Volume 4, Number 2, 2007, pp. 47-60

Decision-Making Considering Dependence Relations for the Improvement of Production Management

Valério A. P. Salomon
Universidade Estadual Paulista (UNESP),
Guaratinguetá, SP, Brazil
E-mail: salomon@feg.unesp.br

Rozann Whitaker
Creative Decisions Foundation,
Pittsburgh, PA, USA
E-mail: rozann@rwspublications.com

Abstract
Traditional Multiple Criteria Decision-Making methods have been effectively applied by Brazilian industries. An intrinsic requirement of applying these methods is that the alternatives and criteria be independent of one another. In this paper we show how a Brazilian company can consider dependencies among the alternatives and among the criteria in solving Production Management problems. The need to consider dependence among alternatives was detected in the course of a study applying traditional decision-making methods. The main benefit from considering dependence was the notably higher satisfaction of the decision-makers. That is, it made the decision-making model closer to the real problem, as perceived by the decision-makers. A main conclusion of this article is that considering dependence in decision making can improve the quality of the process.

Keywords: AHP, ANP, BSC, MCDM, production management

Introduction

In production management, managers must keep the operation flowing and balance their activities. The issue is how to decide where to devote attention and resources to achieve that objective. In this article we will show how a Production Management team in a company used Multiple Criteria Decision Making (MCDM) methods to prioritize its activities for improvement.

A Brazilian company, part of a worldwide group, approached the first author of this study asking for help with waste due to excessive overtime hours, idle workstations and excess inventory levels. The company manufactures equipment for the mining and construction industries and its production process involves assembling standardized products. A team

Volume 4, Number 2, 2007, pp. 47-60

was assembled with the first author serving as a consultant and facilitator and managers from production management serving as the experts and providing the judgments.

The Production Management team decided that the goal of their study should be to use the company's performance indicators to prioritize the list of key activities for Production Management from Silver (1998). The Analytic Hierarchy Process (AHP) developed by Saaty (2001) was chosen as the MCDM method. The Analytic Network Process (ANP) for decision making with dependence and feedback is a generalization of the AHP due to Saaty (2005). The team made the necessary additional assessments. A prioritized list of activities that seemed more realistic than those derived using the AHP was the result. The members of the team were more satisfied with the results from the second model.

We then show how the multiple-criteria decision was structured. A brief comparison of the results from the AHP versus those from the ANP is given in the Conclusions section.

Research Methodology

The Brazilian company is part of a worldwide industrial group and as the study got under way it was learned that the board of the parent company had already implemented the Balanced Scorecard (BSC) proposed by Kaplan and Norton (1992) to identify indicators they wanted to use to measure performance. According to the Production Decision Making Framework proposed by Silver et al. (1998) some of the key activities of production management are: capacity planning; distribution planning and scheduling; materials planning; sale forecasting; and short-range scheduling.

In this way, the Production Management team could determine the key production management activities they should improve. The hierarchy was structured with the goal at the top, the board's performance indicators as established using BSC in the first level (the criteria), and the key activities of production planning in the second level (the alternatives). The weights for the performance indicators had already been determined using the BSC process. The next step would be to use the AHP to prioritize the production management activities with respect to each indicator to get an overall prioritized list of activities for improvement.

After obtaining a list of activities with their priorities from the first AHP model, the team recognized that they had not considered dependence among the factors so they expanded their original AHP model into an ANP model.

Background

For more than ten years, MCDM has been effectively applied by Brazilian industries. Salomon and Shimizu (2006) reported that research in Brazil has been concentrated in applications of the AHP, the *Élimination et Choix Traduisant la Réalité* (ELECTRE) method and the Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH). In Brazil, these three methods have been considered to be the traditional MCDM methods. An intrinsic feature of traditional MCDM methods is that the elements must be independent. So to apply any of these methods, the alternatives must be independent of each other.

The same consideration applies to the criteria. Keeney (1992) stated that independence among criteria is required, because each criterion must allow the analysis of a fundamental aspect, in an independent way. If two or more criteria are mutually dependent then these criteria must be aggregated before applying a traditional MCDM method. Otherwise, the same effect might be counted twice or more.

Traditional MCDM methods also require independence among the alternatives. That is, the performance of an alternative should have no effect on the performance of other alternatives. This consideration may sound strange, nowadays, when companies practice Benchmarking (Camp, 2006). With Benchmarking, also known as Best Practice Benchmarking, companies evaluate various aspects of their processes in relation to best practice, usually within their own sector. This way, how well a company performs a business process can depend on or even influence the performance of other companies. One must, however, remember that AHP, ELECTRE, and most of the other MCDM methods, were developed in the 1970's before Benchmarking became a commonly accepted practice.

The ANP is a newer MCDM method, a generalization of the AHP that does not require independence among alternatives or criteria. As can be seen, the ANP application started out as an AHP application, but when some dependence relations were detected, the method was changed to ANP to accommodate the dependencies.

AHP can be used to make decisions in a complex multi-objective setting that includes both tangibles and intangibles using judgments supplied by key players or experts (Saaty, 1980, 1996). The AHP methodology is based on three principles: (1) identify the elements in the problem and arrange them into hierarchical levels with parent elements in a given level connected to their children elements in a level below; (2) make all possible pairwise comparison judgments on the children of each parent with respect to the common property it represents; and (3) synthesize all the judgments throughout the structure to determine the priorities of the alternatives. In the AHP, the Fundamental Scale, a linear 1 to 9 scale presented in Table 1, is used to make the judgments.

The criteria are pairwise compared with respect to the goal, the sub-criteria with respect to their parent criterion, and the decision alternatives with respect to the last

Table 1 – AHP's Fundamental Scale.

Judgment	Description
1	A and B are equal
3	A is moderately dominant over B
5	A is strongly dominant over B
7	A is very strongly dominant over B
9	A is absolutely dominant over B

The values 2, 4, 6, and 8 are used for judgments in between. The judgments are relative absolute numbers; consider the dominated element to be the unit and enter the judgment that expresses how many times more the dominant element is. Enter the reciprocal in the inverse position in the matrix. Decimals are allowed, i.e., 5.6 is a permissible judgment. If A and B are close, use 1.1, 1.2, …1.9.

level of sub-criteria above them. Let us consider the criteria (or alternatives) A_1, A_2,..., A_n. The purpose in the AHP is to prioritize them with respect to a parent element (the goal) to find the weights of influence w_1, w_2,..., w_n. The vector $w = [w_1\ w_2\ ...\ w_n]^T$ is called a priority vector. For (A_i, A_i) set the judgment to $a_{ii} = 1$ (along the diagonal). For the ordered pair (A_i, A_j) if A_i is dominant over A_j enter the judgment $a_{ij} > 1$ in the (i, j) position in the matrix and enter the reciprocal, $1/a_{ij} < 1$ in the (j, i) position, otherwise enter $a_{ij} > 1$ in the (j, i) position and $a_{ij} = 1/a_{ij} < 1$ in the (i, j) position. If A_i is equal in dominance to A_j, then $a_{ij} = a_{ji} = 1$. One thus forms a reciprocal n × n comparison matrix $A = (a_{ij})$.

A priority vector $w = [w_1\ w_2\ ...\ w_n]^T$ is derived from each comparison matrix $A = \{a_{ij}\}$ and its elements w_i, i = 1, 2, ..., n, are referred to as the priorities or simply the weights of the elements A_i. The set of n relative priorities is often normalized to sum to one, $\sum_{i=1}^{n} w_i = 1$, wi >, i = 1, 2,...n. If $a_{ij}a_{jk} = a_{ik}$, for all i, j, k, then the elicited judgments are consistent, and the matrix is also called consistent. When the matrix A is consistent, it is easy to find w by summing each row and normalizing the resulting vector or by normalizing any column of A. When A is consistent, $a_{ij} = w_i/w_j$, i, j = 1, 2, ..., n.

When A is not consistent, and in practice it is usually not consistent because it is based on subjective judgments, Saaty (2005) proves that the principal eigenvector of the matrix should be used for the priority vector w because it uniquely captures transitivity of dominance along all possible paths in the case of an inconsistent matrix.

All the priorities throughout the network are synthesized by a process of weighting and adding that yields the overall priorities for the alternatives.

Structuring an MCDM Decision in Production Management

The worldwide industrial group that owned the Brazilian company with the production management problem had earlier implemented a management strategy using the Balanced Scorecard (BSC) theory, proposed by Kaplan and Norton (1992), to measure the performance of their companies. The group's board, located in Europe, identified the indicators to be used. As suggested by the BSC theory, the importance values were equally distributed among the main BSC perspectives, and were also equally distributed to the indicators for each perspective resulting in the overall importance percentages for the indicators shown in Table 2.

Table 2 - Relative importance of the indicators.

BSC perspective	Indicator	Importance (%)
Financial	Profitability	25
Customer	Customer satisfaction	25
Internal	Effectiveness	8.3
	Efficiency	8.3
	Productivity	8.3
Innovation	Creativity	25

Among other problems, the Production Management team in Brazil reported that there were too many hours of overtime for employees at workstations that were idle later in the same week. They also reported they had been working with high levels of inventories (raw-materials and work-in-process) in order to deliver their products by the promised dates. The overtime work and high levels of inventory were causing the company to waste money. Because of this the company recognized that Production Management performance must be improved and established a team to work on it.

From the Production Decision Making Framework proposed by Silver et al. (1998), five key activities emerge: capacity planning; distribution planning and scheduling; materials planning; sale forecasting; and short-range scheduling. These are the activities where improvement should be sought and they can be considered to be the alternatives of the decision. The objective of the decision-making is not only to select the best activity to improve, but to determine which activity to improve first.

The team decided to apply a traditional MCDM method to this decision using the indicators presented in Table 2 as criteria and improvements in the Production Management activities as alternatives. The AHP was the MCDM method selected because of its widespread use (Steiguer et al., 2003).

The Analytic Hierarchy Process Application – the First Model

Figure 1 presents the AHP model for the MCDM problem. This model is a three level hierarchical structure. In the first level we have the objective or goal of the decision; in the second level we have the criteria; and in the lowest level are the alternatives. The goal of the model is to prioritize the Production Management activities (in the bottom level) for their potential as candidates for improvement. The arrows from the goal to the criteria,

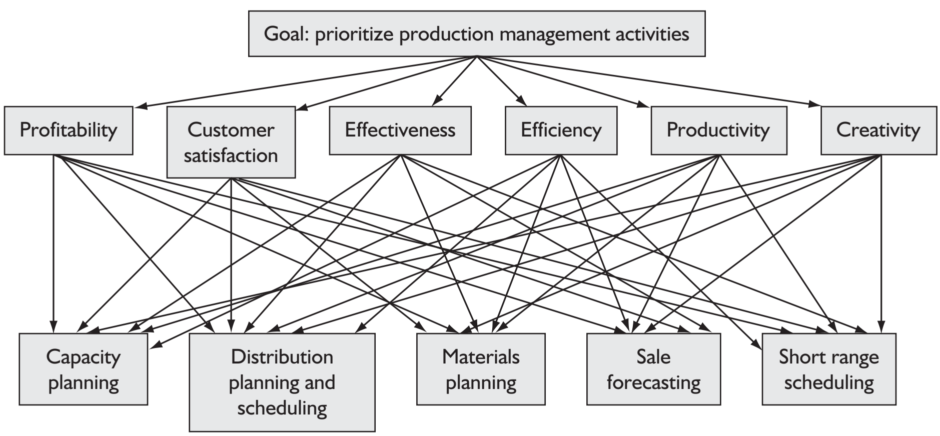

Figure 1 – Hierarchical model for improving Production Management activities.

Volume 4, Number 2, 2007, pp. 47-60

the indicators which were selected using BSC, show that they must be pairwise compared to prioritize them with respect to the goal. The initial values are shown in Table 2. The arrows from the criteria to the alternatives indicate that the alternatives must be pairwise compared with respect to each criterion.

Pairwise comparisons are made using judgments based on the Fundamental Scale (Saaty, 2001), resulting in a judgment matrix A. The priorities are obtained by determining the principal eigenvector, w, of the judgment matrix, A. There are different software packages that can be used to obtain w. There are also several academic or commercial versions of software which make this computation. However, some developers or vendors set limitations for using the free versions of their software. Examples of these limitations are no printing or saving of files and sometimes there are limitations on the number of criteria and alternatives.

In this paper a version of the SuperDecisions software for the ANP (Whitaker and Adams, 2005) was used. The SuperDecisions software was chosen, among other reasons, because there is a free version (to educators and researchers) that can be downloaded from www.superdecisions.com with no limitation on its features. Another great advantage of the SuperDecisions software when comparing it to other AHP capable software is that it can be used for both AHP and ANP applications.

The Production Management team made the judgments to prioritize the activities with respect to the indicators. Table 3 shows their judgments on the activities with respect to the Profitability indicator. For instance, improving distribution planning and scheduling was considered moderately more important than improving capacity planning, so a 3 was placed in the (DIS, CAP) cell. The values in the Priority column are the components of w, obtained with the SuperDecisions software.

A similar judgment matrix was completed for each of the other indicators. Table 4 presents the resulting priorities. To obtain the overall priority, a weighting and adding process was used. For each activity its priority with respect to an indicator was multiplied by the relative importance of the indicator (taken from Table 2 and indicated in bold), and these products summed across the row to yield the overall priority. Note that the sum of the priorities of the indicators is 1, and as each column also sums to 1 the Overall priorities in the final column will sum to 1.

Table 3 – Judgments and resulting priorities to improve Profitability activities.

Profitability	CAP	DIS	MAT	FOR	SCH	Priority (%)
Capacity planning (CAP)	1	1/3	3	1	1	18.5
Distribution planning and scheduling (DIS)	3	1	1	3	1	28.0
Materials planning (MAT)	1/3	1	1	1	1/5	11.0
Sale forecasting (FOR)	1	1/3	1	1	1/5	9.8
Short-range scheduling (SCH)	1	1	5	5	1	32.7

It can be seen from Table 4, that short-range scheduling (SCH) had the greatest overall priority with distribution planning and scheduling (DIS) second for improvement. After performing sensitivity analysis, this result was further reinforced. As can be seen in Table 3, DIS and SCH are the two highest priority alternatives for all the criteria except under Efficiency. Sensitivity analysis shows that only if the importance of Efficiency is increased from 8.3% to more than 30%, will the overall priority of capacity planning (CAP) be higher than that of distribution planning and scheduling (DIS). And only if the importance of Efficiency is higher than about 55%, will the improvement of capacity planning (CAP) have the highest priority. Figure 2 shows how the overall priorities change as the priority of Efficiency changes.

The judges reported that they had some difficulty in making the judgments in Table 2 because of the fact that in Production Management the activities are not independent – they influence each other; for example, consider capacity planning and materials planning, Even so, it was possible to obtain consistent judgments so that the Consistency Ratio was never more than 0.1, as shown by Saaty (2001) for 5 by 5 judgment matrices. Due to this difficulty, however, and due to the feelings the judges expressed that there was some

Table 4 – Overall priorities for improving activities.

Activity	Profitability (%)	Customer satisfaction (%)	Effectiveness (%)	Efficiency (%)	Productivity (%)	Creativity (%)	Overall (%)
	25	25	8.3	8.3	8.3	25	
CAP	18.5	12.1	7.4	46.3	4.9	9.6	14.9
DIS	28.0	41.6	29.5	3.7	16.7	26.3	28.2
MAT	11.0	5.6	18.5	14.4	13.1	12.3	11.0
FOR	9.8	15.3	22.3	6.2	14.0	18.7	14.5
SCH	32.7	25.4	22.3	29.4	51.3	33.1	31.4

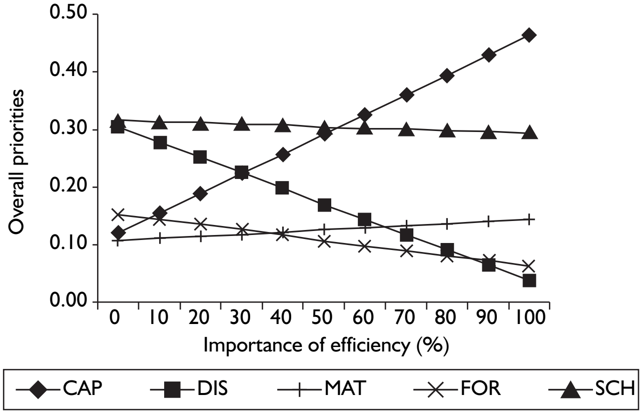

Figure 2 – Variation of overall priorities according to the importance of efficiency.

Brazilian Journal of Operations & Production Management
Volume 4, Number 2, 2007, pp. 47-60

dependence among the activities, the team decided to formulate the decision again as an ANP model that would be able to handle these dependencies.

The Decision Revisited with the Analytic Network Process – the Second Model

The Analytic Network Process (ANP) is a generalization of the AHP that can take feedback and dependencies among the elements into consideration. The first step in an ANP application is to group the elements in clusters. According to Saaty (2005), a cluster is a collection of elements whose function derives from the synergy of their interaction. In this case, the criteria of the AHP application were grouped in a cluster and the alternatives in a second cluster. Figure 3 shows the resulting structure of clusters, nodes and links in a screenshot from the SuperDecisions software.

In the SuperDecisions software, to avoid the visual confusion of too many arrows, the convention is that an arrow from one cluster to another cluster means that a node in the source cluster has a link to at least one node in the destination cluster.

All the links are shown in the Reachability Matrix. For the network exhibited in Figure 3 the Reachability Matrix consists of four blocks: (Alternatives, Alternatives), (Alternatives, Criteria), (Criteria, Alternatives), and (Criteria, Criteria). When there is a 1 in a Reachability Matrix cell, the column element is linked to the row element. It means that the row element influences the column element or, to put it another way, the column elements depends on the row element. If there is only one 1 in a column of a block, this means that the column element is totally dependent on the row element. If there is more than one 1 in a column of a block, then, the next step will be to determinate the priorities

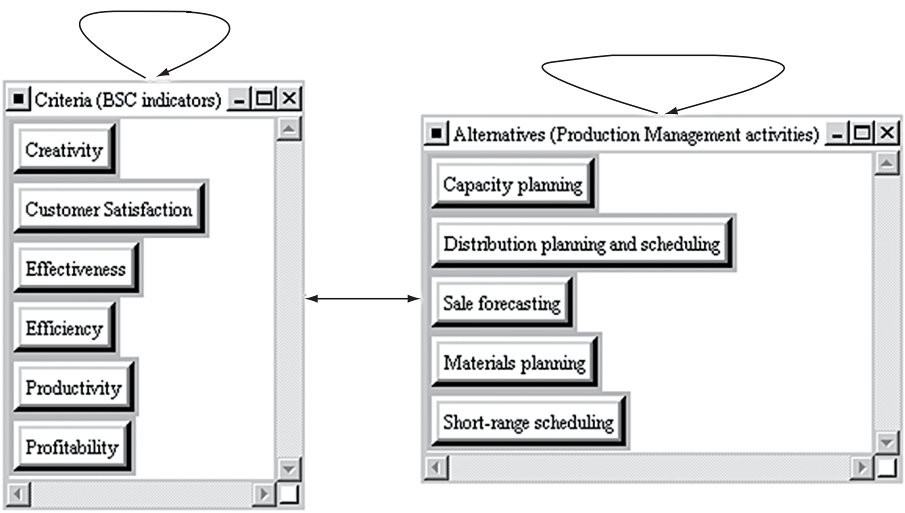

Figure 3 – Network model for improving Production Management activities.

of the influence from the row elements on the column element. So row elements will be pairwise compared as to which influences more the column element.

When the Reachability Matrix presented in Table 5 was completed it was shown to the judges and approved by them.

The inner dependencies in the (Alternatives, Alternatives) block of the Reachability Matrix were based on the Production Decision Making Framework proposed by Silver et al (1998). For example, CAP is connected to CAP, FOR, MAT and SCH. This way, the Production Management team has provided pairwise comparison about the influence of CAP, FOR, MAT and SCH on CAP. These judgments, based on the Fundamental Scale, were input in the SuperDecisions software resulting in the priorities in Table 6.

Table 5 – Reachability Matrix.

		Alternatives					Criteria					
		CAP	DIS	FOR	MAT	SCH	CRT	CST	EFC	EFT	PRF	PRO
Alternatives	Capacity planning (CAP)	1	1	0	1	0	1	1	1	1	1	1
	Dist. plan. and sch. (DIS)	0	1	0	0	0	1	1	1	1	1	1
	Sale forecasting (FOR)	1	1	1	0	1	1	1	1	1	1	1
	Materials planning (MAT)	1	1	0	1	1	1	1	1	1	1	1
	Short-range sch. (SCH)	1	1	0	1	1	1	1	1	1	1	1
Criteria	Creativity (CRT)	1	1	1	1	1	0	1	1	0	0	0
	Customer Sat. (CST)	1	1	1	1	1	0	0	0	0	1	0
	Efficiency (EFC)	1	1	1	1	1	0	0	0	0	0	1
	Effectiveness (EFT)	1	1	1	1	1	0	1	0	0	0	1
	Profitability (PRF)	1	1	1	1	1	0	0	0	0	0	0
	Productivity (PRO)	1	1	1	1	1	0	0	0	0	1	0

Table 6 – Supermatrix of resulting priorities.

		Alternatives					Criteria					
		CAP (%)	DIS (%)	FOR (%)	MAT (%)	SCH (%)	CRT (%)	CST (%)	EFC (%)	EFT (%)	PRF (%)	PRO (%)
Alternatives	CAP	64.9	15.5	0	14.9	0	9.6	12.1	46.4	7.4	18.5	4.8
	DIS	0	47.1	0	0	0	26.3	41.6	3.7	29.5	28.0	16.7
	FOR	15.9	4.0	100	0	5.9	18.7	15.3	6.2	22.3	9.9	14.0
	MAT	11.2	6.9	0	78.5	24.0	12.3	5.6	14.4	18.5	11.0	13.1
	SCH	8.0	26.5	0	6.6	70.1	33.2	25.4	29.5	22.3	32.7	51.3
Criteria	CRT	25.0	25.0	25.0	25.0	25.0	0	16.7	0	100	0	0
	CST	25.0	25.0	25.0	25.0	25.0	0	0	0	0	83.3	0
	EFC	8.3	8.3	8.3	8.3	8.3	0	0	0	0	0	25.0
	EFT	8.3	8.3	8.3	8.3	8.3	0	83.3	0	0	0	75.0
	PRF	25.0	25.0	25.0	25.0	25.0	0	0	0	0	0	0
	PRO	8.3	8.3	8.3	8.3	8.3	0	0	0	0	16.7	0

Volume 4, Number 2, 2007, pp. 47-60

The elements from the criteria cluster also have some dependence among themselves. The dependence relations among the BSC indicators had been established independently by the company board in Europe as shown in an actual graphic from the company, presented in Figure 4.

It is interesting to note that in Figure 4, a graphic from the company based on the BSC theory, the convention used for the direction of the arrows is opposite to that used in the ANP. For example, the link is from Customer Satisfaction to Creativity and Effectiveness in ANP as shown in Table 5, meaning Customer Satisfaction depends on Creativity and Effectiveness, but it goes the opposite direction in Figure 4.

The next step in the ANP application is to establish the priorities. This is done by making pairwise comparisons in the same way as in the AHP by making judgments using the Fundamental Scale, and deriving priorities as the eigenvector of the judgment matrices. The Supermatrix has the same structure as the Reachability Matrix with priorities replacing the link indicators as shown in Table 6.

The priorities from the AHP application for improving the activities with respect to each of the indicators (Table 4) were inserted in Table 6 in the (Alternatives, Criteria) block. That is, the same priorities from the AHP model were re-used in the ANP model.

The priorities of the criteria, that is, the BSC indicators importance as specified by the European board in Table 2 were used as the priorities of the influence of the criteria on the alternative. The same priorities were used for all the alternatives in the (Criteria, Alternatives) block. Usually in an ANP model (Saaty, 2005) these feedback priorities are also derived by making pairwise comparisons, and would be different for each alternative.

The overall priorities of the elements in the ANP come from the Limit Supermatrix. But, at first, a Weighted Supermatrix is obtained from the initial Supermatrix in Table 6. In this

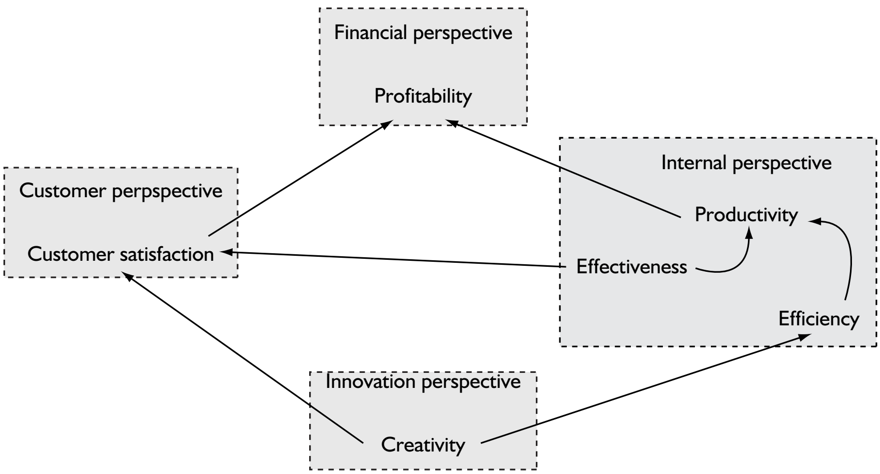

Figure 4 – Dependence among the criteria.

simple case that has only two clusters, it can be achieved by multiplying the blocks of the Supermatrix by ½. The Limit Supermatrix is then obtained from the Weighted Supermatrix by raising this matrix to powers until it converges. The Weighted Supermatrix here has converged by the 16th power and is given in Table 7. Note that all the columns are the same in this instance.

The new overall priority vector for the alternatives is obtained by normalizing the priorities in the alternatives component in the Limit Supermatrix. They are given in Table 8 along with the original priorities obtained using AHP.

We observe that improving short-range scheduling has the highest priority when applying either AHP or ANP. The overall priority value is almost the same with both methods (32.0% for AHP and 29.2% for AHP).

With the AHP the improvement of distribution planning and scheduling has the next highest priority (28.5%); while with the ANP application it is markedly less (18.6%), coming after improving sales forecasting (21.6%). The reason for the difference can be explained this way: improving sales forecasting would have an impact on the improvement of capacity planning, distribution planning and scheduling and short-range scheduling, but improving distribution planning and scheduling has only expected impacts on itself.

Table 7 – Limit supermatrix.

		Alternatives					Criteria					
		CAP (%)	DIS (%)	FOR (%)	MAT (%)	SCH (%)	CRT (%)	CST (%)	EFC (%)	EFT (%)	PRF (%)	PRO (%)
Alternatives	CAP	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
	DIS	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9
	FOR	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7
	MAT	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8
	SCH	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6
Criteria	CRT	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6
	CST	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
	EFC	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
	EFT	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9
	PRF	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
	PRO	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1

Table 8 – Priorities for improving activities with AHP versus ANP.

Activity	Overall priority (AHP) (%)	Overall priority (ANP) (%)
Capacity planning	14.5	13.1
Distribution planning and scheduling	28.5	18.6
Materials planning	10.9	18.4
Sale forecasting	14.1	21.6
Short-range scheduling	32.0	28.3

Limitations and Thrust of the Research

The Production Management activities were evaluated against the indicators developed by the parent company, but additional indicators could be added. The judgments were done through consensus but the AHP also has the capability to use individuals' judgments. Finally, the problem areas of excessive overtime hours, idle workstations and excess inventory levels that inspired the study in the first place were not specifically addressed in the model. A cluster containing these elements could be added into the ANP model. Some initiatives, such as the use of *kanbans* and optimized production technology, are beginning to be studied. However, these are subjects for future research.

This is a multicriteria problem where the influence of many factors is brought to bear on the outcome and one needs to know the priorities of these factors to take the necessary measures to improve the highest priority activities. It is clear that expert judgment is essential because a large number of intangible factors are involved and there is no way to made sense of raw data apart from expert judgment in this case. Multicriteria decision methods make the role of human judgment central in any undertaking, either directly or by using it to interpret numerical data. These methods have introduced a shift in paradigm in scientific research by making the judgment process explicit by structuring it mathematically. So one of the main contributions of this study is to show how such a method can be used to bring human judgment into an important practical business problem.

Conclusions

An application using first the Analytic Hierarchy Process (AHP) then the Analytic Network Processes (ANP) to prioritize improvements of Production Management activities for a Brazilian company is presented in this article. The result for both approaches is that the highest priority area for improvement is short-range scheduling in the factory. However, the results for improving the other activities were different for the ANP than for the AHP. After some reflection and analysis, the ANP results for the secondary improvements seemed to be more realistic.

The example presented in this article was a real world application of MCDM. The Brazilian company, part of a worldwide industrial group, had five different alternatives to reduce some problems. With the AHP and ANP applications it was possible to determinate which alternative to do first, that is, which alternative ranked highest for improvement. In this decision-making exercise, some previous information, such as the BSC indicators determined by the company board, was incorporated.

The first observation learned from this article is that considering dependence among the elements of an MCDM application did not change the result much for the top priority alternative, but it did change the order of the lower ranked alternatives and it did clarify the results. The judges concurred that the order obtained in the ANP result made more sense to them and was more what they expected. The main benefit from the ANP application was the notably higher satisfaction of the decision-makers. With dependence the model was more able to capture the real problem and the results were easier to explain and better matched the intuitive understanding of the judges. The judges were more satisfied with the process when they could include their feelings about the dependencies. This cannot be done with traditional MCDM methods. Perhaps the main contribution of this article is that considering dependence in decision-making can improve the quality of the process.

Acknowledgments

This work was financially supported by the Sao Paulo State Research Foundation (FAPESP - *Fundação de Amparo à Pesquisa do Estado de São Paulo*), under the Grant No. 2007/00158-2.

References

Camp, R.C. (2006), Benchmarking - The Search for Industry Best Practices That Lead to Superior Performance, Productivity Press, Chicago, IL.

Kaplan, R.S. and Norton, D.P. (1992), "The Balanced Scorecard - measures that drive performance", Harvard Business Review, Vol. 70, No. 1, pp. 71-79.

Keeney, R.L. (1992), Value-Focused Thinking - a path to creative decision-making, Harvard University Press, Cambridge, MA.

Saaty, T.L. (1980), The Analytic Hierarchy Process, McGraw-Hill, New York, NY.

Saaty, T. L. (1996), Decision Making with Dependence and Feedback: the Analytic
Network Process, RWS Publications, Pittsburgh, PA.

Saaty, T.L. (2001), Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process, RWS Publications, Pittsburgh, PA.

Saaty, T.L. (2005), Theory and Applications of the Analytic Network Process - decision making with benefits, costs, opportunities, costs and risks, RWS Publications, Pittsburgh, PA.

Salomon, V.A.P. and Shimizu, T. (2006), Performance of three different methods of multiple criteria decision making applied to the supplier selection. Proceedings of the 18th International Conference on Multiple Criteria Decision Making, Chania (Greece), 200 pages.

Silver, E.A. & Pyke, D.F. & Peterson, R. (1998), Inventory Management and Production Planning and Scheduling, John Wiley & Sons, New York, NY.

Steiguer, J.E. & Duberstein, J. & Lopes, V. (2003), The Analytic Hierarchy Process as a Means for Integrated Watershed Management, First Interagency Conference on Research on the Watersheds, pp. 736-740.

Whitaker, R. and Adams, W. (2005), SuperDecisions software version 1.6., Creative Decisions Foundation, Pittsburgh, PA.

Volume 4, Number 2, 2007, pp. 47-60

Biography

Valério Antônio Pamplona Salomon is an associate professor at UNESP and a consultant for the Foundation for UNESP Development. Since 1999, he teaches Operations Management for undergraduate programs in Electrical, Industrial and Mechanical Engineering. He also acts as teacher and adviser for MBA and PhD programs.

Rozann Whitaker is Executive Director of the Creative Decisions Foundation, a charitable organization with the mission or promoting rational decision-making and providing education in decision-making. Most recently she directed the development of the software SuperDecisions for decision making with dependence and feedback with the Analytic Network Process (ANP). She has taught decision-making at the Joseph P. Katz Graduate School of Business of the University of Pittsburgh and at the Katz school's associated MBA programs in the Czech Republic and Brazil.