Selection of Simultaneous Engineering Environments by Means of Fuzzy Logic

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Summary

Intensified turbulence on the world market, as well as the trend towards the production of a single product for the known customer, put new demands upon a factory. To increase competiteveness on the market it is necessary to increase the efficiency of product development process, i.e. to reduce the time period that elapses between the very idea of the product and its appearance on the market. The mostly used concept today, intended to fulfil these demands, is simultaneous engineering (SE), which represents integrated and time simultaneous development of the product and production. In the cours of the last ten years several SE techniques have been developed. This paper presents the model of SE techniques selection for a particular factory. To select an optimal combination of SE techniques fuzzy set theory techniques have been used.

Key words: simultaneous engineering, fuzzy logic, Quality Function Deployment, Design for Assembly, Design for Manufacturing, Design for Reliability.

1.0 INTRODUCTION

Introduction of new markets and a rapid development of computer –aided engineering have brought about the reindustrialization of the existing factories. Regarding the sophistical customer needs, product design should be more complex and it should include a great number of design varieties. Increase in product leads to increase of the time necessary for the development of new products. This in turn collide with the need for shortening the product delivery time and the manufacturer may enter the critical time domain – he may appear into the market with the new product when the product life time is expiring.

Reducing time to market of a new product, i.e. reducing the development and innovation cycle can be implemented only using organizational and engineering measures which simultaneously reduce both the manufacturing cycle and the cycle beyond the immediate manufacturing process, particularly product and process planning time. Since present development and application of new strategies and types of organization on the one hand, and manufacturing equipment supporting them on the other hand, have led to greatest possible reduction of manufacturing cycle, investigations are now being directed towards the new organizational and production structures which increase the working speed and reduce all time losses during the stage of product and process planning.

Simultaneous engineering is one of the techniques intended to increase factory competitiveness on the market |1|. The main task of simultaneous engineering (SE furthers on) is to increase the design and production function and to reduce time necessary for the introduction of the new production to production. What SE suggests is to enhance the design function so that above mentioned problems could be predicted and solved as soon as possible, otherwise they would cause problems in later production stages.

In order to implement the SE concept, besides the necessary organizational activities we must also provide:

- computerization,
- synchronization of material and information flow,
- introduction of new technologies,
- cooperation among particular companies.

When implementing the SE concept the following organizational demands must be fulfilled:

- assembling an SE team,
- introduction of project management.

To make good use of SE it is necessary to use the potentialities of CAD/CAM technology. The right combination of software and hardware enables designers and engineers to work simultaneously on both product and process design. During the design stage different SE techniques can be combined with CAD system and data. Integrating these methods a constructor is able to improve the project directly, with reference to manufacturing and assembly.

Several SE techniques have been developed during the last fifteen years. They differ among themselves significantly and their uses are mainly limited to specific areas. These techniques need not be equally useful for the factories that differ among themselves in the size and complexity of product design processes. Therefore, when the introduction of SE in a factory is agreed about, the technique or the combination of techniques most suitable for the factory must be selected.

This paper presents a model for SE techniques selection for one factory. In the suggested method of justifiability, the data for cost/benefit analysis and SE techniques effectiveness are SE experts' estimations and, therefore, inevitably subjective and not precise to a certain extent. Fuzzy set theory techniques have been applied for fuzziness design |2,3|.

2. SELECTION OF SUITABLE SE ENVIRONMENT

For the selection of the optimal SE environment a systematic approach to cost/benefit analysis is indispensable. The term SE environment stands for the use of one or more SE techniques in a particular design situation.

2.1. Estimations necessary for SE environment selection

In this paper, the SE environment selection is presented by the example or rubber shock-absorber design and manufacturing. This product functions as an elastic ship-shore connection, i.e. it alleviates jerks and blows upon the ship while she is being moored. The factory in which the selection has been done is of medium size, with 250 employed and is organized on the basis of process principle |4|.

Up to now, many SE techniques have been developed to enable simultaneous product and manufacturing design. Out of them the following techniques have been applied in this paper:

- QFD (Quality Function Deployment) – T_1,
- DFA (Design for Assembly) – T_2,
- DFM (Design for Manufacturing) - T_3,
- DFR (Design for Reliability) – T_4.

The task was to select techniques T_i in order to improve the existing design process, i.e. to determine how to either find or avoid a particular defect D_j in design. The basis for this was the selection model presented in the paper |5|.

The analysis of document of design modifications, published in a three year period, has discovered five defects:

- losses due to turning work and plug fitting on the model and additional grinding of learning facets (grooves are to be modeled with semi-circular milling cutter, 20 mm in diameter, thus aforesaid will not be necessary),
- more difficult manipulation of the model hot facets because of the lack of handles (handles are to be fitted),
- wrong model shutting due the symmetrically fitted bolts (bolts to be put asymmetrically),
- press under-utilization (there could be four nests in the model instead of two),
- early cracking of rubber in the places where the rope leans against the amortizer (hole edges through the rope passes should be rounded).

The above mentioned design defects will be marked by D_j, where j = 1,2,...,5. Experts are invited to evaluate the detectability of each SE technique against each design defects and the results are shown in Table 1. For detectability (the possibility of detecting a design defect by a SE technique) the set of its linguistic values (very low, low, medium, high, very high) was used. Each of these linguistic values is represented by a TFN (triangular fuzzy number) with its membership function. Note that these linguistic values are TFNs in the interval [0,1].

Table 1. Detectability of example SE techniques against design defects (“very low” (VL), “low” (L), “medium” (M), “high” (H), “very high” (VH))

SE techniques	Design defects				
	D_1	D_2	D_3	D_4	D_5
T_1	M	VH	M	L	VL
T_2	VL	M	VH	L	VL
T_3	VH	H	L	VH	M
T_4	M	VL	L	M	VH

Based on Table 1 detectabilities of SE techniques are represented by fuzzy numbers presented in Table 2. For example, the membership function of “medium” is (0.25,0.5,0.75). That is, an expression of “medium detectability” denotes that the detectability of the concerned SE technique is between 0.25 and 0.75 and most probable value is 0.5. Other membership functions are defined likewise.

Table 2. Detectability of SE techniques represented by fuzzy numbers

SE techniques	Design defects				
	D_1	D_2	D_3	D_4	D_5
T_1	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0, 0, 0.25)
T_2	(0, 0, 0.25)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0, 0.25, 0.5)	(0, 0 , 0.25)
T_3	(0.75, 1, 1)	(0.5, 0.75, 1)	(0, 0.25, 0.5)	(0.75, 1, 1)	(0.25, 0.5, 0.75)
T_4	(0.25, 0.5, 0.75)	(0, 0, 0.25)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.75, 1, 1)

Suppose there are n SE techniques $(T_1, T_2,...,T_n)$ which are considered to be introduced to this factory. These n SE techniques would form m or 2^n-1 alternatives of SE environments:

$$m = 2^n - 1 = 2^4 - 1 = 15 \qquad (1)$$

Alternatives will be marked by A_t, where t =1,2,...,15

$$A_t = (a_{t1}, a_{t2}, a_{t3}, a_{t4}) \qquad (2)$$
$$a_{ti} \in \{0,1\}$$

if technique T_i is included in alternative A_t

then a_{ti}=1

otherwise a_{ti}=0

Detectability of a SE technique can be represented by vector $\overline{E_i} = (E_{i1}, E_{i2},..., E_{i5})$, where E_{ij} is a TFN which represents the detectability of SE technique T_i against design defect D_j. Note that the detectability of technique Ti against design defect D_j under environment A_i can be represented by b_{tij}, where $b_{tij} = a_{tj} \cdot E_{ij}$.

The annual cost of utilizing a SE technique involves two major cost items and can be described as follows:

$$C_i = O_i + \frac{h_i}{r_i} \qquad (3)$$

where
C_i is the annual cost of utilizing SE technique T_i
h_i is the installation cost of SE technique T_i
r_i is the years of deprecation for the installation cost h_i
O_i is the annual operation cost of SE technique T_i.

The h_i, r_i and O_i values can be estimated in such way that the lower bound, the most probable value and the upper bound are defined.

The cost of utilizing SE techniques can be denoted by a vector $\overline{C} = (C_1, C_2, C_3, C_4)$, where $C_i = (C_{i1}, C_{i2}, C_{i3})$. Values C_i are TFN, presents the annual cost of utilizing technique T_i.

Table 3. Cost data relevant to example SE techniques

SE techniques	h_i (\$ x 10000)	r_i (years)	O_i (\$ x 10000)	C_i (\$ x 10000)
T_1	(6, 8, 10)	3	(4, 6, 8)	(6, 8.67, 11.33)
T_2	(13, 16, 19)	5	(3, 5, 7)	(5.6, 8.2, 10.8)
T_3	(17, 21, 25)	5	(3, 4, 5)	(6.4, 8.2, 10)
T4	(23, 28, 33)	6	(1, 2, 3)	(4.83, 6.67, 8.5)

Likewise, the loss saving (benefit) of finding or avoiding a design defect can be modeled by a vector $\overline{S} = (S_1, S_2, S_3, S_4, S_5)$, where $S = (S_{j1}, S_{j2}, S_{j3})$, is a TFN, which represents the amount of loss saving due to the detection of design defects D_j.

Table 4. Amount of loss saving due to the finding of design defects D_j ($ x 10000)

S_1	S_2	S_3	S_4	S_5
(45, 65, 85)	(60, 80, 100)	(90, 120, 150)	(100,125,160)	(140, 170, 200)

2.2. Calculation of total dectabilities of SE environment alternatives

Let $\overline{U_t} = (u_{t1}, u_{t2}, u_{t3}, u_{t4}, u_{t5})$ be a vector of TFNs, where $u_{tj}=(u_{tj1},u_{tj2},u_{tj3})$ represents the aggregated detectability against design defect D_j under SE environment A_t. Value u_{tj} is calculated in the following way:

$$u_{tj} = F_p \cdot (b_{t1j}, b_{t2j}, b_{t3j}, b_{t4j}) \tag{4}$$

where
F_p – propounded union operator with a parameter p=3
$b_{tij} = a_{tj} \cdot A_{ij}$

that is

$$u_{tj} = Min\left\{1, (\sum_{i=1}^{n} a_{ij}^{p})^{1/p}\right\}; p \geq 1 \tag{5}$$

for p=1 total dectability is equal to the sum of single values,
for $p=\infty$ total dectability is equal to the maximum single value.

For example, for alternative A_5=(1,1,0,0)

$u_{51}=F_p(b_{511},b_{521})$
$b_{511} = a_{51} \cdot E_{11} = 1 \cdot (0.25,0.5,0.75) = (0.25,0.5,0.75)$
$b_{521} = a_{52} \cdot E_{21} = 1 \cdot (0,0,0.25) = (0,0,0.25)$
$u_{51}=(c_1,c_2,c_3)$
$C_1 = Min\{1, (0.25^3 + 0)^{1/3}\} = 0.25$
$C_2 = Min\{1, (0.5^3 + 0)^{1/3}\} = 0.5$
$C_3 = Min\{1, (0.75^3 + 0)^{1/3}\} = 0.76$
u_{51}=(0.25,0.5,0.76)

Likewise, total detectabilities of all alternatives of SE environment have been calculated (Table 5). Only one technique is included in the first four alternatives so that there is no difference between the entire detectability of the environment and the very technique included in it.

The growth in the number of involved techniques enables the growth of detectablity of SE environment alternatives. An alternative containing the techniques that enable fretter detactability of a particular defect has greater total detectability than the alternative with “weaker” techniques for detecting that defect. Therefore, alternative A_{15} has the greatest detectability of all five mentioned design defects since it contains all four propounded SE techniques.

Alternatives close to alternative A_{15}, in terms of total detectability but containing smaller number of techniques, are:

for defect $D_1 \rightarrow$ alternative $A_3(0, 0, 1, 0)$
for defect $D_2 \rightarrow$ alternative $A_6(1, 0, 1, 0)$
for defect $D_3 \rightarrow$ alternative $A_2(0, 1, 0, 0)$
for defect $D_4 \rightarrow$ alternative $A_3(0, 0, 1, 0)$
for defect $D_5 \rightarrow$ alternative $A_4(0, 0, 0, 1)$

Technique T_3 (Design for Manufacturing) appears most frequently, this speaking clearly in favor of its effectiveness.

Table 5. Aggregated detectability of SE environment alternatives

SE environment	Design defects				
	D_1	D_2	D_3	D_4	D_5
A_1(1,0,0,0)	(0.25,0.5,0.75)	(0.75,1,1)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)
A_2(0,1,0,0)	(0,0,0.25)	(0.25,0.5,0.75)	(0.75,1,1)	(0,0.25,0.5)	(0,0,0.25)
A_3(0,0,1,0)	(0.75,1,1)	(0.5,0.75,1)	(0,0.25,0.5)	(0.75,1,1)	(0.25,0.5,0.75)
A_4(0,0,0,1)	(0.25,0.5,0.75)	(0,0,0.25)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.75,1,1)
A_5(1,1,0,0)	(0.25,0.5,0.76)	(0.76,1,1)	(0.76,1,1)	(0,0.31,0.63)	(0,0,0.31)
A_6(1,0,1,0)	(0.76,1,1)	(0.82,1,1)	(0.25,0.52,0.82)	(0.75,1,1)	(0.25,0.5,0.76)
A_7(1,0,0,1)	(0.31,0.63,0.94)	(0.75,1,1)	(0.25,0.52,0.82)	(0.25,0.52,0.82)	(0.75,1,1)
A_8(0,1¸1,0)	(0.75,1,1)	(0.52,0.82,1)	(0.75,1,1)	(0.75,1,1)	(0.75,1,1)
A_9(0,1,0,1)	(0.25,0.5,0.76)	(0.25,0.5,0.76)	(0.75,1,1)	(0.25,0.52,0.82)	(0.75,1,1)
A_{10}(0,0,1,1)	(0.76,1,1)	(0.5,0.75,1)	(0,0.31,0.63)	(0.76,1,1)	0.76,1,1)
A_{11}(1,1,1,0)	(0.76,1,1)	(0.83,1,1)	(0.76,1,1)	(0.75,1,1)	(0.25,0.5,0.77)
A_{12}(0,1,1,1)	(0.76,1,1)	(0.52,0.82,1)	(0.75,1,1)	(0.76,1,1)	(0.76,1,1)
A_{13}(1,0,1,1)	(0.77,1,1)	(0.82,1,1)	(0.25,0.54,0.88)	(0.76,1,1)	(0.76,1,1)
A_{14}(1,1,0,1)	(0.31,0.63,0.95)	(0.76,1,1)	(0.76,1,1)	(0.25,0.54,0.88)	(0.75,1,1)
A_{15}(1,1,1,1)	(0.75,1,1)	(0.83,1,1)	(0.76,1,1)	(0.76,1,1)	(0.76,1,1)

2.3. Cost/benefit analysis of SE environment

As said above, data on design defects were gathered from the documents of design changes from previous *z* years. Cost/benefit analysis for utilizing a SE environment is thus made for that time period.

The cost *(Q_t)* for utilizing a SE environment A_t can be computed as follows:

$$Q_t = \left(\sum_{i=1}^{n} a_{ti} \cdot C \right) \cdot z \qquad (6)$$

where
$a_{ti} = 1$ if technique T_i is included in the SE environment
$a_{ti} = 0$ otherwise
C_i annual cost of utilizing technique T_i
z concerned time horizont for the economic justification
n total number of prospective techniques

The benefit *(B_t)* for utilizing a SE environment A_t can be computed as below.

$$B_t = \sum_{j=1}^{k} u_{tj} \cdot S_j \qquad (7)$$

where

u_{tj} is the aggregated detectability against defect D_j under CE environment A_t

S_j is the loss saving due to the detection of design defect D_j

k total number of design defects.

Finally, the net benefit *(N_t)* for SE environment A_t can be formulated as below,

$$N_t = B_t - Q_t \qquad (8)$$

Based on the equations (6-8) in Table 6, the survey of cost, benefit and net benefits of all the alternatives of a SE environment is given. Here, similarly to behavior of total detectabilities, there is more benefit with the alternatives with more techniques.

However, the most benefit is not obtained by alternative A_{15}, which has maximum number of techniques (but its costs are big) but by alternative A_{12}.

Alternative A_{12} includes the following SE techniques:

- DFA - Design for Assembly,
- DFM - Design for Manufacturing,
- DFR - Design for Reliability.

Table 6. Cost/benefit analysis of SE environment alternatives

SE environment	Q_t (\$ x 10000)	B_t (\$ x 10000)	N_t (\$ x 10000)
A_1(1,0,0,0)	(30,43.35,56.65)	(78.75,203.75,401.25)	(48.75,160.15,344.6)
A_2(0,1,0,0)	(28,41,54)	(82.5,191.25,371.25)	(54.5,150.25,317.25)
A_3(0,0,1,0)	(32,41,50)	(173.75,365,560)	(141.75,324,510)
A_4(0,0,0,1)	(24.15,33.35,42.5)	(141.25,295,476.25)	(117.1,261.65,433.75)
A_5(1,1,0,0)	(58,84.33,110.67)	(125.25,271.25,470.25)	(67.25,186.92,359.58)
A_6(1,0,1,0)	(62,84.33,106.67)	(215.9,417.4,610)	(153.0,333.07,503.33)
A_7(1,0,0,1)	(54.15,76.67,99.17)	(211.45,418.35,625.9)	(157.3,431.68,526.73)
A_8(0,1,1,0)	(60,82,104)	(242.45,460.6,637)	(182.45,378.6,533)
A_9(0,1,0,1)	(52.15,74.35,96.5)	(223.75,427.5,613.6)	(171.6,353.15,517.1)
A_{10}(0,0,1,1)	(56.15,74.33,92.5)	(246.6,457.2,629.5)	(190.45,382.87,537)
A_{11}(1,1,1,0)	(90,125.33,160.65)	(262.1,475,639)	(172.1,349.67,478.35)
A_{12}(0,1,1,1)	(84.15,115.33,146.5)	(315.3,545.6,685)	(231.15,430.27,538.5)
A_{13}(1,0,1,1)	(86.15,117.67,149.17)	(288.75,504.7,667)	(202.6,387.13,517.83)
A_{14}(1,1,0,1)	(82.15,117.67,153.17)	(257.95,478.45,662.75)	(175.8,360.78,509.58)
A_{15}(1,1,1,1)	(114.15,158.67,203.17)	(334.65,560,685)	(220.5,401.33,481.83)

4. CONCLUSION

Four most suitable techniques of simultaneous engineering, with reference to factory size and product selection, have been selected in this paper.

The existing documents of design modification, in which the existence of five defects is note, were used to estimate the efficiency of each technique. Detectability of defect in each SE technique design was calculated by triangular fuzzy numbers (TFN). An adaptable union operator was used to calculate total detectabilities for each environment.

Benefit of utilizing a SE environment was estimated on the basis of total detectabilities and reduction of losses that had occurred thanks to the removal of the above mentioned design defects. Data on costs and benefits from utilizing a SE environment were modeled by TFN, thus net benefit from utilizing a SE environment is TFN as well.

In the course of selection process annual budget limit to introduction a SE environment by fuzzy numbers was calculated. The optimal simultaneous engineering alternative is the one which meets the limits of the budget and by the use of which the most net benefit is obtained. However, due to space limit in this paper this selection has not been mentioned. It can be pointed out that two techniques of SE, DFA (Design for Assembly) and DFM (Design for Manufacturing) have been selected for the limited budget.

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