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DEPENDENCE ANALYSIS AND REDUCTION ON THE NUMBER OF JUDGMENTS APPLIED TO AN INFORMATION TECHNOLOGY DECISION PROBLEM WITH THE ANALYTIC NETWORK PROCESS

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Summary*: This paper presents the multiple criteria modeling for an Information Technology decision problem. There are presented two multiple criteria models to evaluate different alternatives for the implementation of one Enterprise Resources Planning module. The first model was developed with the Analytic Hierarchy Process. From this model, the Analytic Network Process was applied in order to include the analysis of dependence among elements of the model. Some alternatives to reduce the number of required judgments are also presented.*

1. Introduction

Decisions regarding the choice among alternatives for implementation of an Information Technology (IT) application are frequently complex. The evaluation of IT applications can be fit in the "disorganized complexity" (Norden, 1993). In the literature, these applications have typically been evaluated on not only a single criterion. This way, Multiple Criteria Decision Making (MCDM) methods had been used to support this decision (Forgionne, 1999; Phillips-Wren et al., 2004; Shimizu et al., 2006).

In this work, MCDM methods were used for a Brazilian industrial company to solve an IT decision problem. The decision was to choose one from three alternatives for a specific application of IT: the implementation of the Enterprise Resources Planning (ERP) module for the inventory and production management, for one business area of the company. The ERP system allows a "visibility in real time of the status of the plant for all the departments, including Marketing, Production, Finances, etc." (Slack et al., 2004). According to Marks (2002), ERP systems, or integrated systems of enterprise management, have been worldwide used since the 90's.

As shown in Section 2, there were 3 major alternatives to implement the ERP module in the studied business area. Alternatives evaluation was based on the results from interviews with several IT company managers. These managers were in charge of the judgments. In a first moment, a model was built using the Analytic Hierarchy Process (AHP). This model was extended with the application of the Analytic Network Process (ANP) in order to include the analysis of dependence among elements of the model. It is also presented some alternatives to reduce the number of required judgments.

2. The Problem

In this section, it is presented a multiple criteria model to evaluate different alternatives for implementing one ERP module. This module is concerned to the inventory and production management for one of the business areas of a Brazilian industrial company. The studied business area was facing several changes in the Production Management in the last years. There was given emphasis to the Just In Time (JIT) and the production programming system was deactivated. The programming has changed to be executed directly by the productive areas. The number of products was great (4,000 products and 2,000 repair parts). It made difficult the adoption of JIT, according to Slack et al. (2004). Thus, the necessity of an IT application has become clear. A process of discussion with the Corporate IT area has resulted in three alternatives for solving this problem:

- Purchase a manufacturing software, keeping the internally developed systems basis;
- Internal complementation of the ERP, developed by the corporation;
- Purchase an entire ERP package available in the market.

The Critical Success Factors (CSF) method (Rockart, 1979; Shimizu et al., 2006) was used to generate a set of criteria to evaluate the alternatives. Figure 1 shows the hierarchical structure, i.e., a MCDM modeling with the Analytic Hierarchy Process (AHP).

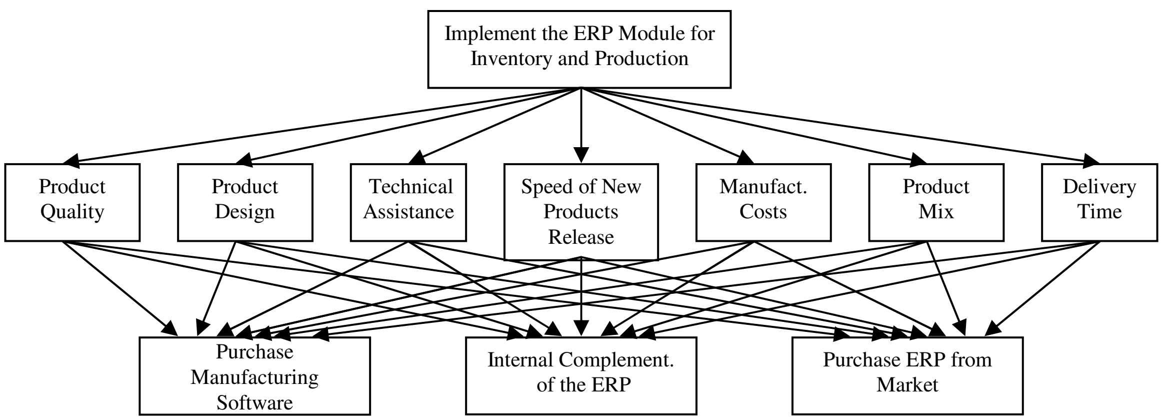

Figure 1. Hierarchical Structure to Evaluate IT Alternatives to Implement an ERP Module

Table 1 presents the judgments on CSF importance for the alternative evaluation. The Fundamental Scale (Saaty, 1980), a simple linear 1 to 9 scale, was used for these judgments. For example, Product Quality was judged as “strongly more important” than Product Design. The Fundamental Scale was adopted due their ability to “capture a great deal of information” and the “evidence as shown by various experiments and by the use of the AHP in practice that the 1 to 9 scale can accurately portray an individual’s intensity of preference.” (Harker & Vargas, 1987).

Table 1. Importance of the Critical Success Factors

CSF	PQ	PD	TA	NP	MC	PM	DT	Importance
Product Quality (PQ)	1	5	6	7	3	8	4	39.1%
Product Design (PD)		1	2	5	1/3	5	1/3	9.6%
Technical Assistance (TA)			1	5	1/5	3	1/3	6.7%
Speed of New Products Release (NP)				1	1/6	3	1/5	3.3%
Manufacturing Costs (MC)					1	7	3	23.8%
Product Mix (PM)						1	1/7	2.4%
Delivery Time (DT)							1	15.1%

The importance values for the CSF presented in Table 1 were obtained with the judgments matrix eigenvector, as proposed by Saaty (1980). The consistency ratio (CR) for these judgments is equal to 0.078. As the CR is lower than 0.2, the judgments can be considered as coherent one with another.

The performances of the alternatives according to the CSF are presented in Tables 2 to 7. For Product Mix and Delivery Time, the judgments were the same. Therefore, only Table 7 presents them.

Table 2. Performance on Product Quality

	A1	A2	A3	Performance
Purchase Manufacturing Software (A1)	1	4	3	59.6%
Internal Complement of the ERP (A2)		1	1/5	9.6%
Purchase ERP from Market (A3)			1	30.8%

Table 3. Performance on Product Design

	A1	A2	A3	Performance
Purchase Manufacturing Software (A1)	1	5	4	65.7%
Internal Complement of the ERP (A2)		1	1/5	8.3%
Purchase ERP from Market (A3)			1	26.0%

Table 4. Performance on Technical Assistance

	A1	A2	A3	Performance
Purchase Manufacturing Software (A1)	1	4	2	54.7%
Internal Complement of the ERP (A2)		1	1/4	10.8%
Purchase ERP from Market (A3)			1	34.5%

Table 5. Performance on Speed of New Products Release

	A1	A2	A3	Performance
Purchase Manufacturing Software (A1)	1	6	5	69.5%
Internal Complement of the ERP (A2)		1	1/6	6.8%
Purchase ERP from Market (A3)			1	23.7%

Table 6. Performance on Manufacturing Costs

	A1	A2	A3	Performance
Purchase Manufacturing Software (A1)	1	1/2	1/3	15.2%
Internal Complement of the ERP (A2)		1	1/4	21.8%
Purchase ERP from Market (A3)			1	63.0%

Table 7. Performances on Product Mix and Delivery Time

	A1	A2	A3	Performance
Purchase Manufacturing Software (A1)	1	4	2	54.7%
Internal Complement of the ERP (A2)		1	1/4	10.8%
Purchase ERP from Market (A3)			1	34.5%

Only two judgments matrices have CR values higher than 0.20: 0.21 for Product Design and 0.28 for Speed of New Products Release. These judgments had been revised and maintained.

Table 8 presents the decision vector to implement the ERP module for inventory and production management. The result is "purchase of manufacturing software" as the best alternative, i. e., the alternative with higher global performance, considering the importance of the CSF showed on Table 1.

Table 8. Global Performance

	Global Performance
Purchase Manufacturing Software	48.7%
Internal Complement of the ERP	12.8%
Purchase ERP from Market	38.5%

The sensitivity analysis, as can be observed in Figure 2, shows that if it had been attributed for Manufacturing Costs an importance higher than 40%, then “purchase of ERP from market” will the best alternative. For other values, “purchase of manufacturing software” continues to be the best alternative to implement the ERP module of inventory and production management. The sensitivity analysis strengthens the decision of “purchase of manufacturing software”.

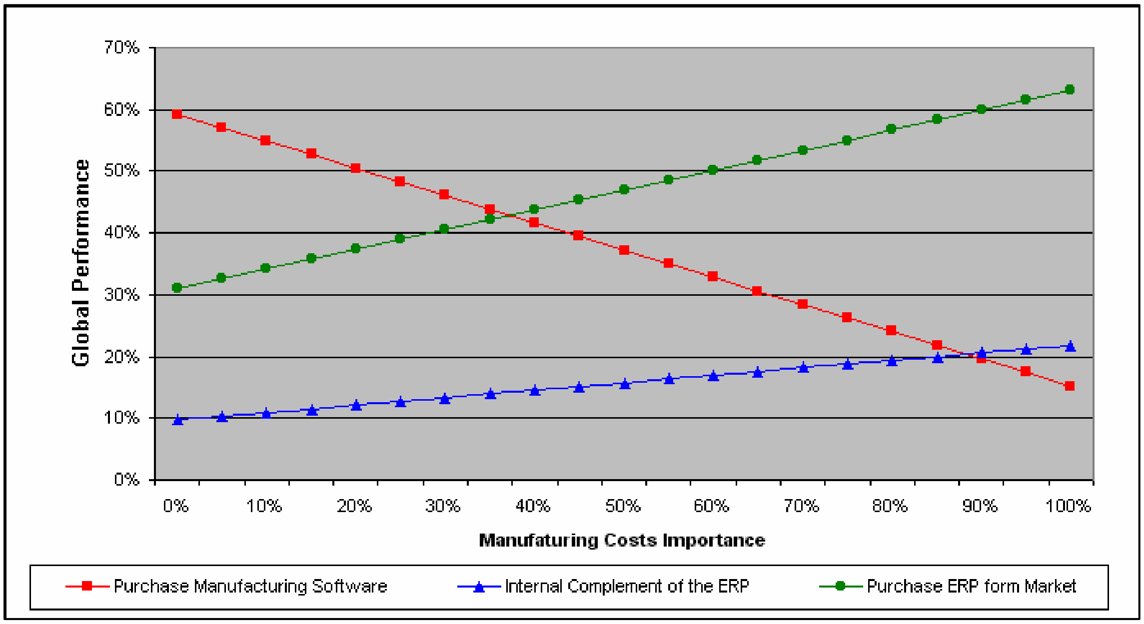

Figure 2. Sensitivity of Alternatives Global Performance to Manufacturing Costs Importance

In this section, the Analytic Hierarchy Process (AHP) was used to model the decision making with multiple criteria. The judgments of the alternatives performance were identical for two criteria (Product Mix and Delivery Time). This fact may suggest the existence of some dependence between these criteria. In the next section, the Analytic Network Process (ANP) will be applied in order to include the analysis of dependence among elements of the model.

The AHP application, presented in this section, needed 42 judgments: 21 on the importance of the criteria (Table 1) and more 21 judgments on the performance of the alternatives for each criterion (Tables 2 to 7). In Section 4, some comments about the reduction on the number of judgments will be made.

3. Dependence Analysis

Due to the possibility of dependence analysis, the ANP is considered as an extension of the AHP (Saaty, 2001). In practice, the ANP application needs the same judgments used for the AHP application, but ANP needs more judgments regarding the dependence or influence among elements of the model. The dependence and influences are judged by pairwise comparisons (Tesfamariam and Lindberg, 2005). The Fundamental Scale can also be used for these judgments. The ANP also differs of AHP in the computation with the use of stochastic matrices, based on Markov Chain theory (Saaty, 2001).

In order to structure the decision using ANP, the relations of dependence or influence among the elements must be represented. The new structure is called “network” (Saaty, 2001). Figure 3 shows a network for the decision problem introduced in Section 2. The criteria were considered as being dependent of each other. There is a curved arrow above the Criteria Box (starting and ending at the box) that represents this dependence. The alternatives were considered independent of each other: there is no arrow above the Alternative Box. The two-way arrow between the blocks means that the criteria have influence on the alternatives and vice-versa, the alternatives have influence on the criteria.

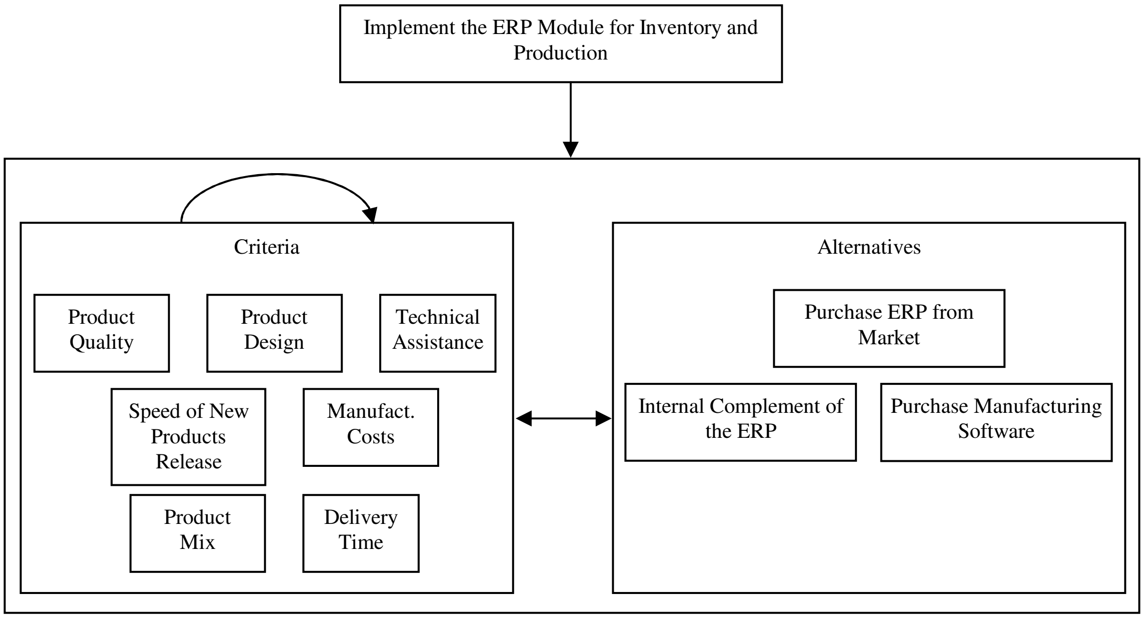

Figure 3. Network Structure to Evaluate IT Alternatives to Implement an ERP Module

The vectors of dependence or influence must be inserted in a Supermatrix (Saaty, 2001). For the network presented in Figure 3 we have a four blocks Supermatrix, as the presented in Figure 4. Each block of the Supermatrix is a column stochastic matrix.

<table>
<tr><th></th><th>PQ</th><th>PD</th><th>TA</th><th>NP</th><th>MC</th><th>PM</th><th>DT</th><th>A1</th><th>A2</th><th>A3</th></tr>
<tr><td>Product Quality (PQ)</td><td colspan="7" rowspan="7">1st Block
(Dependence among the criteria)</td><td colspan="3" rowspan="7">2nd Block
(Influence of the criteria on the alternatives)</td></tr>
<tr><td>Product Design (PD)</td></tr>
<tr><td>Technical Assistance (TA)</td></tr>
<tr><td>Speed of New Products Release (NP)</td></tr>
<tr><td>Manufacturing Costs (MC)</td></tr>
<tr><td>Product Mix (PM)</td></tr>
<tr><td>Delivery Time (DT)</td></tr>
<tr><td>Purchase Manufact. Software (A1)</td><td colspan="7" rowspan="3">3rd Block
(Influence of the alternatives on the criteria)</td><td colspan="3" rowspan="3">4th Block
(Dependence among the alternatives)</td></tr>
<tr><td>Internal Complement of ERP (A2)</td></tr>
<tr><td>Purchase ERP from Market (A3)</td></tr>
</table>

Figure 4. Supermatrix Blocks

On Table 9, in the column for Product Quality (PQ), it can be noted that this criterion was judged only dependent of Product Design (PD) and Speed of New Products Release (NP). The criterion PQ was judged equally dependent from PD and NP with dependence values equal to 50%. This equality can be observed in others columns of this block, because it was decided only to evaluate what criteria was dependent from others, and not how much. In practice, this procedure is equivalent to recognize that there is dependence among the criteria, but it is not possible to be sure of how strong this dependence is compared to another for the same dependent element.

The vectors of influence of the criteria on the alternatives are in the second block of the Supermatrix. They can be obtained with judgments in ANP. For example, if there is one alternative taking one criterion in account more than the other alternatives take, this can cause some impacts in the alternative performance. But, for this decision problem, this aspect was not considered. So, for the three columns of the block, A1, A2 and A3, the vector of importance of the criteria (Table 1) was used as vector of influence of the criteria on the alternatives.

The vectors of influence of the alternatives on the criteria are in the third block of the Supermatrix. For these vectors were used the vectors of performance of the alternatives on each criterion (Table 2 to 7).

The vectors of dependence among the alternatives are in the fourth block of the Supermatrix. The ANP allows incorporate a kind of information like an alternative establishing the standard for the performance on a criterion and others alternatives basing their performances on it. As presented in Section 2, the alternative may be considered as mutually exclusive. So the fourth block of the Supermtatrix presented in Table 9 is a null matrix. If we had the first and fourth blocks as zero matrices, then the results obtained with the ANP application would be the same from the AHP application.

Table 9. Supermatrix

	PQ	PD	TA	NP	MC	PM	DT	A1	A2	A3
PQ	0	50.0%	0	50.0%	0	0	0	39.1%	39.1%	39.1%
PD	50.0%	0	0	50.0%	0	0	0	9.6%	9.6%	9.6%
TA	0	0	0	0	0	50.0%	50.0%	6.7%	6.7%	6.7%
NP	50.0%	50.0%	0	0	0	0	0	3.3%	3.3%	3.3%
MC	0	0	0	0	0	0	0	23.8%	23.8%	23.8%
PM	0	0	50.0%	0	0	0	50.0%	2.4%	2.4%	2.4%
DT	0	0	50.0%	0	0	50.0%	0	15.1%	15.1%	15.1%
A1	59.6%	65.7%	54.7%	69.5%	15.2%	54.7%	54.7%	0	0	0
A2	9.6%	8.3%	10.8%	6.8%	21.8%	10.8%	10.8%	0	0	0
A3	30.8%	26.0%	34.5%	23.7%	63.0%	34.5%	34.5%	0	0	0

The Supermatrix must be weighted in order to become a column stochastic matrix. The supermatrix was weighted in an equilibrate way: it was considered that the influences among the criteria are as important as the performances of the alternatives. This way, the sum of the components of each column of the first block is equal to 50% in the Weighted Supermatrix (Table 10), except for MC column. The same occurs for the third block. However, this consideration will be checked with a sensitivity analysis (Figure 5).

Table 10. Weighted Supermatrix

	PQ	PD	TA	NP	MC	PM	DT	A1	A2	A3
PQ	0	25.0%	0	25.0%	0	0	0	39.1%	39.1%	39.1%
PD	25.0%	0	0	25.0%	0	0	0	9.6%	9.6%	9.6%
TA	0	0	0	0	0	25.0%	25.0%	6.7%	6.7%	6.7%
NP	25.0%	25.0%	0	0	0	0	0	3.3%	3.3%	3.3%
MC	0	0	0	0	0	0	0	23.8%	23.8%	23.8%
PM	0	0	25.0%	0	0	0	25.0%	2.4%	2.4%	2.4%
DT	0	0	25.0%	0	0	25.0%	0	15.1%	15.1%	15.1%
A1	29.8%	32.9%	27.4%	34.8%	15.2%	27.4%	27.4%	0	0	0
A2	4.8%	4.2%	5.4%	3.4%	21.8%	5.4%	5.4%	0	0	0
A3	15.4%	13.0%	17.3%	11.9%	63.0%	17.3%	17.3%	0	0	0

Table 11 shows the Limit Matrix, obtained with the 64th power of the Weighted Supermatrix. The normalization of the Limit Matrix third block results the Global Performance vector showed on Table 12.

Table 11. Limit Matrix

	PQ	PD	TA	NP	MC	PM	DT	A1	A2	A3
PQ	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%
PD	10.3%	10.3%	10.3%	10.3%	10.3%	10.3%	10.3%	10.3%	10.3%	10.3%
TA	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%
NP	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%
MC	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%
PM	4.2%	4.2%	4.2%	4.2%	4.2%	4.2%	4.2%	4.2%	4.2%	4.2%
DT	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%
A1	18.1%	18.1%	18.1%	18.1%	18.1%	18.1%	18.1%	18.1%	18.1%	18.1%
A2	4.4%	4.4%	4.4%	4.4%	4.4%	4.4%	4.4%	4.4%	4.4%	4.4%
A3	13.7%	13.7%	13.7%	13.7%	13.7%	13.7%	13.7%	13.7%	13.7%	13.7%

It can be seen in the Table 12 that the "purchase of manufacturing software" is the best alternative for both methods application (AHP or ANP). Moreover, there is the same ordinal vector for the alternatives global performance: [1, 3, 2].

Table 12. Global Performance (AHP or ANP)

	Global Performance (AHP)	Global Performance (ANP)
Purchase Manufacturing Software	48.7%	49.9%
Internal Complement of the ERP	12.8%	12.3%
Purchase ERP from Market	38.5%	37.8%

In the Figure 5, it can be observed that no matter what is the weight of the Supermatrix first block values, the "purchase of manufacturing software" will be the best alternative. Moreover, the cardinal vectors for the alternatives Global Performance do not suffer great disturbances with change in these weights. This way, also for the ANP model, the sensitivity analysis strengthens the decision of "purchase of manufacturing software"

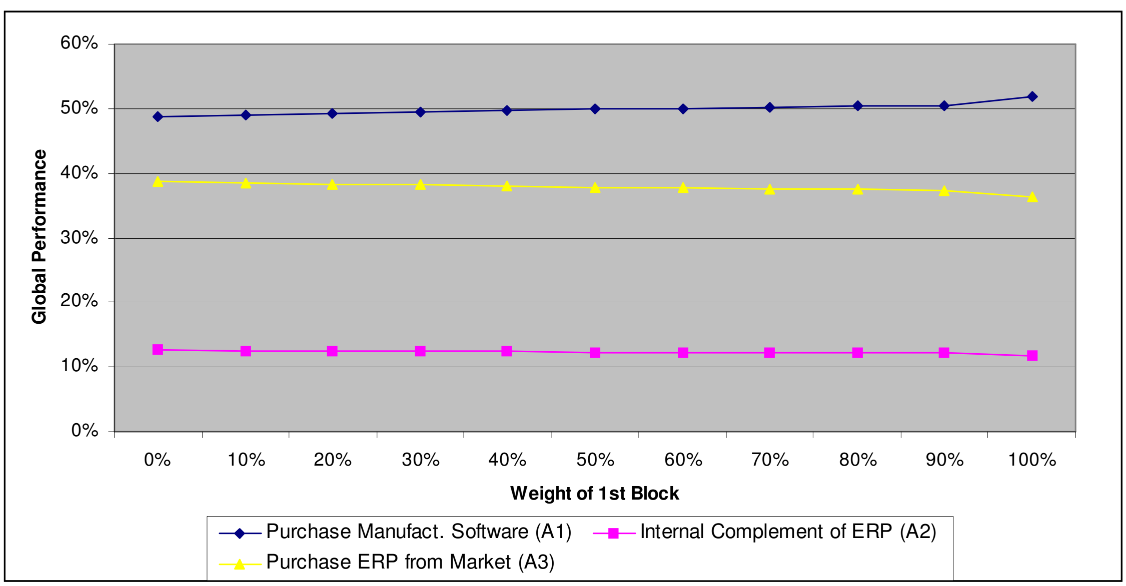

Figure 5. Sensitivity of Alternatives Global Performance to the Weight of First Block Values

With the results presented in this section, it can be argued about the relevance of dependence analysis. After all, with or without the dependence analysis, the results are quite the same. There are two remarks on this fact. At first, with the ANP model it was recognized that there was a small level of dependence among the criteria and none among the alternatives. Anyway, this was a case where there is dependence among the criteria. So, the dependence analysis made the model more realistic. If there would be more cases or higher level of dependence, the results could significantly differ. The second remark is that, only after the dependence analysis has been made, the dependence was considered small. Before the analysis, it was only known that there was dependence among the criteria. But, it was not possible to know how the dependence would affect the final results.

In the ANP application shown in this section, two new procedures were adopted. One consequence is that we need much less judgments than the usual procedures. This aspect was discussed in next section.

4. Reduction on the Number of Judgments

According to Chung et al. (2005), "while AHP has been a popular research and application tool for multi-attribute decision-making, the ANP technique so far has had only a few applications in literature". One reason for this is the number of judgments that is needed to get the results for decision. In their paper, Chung et al. (2005) have involved with a total of 15 judgments matrices.

The total number of judgments matrices to an ANP application can be obtained adding the number of non-zero columns from the blocks of the Supermatrix. For our case, there will be necessary 16 judgments matrices. But, with two new procedures, there is need no more than the judgment required for the AHP application. The first procedure was to judge equally influent the criteria for a dependent criterion. As observed in last section, this procedure is equivalent to recognize that there is dependence among the criteria, but we are not sure of how strong is the criterion influence compared to another for the same dependent criterion. This procedure was adopted, at first, due to the lack of access to the same managers those made the judgments in Tables 1 to 7. Besides, there was a gap of time and some judgments may vary by economical, political or social different moments.

The second procedure to reduce the number of judgments was to use the same vector of influence of the criteria on the alternatives (second block of the Supermatrix). As the ANP model came from an AHP model, the use of previous information seems to be useful. This way, the vector of importance of the criteria was used as vector of influence of the criteria on the alternatives. Therefore, it was considered that a criterion influences all the alternatives in the same proportion. It was considered that there is no difference in the importance of a criterion for the alternatives.

Is important to note that with the new procedures, we have saved 69 judgments: six 2x2 matrices (first block of the Supermatrix) and three 7x7 matrices (second block of the Supermatrix). These procedures also permit to incorporate the dependence analysis to the decision making. And the model was considered quite realistic. According to Multiple Criteria Decision Making literature, when it is detected that two or more criteria are dependent, then, the set of criteria must be changed: some criteria must be agglutinated in order "to avoid double-counting of possible consequences" (Kenney, 1992). This way, the ANP application is a new way of facing decision problems, dealing with dependent criteria or dependent alternatives.

5. Conclusions

This paper presents the decision making for an IT decision problem. The case studied concerns to how a Brazilian industrial company should implement one ERP module. For this decision problem solution, the Multiple Criteria Decision Making was applied, at first with the AHP. From three proposed alternatives, the "purchase of manufacturing software" has presented the best global performance. A sensitivity analysis on importance of the criteria strengthens this decision.

It was developed an ANP model extending an AHP model, incorporating the dependence analysis. With the use of two new procedures, the decision effort was not increased with more judgments. As for the AHP model, a sensitivity analysis applied in the ANP model strengthens the decision for the "purchase of manufacturing software".

The reduction on the numbers of judgments in AHP is a topic that has been studied (Harker, 1987; Millet & Harker, 1990). But this reduction on ANP is a not so much studied theme. A more formal analysis of the two new procedures used to reduce the total number of judgments, is subject of future research.

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