigurable Manufacturing Systems (RMS).

The DSS proposed in this chapter goes toward this direction. It allows the entrepreneur to plan its production strategy starting from company business strategy, market strategy, competition scenario and outsourcing scenario. Starting from such information, a Fuzzy Expert Systems allows to define the kind of strategic flexibility the company needs and how the company should compose its production mix between internal production and outsourced one.

This strategic information represents the input of a Long Term Capacity Planning Model that constitutes the economic and financial hearth of the DSS. The Decision Model allows entrepreneur to make investment decisions in long term fashion by mixing up different manufacturing systems such as Dedicated Machining Lines (DML), Flexible Manufacturing Systems (FMS) and Reconfigurable Manufacturing Systems (RMS). In order to do that the Decision Support System employs an innovative parametric approach in comparing different manufacturing systems. The suggested approach consists in modeling long term capacity characteristics of FMS and RMS starting from the DML ones and accounting for the differences through proper parameters which take into account for scope and reconfiguration economies.

A prototype of the DSS has been built by using Microsoft Access and Microsoft Visual Basic. The Strategic Planning Model has been implemented by using a Visual Basic engine incorporating Fuzzy Rules. The Long Term Capacity Planning Model consists of a Visual Basic applications that, starting from the results of the Strategic Planning Model, builds up a multi objective economic-financial optimization model for making capacity decision regarding three kind of manufacturing system type, i.e. DML, FMS and RMS. The optimization model is solved by using the Lingo Solver. The DSS results suggest the entrepreneur how many DML, FMS and RMS to buy for each planning period, the optimal volumes to be produced and to be outsourced.

The DSS has been tested under two different scenarios. The results confirm, in both the cases, that the DSS provides important strategic information for making long term production capacity decisions in manufacturing enterprises. Authors believe that SME can obtain great advantages in term of decision making consistency by using a commercial evolution of the DSS here presented.

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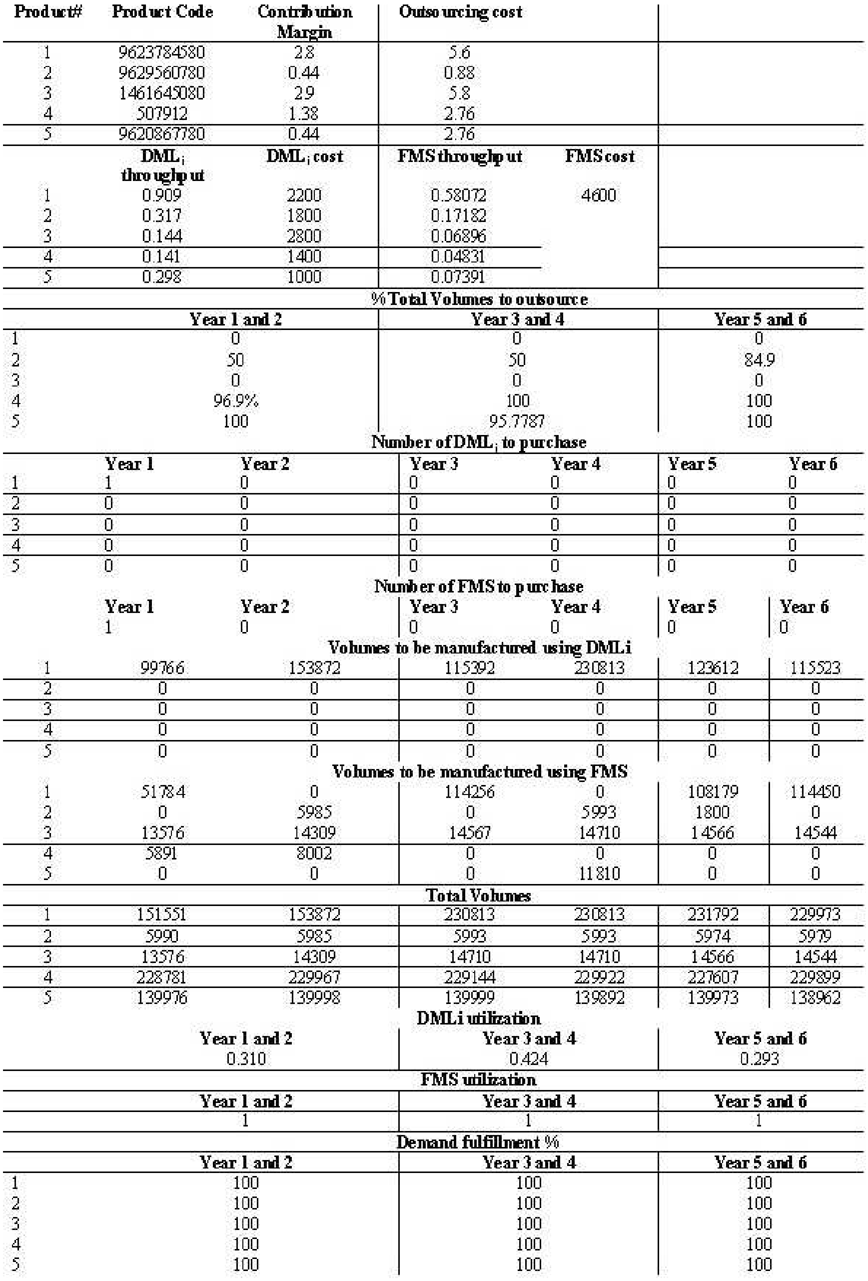

Product#	Product Code	Contribution Margin	Outsourcing cost	
1	9623784580	2.8	5.6	
2	9629560780	0.44	0.88	
3	1461645080	2.9	5.8	
4	507912	1.38	2.76	
5	9620867780	0.44	2.76	

	DML_i throughput	DML_i cost	FMS throughput	FMS cost
1	0.909	2200	0.58072	4600
2	0.317	1800	0.17182	
3	0.144	2800	0.06896	
4	0.141	1400	0.04831	
5	0.298	1000	0.07391	

%Total Volumes to outsource

	Year 1 and 2	Year 3 and 4	Year 5 and 6
1	0	0	0
2	50	50	84.9
3	0	0	0
4	96.9%	100	100
5	100	95.7787	100

Number of DML_i to purchase

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
1	1	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0

Number of FMS to purchase

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
1	0	0	0	0	0

Volumes to be manufactured using DMLi

1	99766	153872	115392	230813	123612	115523
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0

Volumes to be manufactured using FMS

1	51784	0	114256	0	108179	114450
2	0	5985	0	5993	1800	0
3	13576	14309	14567	14710	14566	14544
4	5891	8002	0	0	0	0
5	0	0	0	11810	0	0

Total Volumes

1	151551	153872	230813	230813	231792	229973
2	5990	5985	5993	5993	5974	5979
3	13576	14309	14710	14710	14566	14544
4	228781	229967	229144	229922	227607	229899
5	139976	139998	139999	139892	139973	138962

DMLi utilization

Year 1 and 2	Year 3 and 4	Year 5 and 6
0.310	0.424	0.293

FMS utilization

Year 1 and 2	Year 3 and 4	Year 5 and 6
1	1	1

Demand fulfillment %

	Year 1 and 2	Year 3 and 4	Year 5 and 6
1	100	100	100
2	100	100	100
3	100	100	100
4	100	100	100
5	100	100	100

Figure 2.16. Scenario 2 Output.