A virtual enterprise designs short-lived products and forms temporary coalitions with other enterprises to manufacture and distribute these products. This paper presents a generic process for developing new products in virtual enterprises and two procedures supported by fuzzy cognitive maps. The first one allows for industrial design of the products when the manufacturing subcontractor is not known. The second one allows for remote evaluation and selection of the virtual enterprise partners: manufacturing subcontractors, suppliers of materials and distributors. These procedures are applied to an enterprise that designs garments.

Keywords. Virtual enterprise, supply chain, product development, fuzzy cognitive maps, Internet, neural networks.

1. Introduction

A virtual firm is a temporary alliance of enterprises formed to take advantage of a business opportunity (Presley et al., 2001). Once the latter is taken, the virtual firm is disbanded because it is project oriented. A virtual firm differs from an extended enterprise that includes long term alliances between the partners (Martinez et al., 2001; Browne and Zhang, 1999). In the extended
enterprise, the design of the partners’ interactions is important and can be done using methods on current development (Huang et al., 2002; Gou et al., 2003; New, 1996). In the virtual enterprise, the selection of partners whose internal organizations are focused on the target market of the virtual enterprise is more important than the optimization of their interactions.

This paper assumes that a virtual enterprise is created for designing new products that are produced by overseas manufacturing subcontractors and distributed by independent retailers. In this context, two activities of the product development process become problematic. The first activity is the modification of the product design for high volume production (industrial design) when the manufacturer is not known. The second activity is the remote evaluation of distant manufacturing subcontractors and retailers to select the appropriate partners. This paper suggests the use of fuzzy cognitive maps (Macedo, 1999) to support both activities.

Current literature does not show applications of fuzzy cognitive maps to support the activities of the product development process (Vellido et al. 1999). For example, Suwignjo et al. (2000) use cognitive maps, in a limited way, as diagram tools that could not calculate the effects produced by causal variations; these effects are estimated using the analytic hierarchy process. Mikhailov (2002) also uses the analytic hierarchy process to select the partners of a virtual enterprise and fuzzy nets to estimate some required parameters. Tung-Hsu et al. (2003) use neural networks to predict defective products from operational measurements and data mining to identify the causes of these defects (data mining is necessary because the neural networks do not have cause-effect structure like the ones included in fuzzy cognitive maps). Choy et al. (2002) identify the subcontractor candidates whose performances are close to the desired ones using case base reasoning and then predict their performances using neural networks.

In the second section of this paper, a product development process for virtual firms is introduced to position the activities that will be supported by fuzzy cognitive maps. In the third section, procedures to execute these activities are presented. In the fourth section, these procedures are applied to support the industrial design of polos and the selection of the partners of an apparel virtual enterprise.
2. Product development process

The process of developing new products in real manufacturing enterprises is well known (Webb, 2000). This is not the case for virtual enterprises. Hence, the process in Figure 1 is suggested. This process includes the activities pointed out by Rosenau and Wilson (2001) but is focused on the development of products that generate the desired profit and efficiency as suggested by Monden (1995). At this point, note that the efficiency is measured by the delay to deliver the products, the percentage of defective products, the cost and variety of the products delivered.

The process in Figure 1 includes the four steps of the life cycle for developing a portfolio of new products: Product requirements specification, product conception, product design-partner selection, and product implementation. In the product requirements specification step, the socio-economic profile of the targeted customer is identified and his needs specified in terms of products styles and desired efficiency. In the product conception step, the target product is conceived using the specifications above and without any type of constraint. In the product design-partner selection step, the design of the target product is modified so that the product made in series satisfies the desired profit and efficiency. The resulting design is called profitable product design or industrial design and is used to calculate the allowable cost for the workforce and materials. The latter are part of the criteria employed to select the manufacturing subcontractor and the materials supplier. Finally, in the product implementation step, the virtual enterprise contracts the working procedures with the materials suppliers and the manufacturing subcontractors. At this point, note that the four activities in bold (Figure 1) are supported by fuzzy cognitive maps called reference models (Macedo, 1999).

The solutions of the reference models are operational benchmarks for evaluating the current performance of the candidate partners as suggested elsewhere (Najmi and Kehoe, 2001; Dabhilakar and Bengtsson, 2002; Norton and Kaplan, 1996). In addition, the reference models deploy the desired efficiency in terms of operational measures, as suggested by Hudson et al. (2001). This deployment is done with differential equations that have cause-effect structure. In
Figure 1. Generic product development process in virtual manufacturing firms. The video conference and files transfers are done using instant messaging software and internet.
addition, the reference models are intelligent so that they suggest new values for the operational measures when the efficiency desired by the target market changes, as suggested by Kennerley and Neely (2002).

In practice, the activities in bold in Figure 1 are remote evaluations that are applied using internet technology as in telemedicine (Turner et al., 2003), and teleoperation of machines (Hu et al., 2001).

3. Remote product design and partner selection

In section 3.1 an overview of the reference models is presented, and in sections 3.2 and 3.3 procedures for executing the four activities in bold in the product development process of Figure 1 are presented.

3.1. Reference model overview

A reference model includes three types of variables: Managerial attributes, control variables and state variables. The managerial attributes are measures of the product portfolio efficiency (see bottom of Figure 6 for examples) and the control variables are the production system attributes that govern the behaviour of the managerial attributes (see Figures 8, 9, 10, 11 for examples). The state variables are attributes of the production system used to complete the modelling of the cause-effect chains between the control variables and the managerial attributes.

A reference model is a set of nonlinear differential equations and an objective function. The differential equations model the cause-effect chains above. Each equation represents the variation rate of a state variable as the weighted sum of the variation rates of the variables that influence this one multiplied by a bell shaped function that constraints the equilibrium solution of the equation to zero or one. The weights above are between -100% and +100% and represent the force of the relationship (positive or negative) between the cause variable and the effect variable. The objective function of the reference model is the minimization of the integral of the gaps between the current and the desired values of the managerial attributes.
A reference model can be solved to obtain the control variable values that allow reaching the desired values of the managerial attributes. In this case the operation of the reference model is done in the following way. First, a family of reference models that cover the topics analyzed (product structure, machine set-up operations, production flow, human factor, production planning or supply chain) is selected from a database. Second, a reference model whose cause-effect values match the ones of the analyzed system is chosen from the selected family. Third, desired values for the managerial attributes are introduced into the objective function of the selected reference model that is then solved to generate equilibrium values of its control variables. These equilibriums have values of 0% or 100% only and represent the control variables values capable of generating the desired values of the managerial attributes.

At this point, note that the values of the reference model variables are percentages between 0% and 100%. The advantage of using percentages is that the unit conversions are avoided. The disadvantage is that the values of the control variables obtained by solving the reference models are only conceptual benchmarks.

3.2. Industrial design without manufacturing subcontractor

At the beginning of the development process (Figure 1), the virtual firm designers conceive a product portfolio without any constraint. The resulting design is called design of the target product portfolio. The latter is then modified to obtain a new design called profitable or industrial design that satisfies the efficiency desired by the target market. In order to prepare the industrial design, the virtual firm designers need to ask the manufacturer about the potential modifications in the design of the target product portfolio but the manufacturer is not known. In order to solve the unavailability of the manufacturer, reference models of the product structure are used to identify the potential modifications in the design of the target product portfolio. Hence, the identification of the modifications in the product structure is done using the procedure in Figure 2 that is supported by reference models that “replace” the manufacturing subcontractor’s point of view. These reference models cover the product structure and exploit the control variables defined in the bottom of Figure 7.
The procedure of Figure 2 consists of the following main steps. First, one is required to solve the reference model of the product structure (Macedo, 2001a) to generate equilibrium values for its control variables. These equilibrium values are 0% or 100% and represent the desired values of the control variables (a value of 100% -0%- means to satisfy -not satisfy- the behaviour described in the definition of the corresponding control variable). Second, one must adapt and match the control variables of the reference model to the attributes of the analysed products. Build scales to evaluate the product attributes. Third, it is necessary to analyze the current state of the matched attributes using system analysis tools focused on the product structure (Table 1). Fourth, one must rate the current state of these attributes as percentages in scales from 0% to 100%. Fifth, it is vital to calculate the gaps between the current and the desired values of the attributes. Sixth, one must modify the current design of the products to reduce these gaps to a satisfactory level.

Figure 2. Procedure for focusing the structure of the product portfolio on the efficiency required by the target market.
Structure of products designed by the virtual firm

P1 Decomposition diagram of the products included in the product portfolio

P2 Matrix of components and materials included in the products of the product portfolio

P3 Matrix of process steps to make the products included in the product portfolio

P4 Matrix of functions fulfilled by the components included in the products of the product portfolio

P5 Matrix of machines types used to make the products included in the product portfolio

P6 Product styles and quantities included in a typical product portfolio

P7 Typical product portfolio efficiency required by the target market

P8 Quality deployment function

Set-up operations of a manufacturing subcontractor machine

S1 Machine-operator diagram of the activities to set-up a machine that makes the product portfolio

Operator of a manufacturing subcontractor workstation

H1 Matrix of information exchange between operators that makes the product portfolio

H2 Diagram of motions of the operators that makes the product portfolio

H3 Diagram of movements of the operators that makes the product portfolio

H4 Maintenance register of the machines that makes the product portfolio

Production flow of a section of the manufacturing subcontractor production system

F1 Diagram of production flows of the products included in the product portfolio

F2 Matrix of technology group of the products included in the product portfolio

F3 Matrix of distances between the machines that make the product portfolio

F4 Matrix of multitasking degree of the operators that make the product portfolio

F5 Diagram of workloads of the operators that makes the product portfolio

Production planning of a section of the manufacturing subcontractor production system

C1 Percentage of portfolio products delivered on time

C2 Time to make the product portfolio as a percentage of the time allowed by the customer

C3 Materials stock days as a percentage of the required number of days to use this stock

C4 Work in process stock days as a percentage of the required number of days to use this stock

C5 Finished product stock days as a percentage of the required number of days to sell this stock

C6 Production lot size as a percentage of the product portfolio order size

C7 Typical schedule to make a typical product portfolio

Table 1. Sample of system analysis tools to support the ratings included in the evaluation scales.
Table 1 (continuation)

**Interactions between the manufacturing subcontractor and the materials supplier**

- M1 Set-up time of materials supplier machines
- M2 Frequency of communication between the materials supplier and the manufacturing subcontractor
- M3 Percentage of purchase contracts manufacturing subcontractor—materials supplier that accumulate over 2 years
- M4 Materials supplier delay to deliver a typical order to the manufacturing subcontractor
- M5 Safety stock maintained by the manufacturing subcontractor to cover delayed deliveries by the materials supplier

**Interactions between the manufacturing subcontractor and the retailer**

- R1 Percentage of retailer order variations (product style and volume) that are satisfied by the manufacturing subcontractor
- R2 Frequency of communications between the retailer and the manufacturing subcontractor
- R3 Percentage of sales contracts manufacturing subcontractor-retailer that accumulate over 2 years
- R4 Manufacturing subcontractor delay to deliver a typical order to the retailer
- R5 Safety stock maintained by the retailer to cover delayed deliveries by the manufacturing subcontractor

**Product portfolio efficiency**

- E1 Delay of manufacturing subcontractor to deliver a product portfolio to the retailer
- E2 Percentage of defective products included in a product portfolio delivered by the manufacturing subcontractor to the retailer
- E3 Product portfolio purchase price paid by the retailer to the manufacturing subcontractor
- E4 Percentage of retailer order variations in product portfolio (style and volume)

Table 1. Sample of system analysis tools to support the ratings included in the evaluation scales.

3.3. Partners selection

During the product development process (Figure 1), the operations agent of the virtual firm evaluates the competence of the manufacturing subcontractors’ candidates to select one that is capable of making products with the desired efficiency. Later, the degree of integration between the selected subcontractor and the materials supplier’s candidates and the retailer’s candidates is evaluated to select materials supplier’s partners and retailer’s partners. These evaluations are done by applying the procedure in Figure 3 that uses reference models to identify the attributes of the candidate production systems that may be evaluated. In addition, the solutions of the reference models are benchmarks to evaluate these attributes. Each reference model covers one topic of the
Figure 3. Interaction procedure between the virtual firm evaluator and the analyst of the manufacturing subcontractor candidate in order to evaluate the candidate manufacturing system.
following: Machine set-up operations (Macedo and Ruiz-Usano, 1995), production flow (Macedo, 1994), human factor (Macedo, 1996), production planning (Macedo, 1997), interactions manufacturer-materials supplier and interactions manufacturer-retailer (Macedo, 2001b). The control variables included in each one of these models are defined at the bottom of Figures 8, 9, 10, 11, 13, 14, respectively. These variables correspond to the attributes of the production system that will be evaluated.

![Diagram](image)

**Figure 4.** Client-server environment to support the interaction procedure between the virtual firm evaluator and the analysts of the candidate enterprises. The latter are in different geographical areas.
The procedure of Figure 3 is a set of activities applied by the evaluator of the virtual firm and the analyst of the candidate enterprise. Both interact by Internet using instant messaging software and multimedia hardware as shown in Figure 4. This software allows real time video-conferencing, chatting, file transfer, use of whiteboards and control of the candidate computer by the evaluator. The analyst of the candidate enterprise should use a laptop computer in order to ease the collection and transmission of the data required by the virtual enterprise evaluator.

The procedure of Figure 3 consists of the following main steps. First, it is necessary to analyse the product portfolio process to select the topics that will be evaluated in the candidate production system. Second, one must select the reference models that belong to the selected topics. Third, one is required to solve the selected reference models to know, in generic terms, the attributes of the candidate production system that will be evaluated and their desired values (note that these attributes correspond to the control variables of the reference models). Fourth, one must adapt the generic attributes to those of the subcontractor production system. Fifth, using system analysis tools, it is necessary to analyse the current state of the adapted attributes in the candidate production system and rate them using percentages from 0% to 100%. Sixth, it is essential to calculate the gaps between the current and the desired values of the attributes above.

After applying the procedure of Figure 3, the following target market focusing index is calculated for each subcontractor candidate:

\[ \lambda = 100\% - \sqrt{\sum_{i=1}^{n} \frac{(x_i - x_i^*)^2}{n}} \]

\( \lambda \) : Target market focusing index  
\( x_i \) : Current value of control variable \( i \) (percentage)  
\( x_i^* \) : Desired value of \( x_i \) obtained by solving the reference model (percentage)  
\( n \) : Total number of control variables in the reference model

A target market focusing index of 100% (0%) means that the current values of the attributes of the candidate production system are close (far) to the desired ones. The enterprise candidate that globally shows the minimum gaps above and the maximum target market focusing index is selected as a partner of the virtual enterprise.
As indicated in bold in Figure 1, once the manufacturing subcontractor has been selected, the materials supplier candidates and the retailer candidates are evaluated in order to select partners for the virtual enterprise. These evaluations are done twice using the procedure of Figure 3: First, with the materials supplier candidates using the reference model of the manufacturer-materials supplier interactions; second, with the retailer candidates using the reference model of the manufacturer-retailer interactions.

4. Application

A virtual enterprise designs several types of polos per year but does not make nor distribute them. In order to gain flexibility the polos are made by manufacturing subcontractors around the world and distributed by different well established stores. The targeted customers require polos that are quickly delivered, without defects at a low cost and offered in a large variety of styles.

The designers of the virtual enterprise have already conceived a portfolio of polos (Figure 5). The shown designs represent the “target product portfolio” in terms of Figure 1 because they respect the customers’ desires without considering the efficiency problems that arise when they are produced in high volume. The designers have to modify these initial designs to obtain ones that allow making polos with the desired efficiency when they are produced in series. The potential modifications in the initial designs of the polos are identified by applying the procedure in Figure 2 as explained in section 4.1.

Figure 6 shows the efficiency expected from an importer of polos and a local manufacturer of garments for the portfolio of polos specified in Figure 5. As noted, they differ from those required by the target market of the virtual enterprise (see bold items in Figure 6). In total, the importer has a target market focusing index of 41% and the local manufacturer 57% so that both are far from the desired 100%. As a consequence, the virtual enterprise decides to select a foreign manufacturing subcontractor to sew the polos and a textile enterprise to supply the required fabric. In addition, the virtual firm is looking for a distributor of polos. The selection of the partners of the virtual enterprise is done by applying the procedure in Figure 3, as explained in section 4.2.
4.1. Industrial design of product portfolio

According to the procedure in Figure 2, first, the efficiency desired by the target market of the virtual enterprise \((DEL=DEF=COST=0\%,\ VAR=100\%)\) is introduced into the reference model of the product structure (Macedo, 2001a). Second, this model is solved generating the desired values of the polos attributes in bold in Figure 7. As shown, the polos should include a large quantity of common components, be easy to assemble, have few layers in their structures, have common downstream operations, not require different machines to do the same operation, have quality control points based on customer expectations, not include functions that are not required by the cus-
Figure 6. Values desired by the virtual firm for the efficiency of the polos portfolio (in bold). The current values of a local manufacturer are indicated by M and the ones of an importer as I.

<table>
<thead>
<tr>
<th>DEL</th>
<th>Delay to deliver the polo portfolio to the virtual firm</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEF</td>
<td>Percentage of defective polos in the polo portfolio delivered to the virtual firm</td>
</tr>
<tr>
<td>COST</td>
<td>Cost of polo portfolio delivered to the virtual firm</td>
</tr>
<tr>
<td>VAR</td>
<td>Variety in the polo portfolio delivered to the virtual firm</td>
</tr>
</tbody>
</table>

\[ \lambda_I = 41\% \]
\[ \lambda_M = 57\% \]

customers and include a large number of standard components. Third, the attributes of the initial designs of the polos (Figure 5) are analysed using the tools in Table 1 and rated in percentage scales producing the values marked ‘I’ in Figure 7. As noted there are immense gaps between the desired values (in bold in Figure 7) and the current values of the polos attributes in the initial design (indicated as I in Figure 7) so that the target market focusing index has a value of only 32\%. Consequently, the initial designs of the polos are modified iteratively until these gaps are reduced to a satisfactory level. The satisfactory designs of the polos (not shown) have attribute
values indicated by P in Figure 7 that together produce a target market focusing index of 68%. Hence, the satisfactory designs of the polos are more focused on the efficiency desired by the virtual firm target market than the initial ones.

Figure 7. Values desired by the virtual firm for the polos structures (in bold). The values of the initial design (I) and the ones of the satisfactory design (P) are included.

CCOM : The products include a large quantity of common components  
FASS : The products are easy to assemble  
NIV : The number of layers in the structures of the products is high  
MACH : The number of different machines to make the same operation is high  
PDIF : The process operations include common downstream operations  
FONC : The products include functions not required by the customers  
CON : The quality control points of the products are based on customer expectations  
CSTA : The products include a large number of standard components

\[ \lambda_I = 32\% \]
\[ \lambda_P = 68\% \]
As mentioned, the attributes of the initial designs of the polos are analysed using the tools in Table 1. For example, CCOM defined as “the polos of the portfolio include a large quantity of common components” (bottom of Figure 7) is analysed with a matrix of the components and materials included in the polos, as illustrated in Table 2. The latter indicates that the initial designs of the polos include two common components (fabric A and body backs) from a possible five so that CCOM is estimated as 40%. In contrast, the satisfactory designs of the polos include three common components (fabric A, body backs and collars) from a possible five so that CCOM is estimated as 80%.

Table 2. Matrix of components of the polos included in the product portfolio (system analysis tool P2). This matrix allows to rate CCOM attribute of two polos designs.

<table>
<thead>
<tr>
<th>Polo component</th>
<th>INITIAL DESIGN</th>
<th>SATISFACTORY DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polo 1005</td>
<td>Polo 1005</td>
<td>Polo 2012</td>
</tr>
<tr>
<td>Polo 1005 y</td>
<td>Polo 2012</td>
<td>Polo 2012</td>
</tr>
<tr>
<td>Front with placket interfacing of fabric A</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Front with placket interfacing of fabric B</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Body back</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Short sleeve without rib</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Short sleeve with rib</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Long sleeve with knitted cuff</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Knitted sleeve collar style X</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Knitted sleeve collar style Y</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Knitted sleeve collar style Z</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total number of common components in one or more polos</td>
<td>2 components</td>
<td>3 components</td>
</tr>
</tbody>
</table>

CCOM$_{\text{INITIAL DESIGN}} = \frac{2}{5}$ \hspace{1cm} CCOM$_{\text{SATISFACTORY DESIGN}} = \frac{3}{5}$

CCOM$_{\text{INITIAL DESIGN}} = 40\%$ \hspace{1cm} CCOM$_{\text{SATISFACTORY DESIGN}} = 60\%$

*Maximum number of common components when the interfacing fabric and the collar styles are the common.
4.2. Manufacturing subcontractor and retailer selection

The apparel virtual enterprise has identified the following potential partners located in different geographical regions: two manufacturing subcontractors (named F and C), two textile enterprises (named A and B) and two distributors (named W and Z). Each manufacturing subcontractor has facilities to cut, sew and package polos. In addition, each textile enterprise has facilities to produce the main knitted fabric included in the polos. Finally, W and Z are well established chains of stores. Although each one of these candidates has the required facilities, they have different levels of efficiency due to their internal organizations. Hence, the virtual enterprise needs to select as partners the candidates that have organizations focused on the efficiency desired by the virtual firm’s target market. This selection is done by evaluating each one of these candidates with the procedure in Figure 3 and selecting the ones that have the highest values for the target market focusing index.

According to the procedure in Figure 3, first, the following topics of the candidates’ production systems are chosen for evaluation: set-up operations of the cutting table, production flow of the sewing section, human factor at the button holes machine, production planning of the sewing and cutting sections. Second, the desired efficiency of the portfolio of polos (DEL=DEF=COST=0% and VAR=100%) is introduced into the reference models of the set-up operations, production flow, human factor and production planning. Third, these reference models are solved producing the generic definitions of the production system attributes that will be evaluated (in bottom of Figures 8, 9, 10, 11) and their desired values (in bold in Figures 8, 9, 10, and 11). Fourth, these generic definitions and desired values are adapted to specific attributes of the analysed production systems. For example, the time to set-up the spreading machine of the cutting table should be low (COND=0% in Figure 8); the layout of the sewing section should be based on the process of the family of polos (SIM=100% in Figure 9); there should be mechanisms that adequately position the pieces of fabric arriving to the buttonholes machine (POS=100% in Figure 10); the stock of cut fabric waiting to be sewn should be capped (DEC=100% in Figure 11). Fifth, the percentage scales included in the radar diagrams of Figures 8, 9, 10, and 11 are built. Sixth, the attributes of the candidates’ production systems are analysed using the system analysis tools of Table 1 and rated as indicated in Figures 8, 9,
**Figure 8.** Values desired by the virtual firm for the set-up operations of the cutting table of the manufacturing subcontractor (in bold). The current values of subcontractor candidates F and C are included.

OFAC : The number of traceable tools is high
MAU : The number of broken tools is high
OEL : The number of tools distant from the working area is high
STRU : The machine structure makes difficult the installation of its tools
REP : The training of the operations to install the tool in the main machine is high
PAR : The number of simultaneous operations to install the tool in the main machine is high
BFLU : There is an efficient procedure to sequence the orders in the set-upped machine so that the latter is synchronized with the downstream machines
COND : The machine settling time to reach the serial operating conditions is high

\[ \lambda_F = 31\% \\
\lambda_C = 68\% \]
Figure 9. Values desired by the virtual firm for the production flow in the sewing shop floor of the manufacturing subcontractor (in bold). The current values of subcontractor candidates F and C are included.

ESP : The number of specialized operators is high
BAL : There is an efficient procedure to balance operators’ workload
PINS : The inspection is not done by operators of the process workstations
SIM : The process of the products families are the basis of the shop floor layout
EFOC : The warehouses of materials are close to the process workstations
AMEU : The machines layout has U-form
SURA : There are automatic mechanisms that release operators from machine supervision
MGR : The machines have large sizes
MANC : The handling systems allow continuous transport of work in process
MMOB : The machines are movable

\[ \lambda_F = 15\% \]
\[ \lambda_C = 69\% \]
Figure 10. Values desired by the virtual firm for the employee that operates the buttonholes machines of the manufacturing subcontractor (in bold) The current values of subcontractor candidates F and C included.

SIG : The process machines include warning signals
PROP : The workplaces are clean and ordered
ELOI : The working tools are far from the workplace
PAL : The number of management layers between the operator and the reception of the customers’ orders is high
NSUP : The number of managers that control the worker performance is high
METH : The working methods are imposed to the operators
EXC : The operators have working procedures for the special cases
POS : There are mechanisms that adequately position the parts to be worked
PROC : The working procedures are visible
DPDE : The delay to identify the defective products is high
MAIN : The operators apply machine auto-maintenance
DIF : The production line performance is visible
NAUTO: The machine cycle time dominates operator’s work speed
ERG : The workstation design respects the ergonomic principles
EQUI : The conception of the productivity improvements is done in group
ZERO : Zero defect mechanisms are implemented
**Figure 11.** Values desired by the virtual firm for the planning system for the cutting and sewing sections of the manufacturing subcontractor (in bold). The current values of subcontractor candidates F and C are included.

TRAN: The production operations are transferred to the customers
FERM: The quantity of products to make is based on concrete orders
AJU: The workforce level is adjusted to the sales level
LOY: Our customers are loyal so that they wait for our late products
JAL: The production is done in advance so that the products are stocked
DEC: The stocks of work in process are capped
ECOU: The production rates of the upstream workstations are controlled by feedback of the bottleneck workstation stock
IDEN: The work in process is efficiently identified
PREB: Production start date is obtained by backward planning from due date
ORDN: There is an efficient procedure for sequencing orders at the bottleneck workstation
FOUR: The number of materials suppliers is high
COL: There is a strong collaboration with suppliers to improve materials quality
LOTA: The materials are supplied in large batches
PREV: The sales forecasts are accurate

$\lambda_F = 19\%$
$\lambda_C = 61\%$
10, and 11. The latter show that the target market focusing indexes of enterprise C are greater than the ones of enterprise F (68% vs. 31% for the set-up operations of the cutting table, Figure 8; 69% vs. 15% for the production flow of the sewing section, Figure 9; 60% vs. 18% for the human factor of the button holes machine, Figure 10; 61% vs. 19% for the production planning of the cutting and sewing sections, Figure 11), indicating that the production system of C is more focused on the target market efficiency than that of F. Hence, C is chosen as the manufacturing subcontractor of the virtual enterprise.

As mentioned, the production system attributes of candidates F and C are analysed in order to rate them. This analysis is done with the tools in Table 1. Four examples follow. The first example is attribute COND that is analysed with a diagram machine-operator (tool S1 in Table 1) applied to the spreading machine as illustrated in Table 3. The latter shows that candidate C takes 3 minutes to spread the fabric whereas candidate F takes 35 minutes and in the best case this spreading activity takes 2 minutes with an automatic machine. These values allow the evaluation of COND as indicated in Table 3. The second example is attribute SIM that is analysed with a matrix of technology group (tool F2 in Table 1) applied to the sewing section as illustrated in Table 4. The latter shows that, when the family of polos is the basis of the layout, five different types of sewing machines are required, however candidate C uses 6 different types and candidate F uses 13 different types. These values allow the evaluation of SIM as indicated in Table 4. The third example is attribute POS that is analysed with a diagram of movements (tool H3 in Table 1) applied to the operator of the button-holes machine as illustrated in Figure 12. The latter shows that, when the fabric is well positioned, the operator walks 1.5 feet; however he walks 2 feet in factory C and 30 feet in factory F. These values allow the evaluation of POS as indicated in Figure 12. The fourth example is attribute DEC that is analysed with the index “work in process in days as a percentage of the required number of days to use this stock” (tool C4 in Table 1) applied to the stock of cut fabric, as illustrated in Table 5. The latter shows that, when the cut fabric is immediately sewn, the percentage above has a value of 100%, however this percentage has an average value of 625% in factory F and 120% in factory C. These values allow the evaluation of DEC as indicated in Table 5.
Table 3. Machine-operator diagram of activities to set-up the spreading machine of two subcontractor candidates (system analysis tool S1). This diagram allows to rate the COND attribute.

<table>
<thead>
<tr>
<th>Activity duration</th>
<th>Operator activities</th>
<th>Spreading machine activities</th>
<th>Activity duration</th>
<th>Operator activities</th>
<th>Spreading machine activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 min</td>
<td>Manually download the roll of fabric in the spreading machine</td>
<td>Stopped</td>
<td>1 min</td>
<td>Close the path to the finished roll of fabric in the spreading equipment</td>
<td>Stopped</td>
</tr>
<tr>
<td>2 min</td>
<td>Take off the roll bar</td>
<td></td>
<td>2 min</td>
<td>Open the path to the new roll of fabric already loaded in the second roll bar of the spreading machine</td>
<td></td>
</tr>
<tr>
<td>5 min</td>
<td>Walk to the warehouse</td>
<td></td>
<td></td>
<td>Begin to spread the fabric by pushing up and down the spreading machine</td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td>Transport a new roll of fabric from the warehouse to the spreading table</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 min</td>
<td>Unpack the new roll of fabric</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 min</td>
<td>Insert the bar into the new roll of fabric</td>
<td>3 min TOTAL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 min</td>
<td>Load the roll bar in the spreading equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Begin to spread the fabric by pushing up and down the spreading machine</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35 min</td>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CONDF = 2* min / 3 min = 70%**

**CONDC = 2* min / 35 min = 61%**

*Set-up time of an automatic spreading machine

---

Table 4. Group technology matrix of polos portfolio of two subcontractor candidates (system analysis tool F2). This matrix allows to rate the SIM attribute.

<table>
<thead>
<tr>
<th>Sewing machine type</th>
<th>SUBCONTRACTOR F</th>
<th>SUBCONTRACTOR C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Polo 1005</td>
<td>Polo 1005 y</td>
</tr>
<tr>
<td>Plain 301-X</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Overlock 504-X</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Overlock 512-X</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Chain stitch 407</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Overlock 504-Y</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Plain 301-Z</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Overlock 504-W</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Overlock 512-W</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Overlock 504-Z</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Plain 301-W</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Overlock 504-T</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Button holes-X</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Button machine-Z</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total types of machines</td>
<td>13 machines</td>
<td>6 machines</td>
</tr>
</tbody>
</table>

**SIMF = 5* machines / 13 machines = 40%**

**SIMC = 5* machines / 6 machines = 80%**

* Maximum number of different types of machines required.
Figure 12. Diagram of movements by the buttonhole machine operator at the factories of two subcontractor candidates (system analysis tool H3). This diagram allows to rate POS attribute.

<table>
<thead>
<tr>
<th>SUBCONTRACTOR F</th>
<th>SUBCONTRACTOR C</th>
</tr>
</thead>
<tbody>
<tr>
<td>button holes machine</td>
<td>table</td>
</tr>
<tr>
<td>cart 3'</td>
<td>button holes machine</td>
</tr>
<tr>
<td>4'</td>
<td>table</td>
</tr>
<tr>
<td>20'</td>
<td>sewing machine</td>
</tr>
<tr>
<td>3'</td>
<td>cart</td>
</tr>
<tr>
<td>sewing machine</td>
<td>2' 2' 2' 2'</td>
</tr>
<tr>
<td>cart</td>
<td>2'</td>
</tr>
</tbody>
</table>

Total distance walked by operator = 30 feet
POS_F = $\frac{1.5 \text{ feet}}{30 \text{ feet}}$ * 100% = 5%

Total distance walked by operator = 8 feet
POS_C = $\frac{1.5 \text{ feet}}{2 \text{ feet}}$ * 100% = 75%

* Minimum distance that an operator walks in a well designed production line

Once the manufacturing subcontractor C is chosen, the procedure of Figure 3 supported by the supply chain reference model is applied to evaluate the interactions of C with the supplier candidate A and then with B. The results are illustrated in the radar diagram of Figure 13. As noted the target market focusing index of candidate A is higher than the one of candidate B so that A is chosen as the supplier of fabric for the virtual enterprise. In practice, A will send fabrics to the manufacturing subcontractor C.

Finally, the procedure of Figure 3 supported by the supply chain reference model is applied to evaluate the interactions of the manufacturing subcontractor C with the candidate distributor W and then with Z. The results are illustrated in the radar diagram of Figure 14. As noted the target market focusing index of candidate W is higher than the one of candidate Z so that W is chosen as the distributor of the virtual enterprise. In practice, subcontractor C will send the polos made to distributor W.
Table 5. Work in process stock as a percentage of the required number of days to use this stock at the factories of two subcontractor candidates (system analysis tool C4). These percentages allow to rate DEC attribute.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>SUBCONTRACTOR F</th>
<th>SUBCONTRACTOR C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order quantity (garments)</td>
<td>Order 5892</td>
<td>Order 5895</td>
</tr>
<tr>
<td>Order 5892</td>
<td>1080</td>
<td>816</td>
</tr>
<tr>
<td>Current stock of fabric cut for the order (garments)</td>
<td>1080</td>
<td>400</td>
</tr>
<tr>
<td>Required time to sew the current stock (weeks)</td>
<td>1080 garments</td>
<td>500 garments</td>
</tr>
<tr>
<td>Order X-5945-Z</td>
<td>Order 5895</td>
<td>400 garments</td>
</tr>
<tr>
<td>Order X-5948-W</td>
<td>Order 5910</td>
<td>500 garments</td>
</tr>
<tr>
<td>Order 5910</td>
<td>200 garments</td>
<td>200 garments</td>
</tr>
<tr>
<td>Order X-5948-W</td>
<td>Order 5910</td>
<td>200 garments</td>
</tr>
<tr>
<td>Order X-5943-T</td>
<td>Order 5910</td>
<td>100 garments</td>
</tr>
<tr>
<td>Weeks that the cut fabric is stocked until today</td>
<td>5 weeks</td>
<td>5 weeks</td>
</tr>
<tr>
<td>Weeks of cut fabric stock as a percentage of the number of weeks to sew the stock</td>
<td>5 weeks 2 weeks</td>
<td>5 weeks 0.8 weeks</td>
</tr>
<tr>
<td></td>
<td>250%</td>
<td>625%</td>
</tr>
<tr>
<td></td>
<td>average 625%</td>
<td>average 625%</td>
</tr>
</tbody>
</table>

\[
DEC_f = \frac{100\%}{625\%} \quad DEC_c = \frac{100\%}{120\%} \quad \text{This case happens when the weeks of cut fabric stock equals the number of weeks to sew this stock.}
\]

\[
DEC_f = 16\% \quad DEC_c = 83\%
\]
Figure 13. Values desired by the virtual firm for the interactions between the manufacturing subcontractor and the knitted fabric supplier (in bold) The current values of fabric supplier candidates A and B are included.

FTPS: The manufacturing subcontractor order variations correspond to the flexibility of the materials supplier production system
DCTC: The materials are designed jointly by the materials supplier and the manufacturing subcontractor
CTC: The materials supplier and the manufacturing subcontractor have long term mutual assistance in problem solving efforts
RCCT: The manufacturing subcontractor communicates the product sales to the materials supplier in real time
TCTC: The materials supplier and the manufacturing subcontractor use a common terminology to communicate
EDT: The manufacturing subcontractor is efficiently integrated in the materials supplier distribution system

\[ \lambda_B = 45\% \]
\[ \lambda_A = 28\% \]
Figure 14. Values desired by the virtual firm for the interactions between the manufacturing subcontractor and the retailer (in bold) The current values of retailers W and Z are included.

FPC : The retailer order variations correspond to the flexibility of the manufacturing subcontractor production system
DCCD : The product is designed jointly by the retailer and the manufacturing subcontractor
CCD : The retailer and the manufacturing subcontractor have long term mutual assistance in problem solving efforts
TCD : The retailer and the manufacturing subcontractor use a common terminology to communicate
RCVC : The retailer communicates the sales to the manufacturing subcontractor in real time
EDD : The retailer is efficiently integrated in the manufacturing subcontractor distribution system

$\lambda_w = 67\%$
$\lambda_z = 39\%$
5. Conclusions

This paper has demonstrated that fuzzy cognitive maps could be used by virtual firms to support the industrial design of their products and the remote evaluation of its potential partners. These activities are done frequently during the development of new products.

6. References


