PROPOSAL OF A DECISION ANALYSIS MODEL IN PROJECT MANAGEMENT

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Abstract. *This paper presents a proposal of a Decision Analysis model in Project Management. The model is based on techniques and concepts from AHP (Analytic Hierarchy Process), KT method (Kepner and Tregoe) and DSM (Design Structure Matrix). It provides a suitable tool to allow decision makers identify and evaluate the critical level of the activities that composes a project process. The simple application of the AHP method is very limited in Project Management prospects due to the restrictions inherent to the method and the peculiarities of the process. The present study aims at harmonizing the three methods making into account the specific benefits of each one: the robustness in the priorization and classification of criteria and alternatives obtained in a multiple attributes scenery by the AHP method; the simplicity to systematically evaluate parameters, mainly when dealing with subjective aspects, from the KT method; and the clear visibility of the dependency relationship among elements provided by the DSM matrix, whenever the volume of information is huge.*
This paper also presents an example of a house construction in order to illustrate the applications of the model.

Keywords*: Project Management, AHP, KT, DSM*

1. INTRODUCTION

Based on premises and estimative, a project planning is always exposed to face challenges coming from internal and external environments that change the initial expectative and premises demanding from the project manager, precision, knowledge and agility to take the right actions to skirt the adversities.

In this context, the development of a robust model to aim the project managers to quantify either subjective or objective parameters, to identify the critical activities and to ponder the potential impacts and consequences of the possible actions, shows itself of utmost value in an enterprise environment.

2. APPLICATION CONTEXT

Once the project has its formal beginning, the Project Management (PM) starts to take an active position in the accompaniment of the activities in execution, engagement of human and financial resources, delivery of results (intermediate and final) and fulfillment of costs and schedule.

However, many times the project manager faces unexpected external (cambial changes, new governmental politics, nature events, etc.) or internal changes (impossibility of execution of an activity, unfeasibility result, non-availability of resources, etc.). These changes force the project managers to take, sometimes, hard decisions to change some project parameter to keep the expected results.

In this scenery, the decision-making models support the decisor to define the relative critical degree of each activity of the project to expose the most important for the PM. In this context, the critical degree expresses the impacts to the final added value, to the execution schedule, to the final quality, etc. of each activity.

It is expected as a result of this article to propose a new management tool to aim the decision makers to identify the critical activities that needs to be closer accompanied and to assess the potential impact coming from unexpected changes of premises established in the beginning of the project. Eventually, these activities are strategic points to the establishment of Stage Gates.

Focusing in the master objective of the PM practical, that is to guarantee the plenty execution of the project to get, at the end, the contracted deliverables from the stakeholders using the planned resources and within of the negotiated schedule. The model proposed will deal objectively with the aspect of the development, analysis and choice of alternatives, as the rational decision-making model developed by Wright and Noe (1996).

The focus of Wright and Noe's model is the Alternative Development and Choice of Alternatives as showed at Fig. 1. These two stages will be accomplished in the proposed model to establish the critical degree of each activity, applying four tools widely used in the enterprise and academic environment being: i) the AHP (Analytic Hierarchy Process); ii) the KT Method (Kepner and Tregoe); iii) the DSM matrix (Design Structure Matrix) and; iv) the PM (Project Management) concepts.

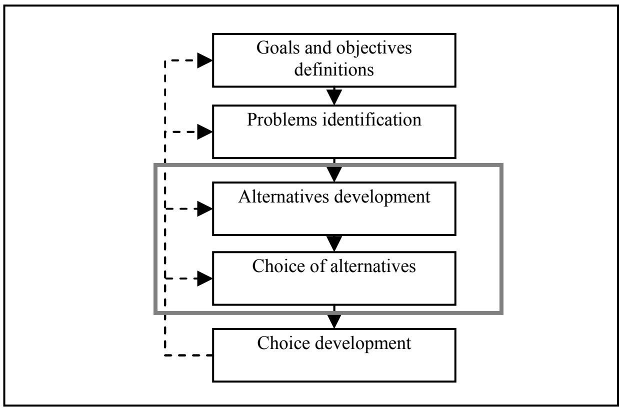


Figure 1 - Rational decision-making model

The result expected from this exploratory study is a model able to carry, from a defined objective, the robustness that the AHP method allows to reach**,** prioritizing and classifying the criteria and alternatives of decision-making problem in multiple attributes sceneries.

With the robustness of AHP method, other important concepts to be improved is the simplicity of the systematic evaluation of parameters that KT method allows, mainly dealing with subjective items, allowing to reach a suitable balance of the alternatives.

As the focus of this work is not to evaluate the weight of different alternatives, here, these elements are changed by the activities that compose the PM process. This way, the right application of PM concepts, also using process of reference, gets high relevance once a wrong definition of activities can change it evaluated weight leading to wrong conclusions.

Finally, the dynamic and lean vision of inter-relationship added from the application of DSM matrix. This allows the model to evaluate the dependent elements chaining, being mainly useful in scenes where the volume of relationships is very great (Figure 2).

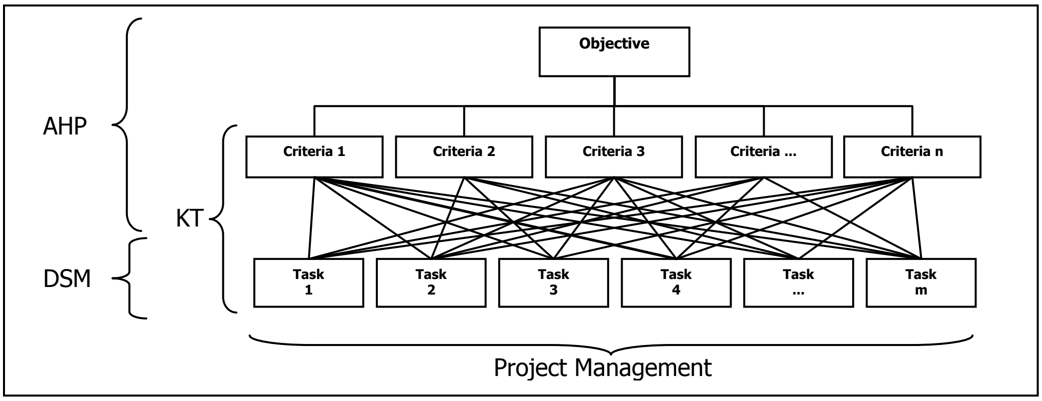


Figure 2 – Structure of the Decision-Making Model in Projects Management environment

This way, as well as the model of KT Modified Process proposed by Silva (2006), the study aims at adding to a base method concepts of other methods widely known to turn the previous one to a more robust and adequate to support that kind of problem.

3. THEORETICAL RECITAL

The concepts involved here will not be presented or argued bellow into its exhaustion, therefore the same one do not represent the backbone of this article. Below, it follows a brief description of each applied method.

3.1. Project Management

According to a classic definition presented in the Project Management Body of Knowledge (PMBOK), the Projects Management "is the application of knowledge, abilities, tools and techniques into project activities to reach all requirements" defined to the project and to fulfill all needs and expectations of the involved parts related with the project. (PMI, 2004).

Still in accordance with the PMI (2004), the projects management consists of the joint application of several techniques of management that aims to reach the goals and objectives considered, through the balance of several variables involved in the process. The variables are: (a) Project Integration, focused in the coordination of the elements of a project; (b) Scope, represented by the delimitation and control of the project's objectives and goals; (c) Schedule, or time's definition, the sequence and control of the activities; (d) Costs, presented by the estimation, budget and control of the financial resources involved; (e) Quality, reached from the planning, guarantee and controlling; (f) Human resources, obtained from the organizational planning, assembly and development of the work teams; (g) Communication, synthesized from the generation, captures, distribution and storage of the information; (h) Risks, represented by the identification, analysis and answers to the involved risks in project; and (i) Acquisitions, the planning and election of suppliers and merchandises.

Herein the applied definition to activity is "the component of work carried through during the course of a project" (PMI, 2004).

3.2. AHP (Analytic Hierarchy Process)

The Analytic Hierarchy Process (AHP) idealized by Thomas L. Saaty in the beginning of 70's was one of the first**,** and probably, one of the most spread out methods of decision-making analysis in discrete multi-criteria environment.

This method is characterized by breaking up the decision-making problem in several hierarchical levels**,** having in its top**,** the main objective and leaving to the below levels the criteria and sub-criteria and in the base of the hierarchy, the alternatives (Figure 3).

This method is based on the pairwise comparisons along all elements of the same hierarchical levels (criteria and sub-criteria) to provide a global measure for each alternative through the synthesis of the weights of each decision agents (Gomes *et al*, 2004).

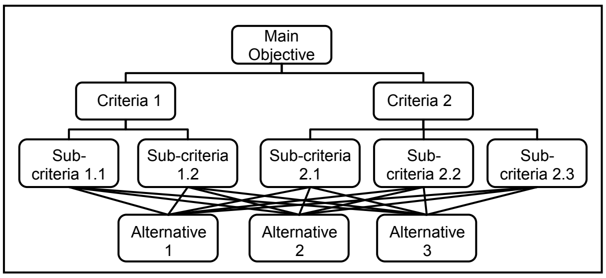


Figure 3 – Hierarchical structure of a problem applying the AHP.

3.3. DSM (Design Structure Matrix)

Also known as Dependency Structure Matrix or Dependency Source Matrix, the Design Structure Matrix method (DSM) consists of modeling the relationships among several elements of a system, teams or process (Eppinger and Salminen, 2001) allowing to define and to get a sensible and coherent sequence (or grouping) expressing the existence of a relationship among these elements (DSMWEB, 2006).

A system (or project) model is generally graphically represented by a flowchart diagram or, in some other graphical forms, as Gantt or PERT (Program Evaluation and Review Technique) diagram, as presented in Fig. 4, where the blocks represent the elements and the lines represent the type of relationship among them. The arrows indicate the influence direction of an element to the other (Yassine, 2004). In this representation, it has three types of basic construction representing the relationship among elements: (1) Sequential (or dependent); (2) Parallel (or competitor); and (3) Connected (or interdependent) (Browning, 2002).

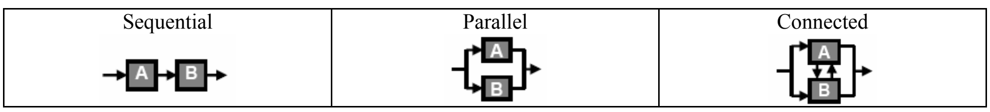


Figure 4 – Graphical representation of the relationship among elements.

The description of a project can be expressed through a matrix based on DSM method, having the activities described both in the lines and in the columns. The marks in the intermediate cells of the matrix indicate, when there is, the kind of relationship existing among the activities (Figure 5). These marks represent that the exit of the corresponding activity provides information, material or data to execute the activity shown in the column expressing its dependence (Browning, 2001).

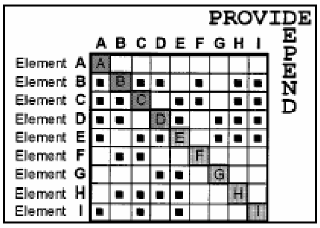


Figure 5 – Dependency relationship representation in a DSM Matrix

In a sequential configuration, an element influences the behavior of the other in a unidirectional form, which means that an activity only will be executed after the end of the previous one. In a parallel configuration, an element does not interact with the other and this represents that an activity is independent of another one, and does not have exchanges between them. Finally, in a connected configuration, the influence or changes is bidirectional, meaning that the execution of one activity depends on the other, in both directions, characterizing a circuit (Yassine, 2004) as showed at Fig. 6.

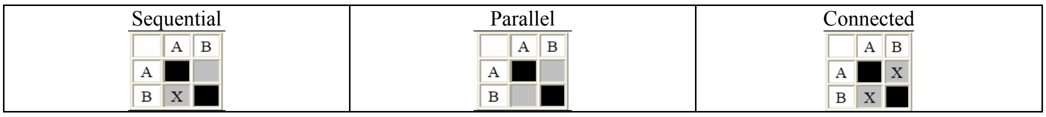


Figure 6 – DSM matrix representation of relationship among elements.

According with the needs, the marks in the cells of the matrix can be express in different forms as symbol that represents the simple existence of the relationship; as different graphical symbols that specify the type of relationship or; as values that quantify the intensity of the relationship (Figure 7).

By this time, the diagonal line of the matrix, that represents the intersection of the same elements, does not use to present values, however, according to the application of the DSM it can express, in this diagonal line, the referred values of a specific attribute varying its degree in accordance with the desired parameters (Cronemyr *et al*, 2001).

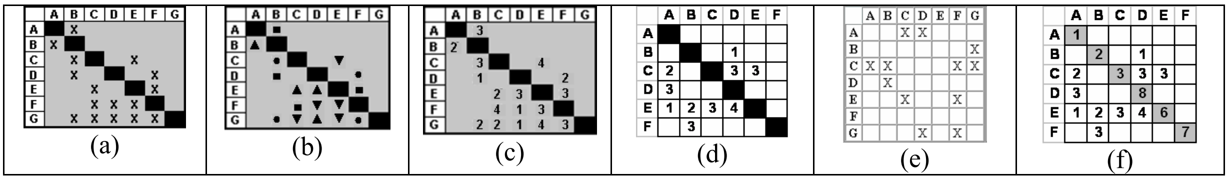


Figure 7 – Forms of interdependence and diagonal line representation in a DSM matrix. (a) simple dependency mark; (b) kind of relationship specification; (c) relationship quantification; (d) and (e) the diagonal line does not supply additional information; (f) the diagonal line is used to quantify an attribute of the element.

3.4. KT Method (Kepner and Tregoe)

Developed and formalized by Charles Kepner and Benjamin Tregoe in 1960's, this method is still widely applied in decision-making processes due to its intuitive characteristic and easy understanding.

KT method considers the goal of the survey and analysis of solutions process from five great stages**,** being: i) establishment of the objectives; ii) establishment and classification of the evaluation criteria; iii) search of alternatives; iv) analysis of alternatives and; v) evaluation of the impacts of each choice (Silva *et al*, 2005).

In the establishment of the objectives (i) it must be chosen from clear and specific objectives in order to hinder irrelevant alternative**s** or without any correlations with that were presented in the searching alternatives stage (iii).

The stage of establishment and classification of the criteria (ii) has it**s** beginning with the detailing and unfolding of the main objective in criteria that, once fulfilled, will allow its attendance. A second step is given with the classification of the criteria according to its relevance, attributing proportional weights to its importance for the achievement of the objective.

With the necessary requirements, begins the search of alternatives (iii) that fulfill the detailed demands of the objective. The analysis of alternatives (iv) is enormously easier when the criteria are classified in mandatory or desirable. Once the chosen alternative does not attempt the mandatory premises**,** they can be simply discarded and has the beginning of the evaluation of the other questions.

Once the alternatives were prioritized (v) they are weighed in face of the possibility to occur impacts not foreseen. The focus of this analysis is to provide suitable risks management where the possible generated impact must be considered together with the probability of its occurrence.

Finally, the alternative that gets the biggest score concerning all of the considered criteria and weights will be selected as the best alternative for the decision problem (Freitas, 2003).

4. PROPOSED INTEGRATED AHP-KT-DSM METHOD

The method has as main objective the establishment of the critical level of each activity that composes the modeled development process, in fact to help the elaboration, analysis and priorization of the managers' actions.

The proposed method has it sequence of execution showed at Fig. 8. First: application of the AHP method to define the most important criteria to reach the objective and to build the hierarchical structure. Second: survey of the main activities using models of references before available concerning the process considered. Third: this step represents the real innovation of the presented method, here the concepts of the KT are applied on the listed process' activities instead the usual alternatives that the method uses to assess the relative importance of each one. Forth: use of the DSM matrix to evaluate the relative weight of each activity considering the existing relationship among activities, and concerning each criterion listed before. Fifth: synthesis of the information obtained in each matrix DSM in a unique matrix of the AHP method.

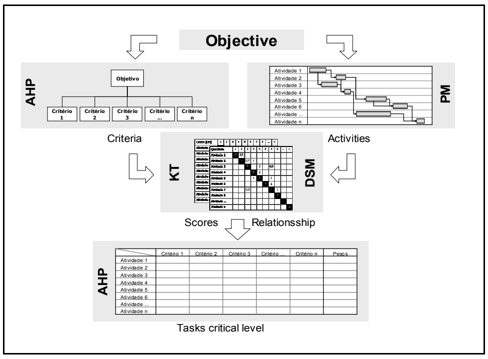


Figure 8 – Workflow of Integrated AHP-KT-DSM Method.

Stage 1: Application of AHP

According with Gomes (2004) the resolution of a multiple criteria problem must follow four basic steps being: i) the main objective definition; ii) survey of the criteria to define the hierarchical structure; iii) evaluation and activities priorization and; iv) results analysis and consistency evaluation.

Observing two of the most important recommendations to score the criteria, that are the homogeneity and the non-redundancy (Gomes *et al*, 2004) to the execution of a project, five criteria were identified: (a) Scope - the part related to complete the planned activities. (b) Schedule - established times to the execution of the activities. (c) Costs - used either to the values applied in the payment of expenditures as in the investments. (d) Quality - conformity and adequacy degree of the results of the process execution. (e) Human resources - these criteria came from the importance denoted to the amount, the profile and abilities of the activities' executor.

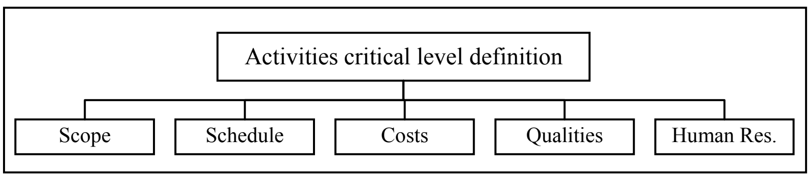


Figure 9 – Hierarchical structure of the project management problem.

Once the criteria are defined and the hierarchical structure problem is built (Figure 9) and approved, begins the stage of criteria evaluation through the fulfilling of the pairwise comparisons matrix, as showed at Table 1, of each criterion in agreement to the Saaty´s Fundamental Scale (Gomes *et al*, 2004).

Table 1 – Pairwise comparisons criteria matrix to development processes

Criterions	Scope	Schedule	Costs	Qualities	HR
Scope					
Schedule					
Costs					
Qualities					
RH					

Stage 2: Survey of the critical activities for the accomplishment of the project

As commented in the introduction of the proposed method, besides joining in a coherent application different technique, this method considers using, instead of alternatives, the activities that constitute the development process of a project. This allows, as the example of the alternatives, to evaluate activities weight to define score graduations that express its degree of relative importance.

Typically the spread out and most studied processes are, at least in higher levels, called as Reference Models that are used to lead a new process development. The detailed activities that compose this process are, generally, considered as strategic and, sometimes, specific or personalized for different types of contexts.

Once the activities are showed at the required detailing degree, the next stage can be taken.

Stage 3: Application of the Method KT

The Fig. 10 represents, as an example, the matrix of Quality criteria, where the columns and lines represent the activities of the project.

Fulfilling the diagonal line of the matrix shows itself to be extremely simple when they are concerned about objective criteria of projects management as time and cost, but if the dealing objects are subjective criteria as quality and scope, the balance starts to take another level of complexity.

The simplicity of the method and its adequacy for evaluation subjective items become the KT method the ideal tool to balance and score each items.

Quality Matrix (balance)											
	1	2	3	4	5	6	7	8	9	10	11
1	0,4										
2		0,1									
3			0,7		0,75	0,75	0,75	0,75	0,75	0,75	
4				0,5	1	1	1	1	1	1	
5					0,45	0,25	0,25	0,25			
6						1	0,75		0,75	0,75	
7							0,8		0,25	0,75	
8								0,8	0,75	1	
9									0,9		
10										0,9	
11											0,1

Figure 10 - Example of Quality matrix after application of the KT method.

As result of the application of the KT process**,** the vector of the activities can be obtained pondering the relationship of each activity in the context of the project management and its influence in the context of activities chaining.

Stage 4: Application of DSM

As well as the AHP, the DSM matrix also is put into it lines the same elements of the columns and it is built from the pairwise comparisons of its elements.

Considering that, the starting point of the application of the DSM is the dependence and not the influence of an array element on another one, the application of the AHP method in this case shows itself to be inadequate by the impossibility to analyze the consistency of the model.

Another fact that acts against the application of the AHP method at this moment is the fact of not being the intention to evaluate alternative to the project, but the relative weight of each activity inside of the project execution process.

As in a traditional model of AHP, for each criterion it must be built a matrix in order to get the vector of weights with the contribution of each element in the evaluated question as presented at equation (1).

The diagonal line that represents the intersection of the same activities describes, in a suitable unit of measures, the contribution of each one to the performance of the project. The other cells of the matrix, scored from 0 to 1, represent the existence of the dependence (of information, material, energy, etc.) and its degree, where 0 represent the inexistence of relationship and the 1 total dependence (Browning and Eppinger, 2002), as showed at Fig. 11.

$$\text{Activity Pondered Weight } x = \frac{\dfrac{\sum_1^m \text{relationship}\,(x, j)}{\sum_1^m \sum_1^m \text{relationship}\ (i, j)} + \dfrac{\text{Task Value } x}{\sum_1^m \text{Task Value}\ (i, i)}}{2} \tag{1}$$

Cost Matrix (x1000 Reais)	1	2	3	4	5	6	7	8	9	10	11	Balanced weight
1	2		0,5		0,5	0,5	0,5	0,5	0,5	0,5		12%
2		1		0,5								2%
3			10	0,75	1	1	1	1	1	1		26%
4				1								0%
5				0,75	10							7%
6				0,5	1	10						9%
7				0,5	1	0,75	10					12%
8								15	0,5	0,5		10%
9									20	0,25		10%
10										30		14%
11											1	0%

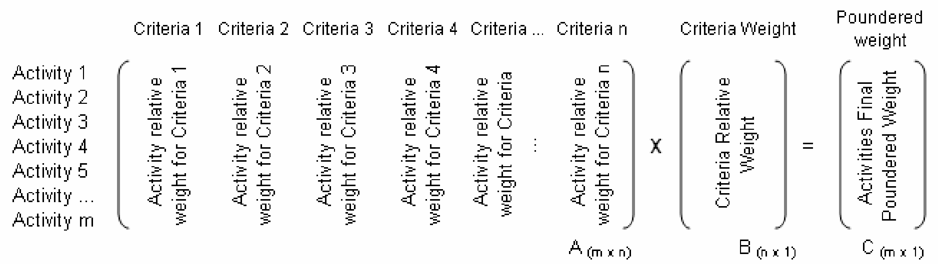
Figure 11 - Example of Costs matrix.

Stage 5: Attainment of the critical degree of the activities

The final stage of the presented method can be summarized as the calculation of the critical degree of each activity evaluated from the values attributed to the DSM matrices of the defined criteria. This summarization can be made using first the AHP method, considering the activities in the lines and the criteria and weights in the columns.

To a process of development with m activities and n criteria, the matrix A $_{(m \times n)}$ represent the activities and criteria, being B $_{(n \times 1)}$ the vector weight of the criteria.

The pondered weight vector results from the product of A and B matrixes, being the vector C $_{(m \times 1)}$ the result from this operation, as showed at equation (2).



(2)

5. AHP-KT-DSM INTEGRATED METHOD APPLICATION AND EXAMPLE

This presented AHP-KT-DSM Integrated Method has its focus straight in the projects management to help the managers to identify critical activities and the impacts resulting from changes of parameters.

As an illustrative form to show the application of the method, an exercise of its use is presented by an example of a house construction.

The main objective in this case is to identify the critical activities with intention to apply more attention to these ones, aiming at guiding the project development to reach its awaited deliverables.

Stage 1: Application of AHP

Following the concepts of homogeneity and the non-redundancy for the criteria definition to solve the problem, the conclusion was that the activities must be evaluated concerning: i) the importance of the Scope; ii) the involved Schedule; iii) the added Costs; iv) aggregate Quality and; v) the necessary Human Resources. The resulting hierarchical structure is showed at Fig. 12.

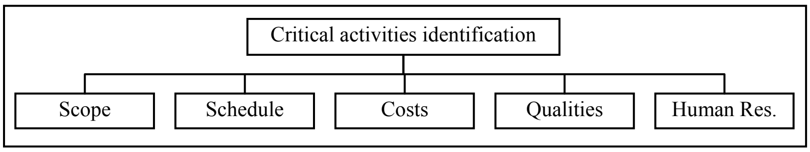


Figure 12 – Most important criteria to build a house.

By this time, as in the AHP method, attributing weights to each criterion and the existing relationship among then and calculating the respective relative weights for each case, it is obtained a vector weight from the matrix (Figure 13).

	Scope	Schedule	Cost	Quality	HR		
Scope	1	1	1/6	3	4		17%
Schedule	1	1	1/7	2	6		16%
Cost	6	7	1	2	7	=	49%
Quality	1/3	1/2	1/2	1	7		15%
HR	1/4	1/6	1/7	1/7	1		4%

Figure 13 – Pairwise comparisons criteria matrix to build a house

Stage 2: Survey of the critical activities for the accomplishment of the project

Different sources present different numbers of activities and detailing levels to show the necessary sequence of activities to build a house. The example presented here adopts the follow sequence of activities: 1) Elaboration of the basic project. 2) Attainment of the authorization for construction. 3) Elaboration of the detailed project. 4) Contract of the contractors. 5) Execution of the foundations. 6) Assembly of the walls beams and pillars. 7) Assembly of the flagstone and roofs. 8) Installation of the hydraulic and electric part. 9) Execution of the external finishing. 10) Execution of internal finishing and. 11) Attainment of license.

The hierarchical structure of the project is showed at Fig. 14:

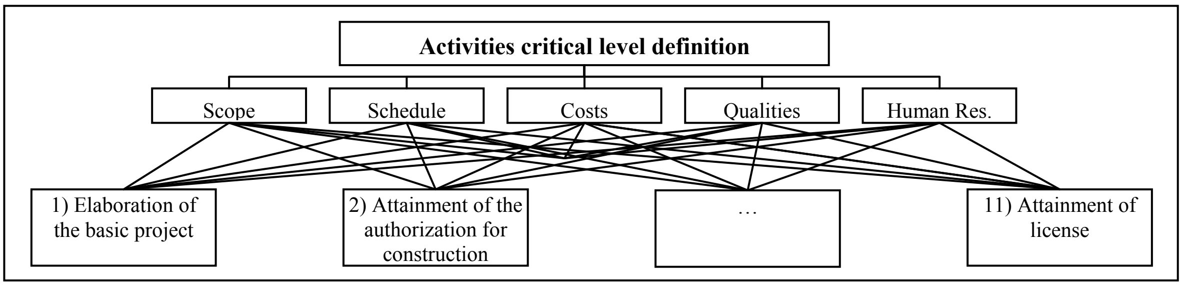


Figure 14 – Hierarchical structure of building a house.

Stage 3: Application of the Method KT

Once defined the activities that composes the process of house construction, a matrix for each criterion is built where the lines and columns represent the sequence of activities. In its diagonal line are inserted for each criterion, the values demanded for the execution of the activity in its respective scales of unit.

This stage shows to be very simple when it is dealing with objective criteria as schedule and costs, however acquires a higher degree of difficulty to deal with subjective criteria as scope and quality. To express the relative importance of each activity regarding these subjective aspects, the concepts of the KT Method should be applied.

For objective criteria, the diagonal line is fulfilled with values that represents the demanded effort to execute the activity regarding the applied scale (month, day, money, etc.), as showed at Fig. 15(a). When dealing with subjective criteria, the first step for this is to define the most significant activity attributing to it the value 1, and after, graduating the following activities with intermediate values from 0 to 1 in accordance with its relative importance, as showed at Fig. 15(b).

Schedule Matrix (months)

	1	2	3	4	5	6	7	8	9	10	11
1	2										
2		2									
3			6								
4				2							
5					1						
6						2					
7							1				
8								2			
9									4		
10										4	
11											2

(a)

Scope Matrix (pondered)

	1	2	3	4	5	6	7	8	9	10	11
1	0,5										
2		0,1									
3			1								
4				0,9							
5					0,8						
6						0,6					
7							0,6				
8								0,8			
9									0,5		
10										0,5	
11											0,1

(b)

Figure 15 – Fulfilling the diagonal line values of (a) Objectives e (b) Subjective criteria.

Stage 4: Application of the DSM

This stage summarizes the construction and evaluation of the relationship matrices (DSM) for the activities that compose the process "construction of a house".

After fulfilling the diagonal line of the matrix with the representative values of each activity, the remaining cells of the matrix are completed with values between 0 and 1, observing the concepts of KT Method. These cells are fulfilled, at first, in accordance with the existence or not of relationship (anteriority or succession) and, in second, with the relative relationship degree, where 0 means the inexistence of the dependence and the 1 means the complete dependence of a activity in relation to the other. This rule is applied both to objective and to subjective criteria (Figure 16).

Schedule Matrix (months)

	1	2	3	4	5	6	7	8	9	10	11		Pondered Weight
1	2	1											6%
2		2	0,25										4%
3			6	0,25	0,75	0,75	0,75	0,75	0,75	0,75			22%
4				2	1								6%
5					1	0,75	1	1	1	1			13%
6						2	1	1	1	1		=	13%
7							1	0,75	0,5	0,75			6%
8								2	0,75	1			8%
9									4		1		9%
10										4	1		9%
11											2		4%

(a)

Scope Matrix (pondered)

	1	2	3	4	5	6	7	8	9	10	11		Pondered Weight
1	0,5	1	0,5										8%
2		0,1	0,75										3%
3			1	1	1	1	1	1	1	1	1		31%
4				0,9									7%
5				0,75	0,8								8%
6				0,75	1	0,6						=	10%
7				0,75	0,75	0,75	0,6						11%
8				0,25	0,25	0,25	0,75	0,8	0,25	0,25			12%
9									0,5				4%
10										0,5			4%
11											0,1		1%

(b)

Figure 16 – Pondered weight of activities for each criterion, for example: (a) Schedule and (b) Scope.

Stage 5: Attainment of the critical degree of the activities

Finally, once the vector weight of the activities for each criterion was defined the global matrix is built to evaluate the influence of each activity for the whole process of construction of a house.

Activities	Scope	Schedule	Cost	Quality	HR		Criterion		Weight
Elaboration of the basic project	8%	6%	12%	3%	3%		17%		9%
Attainment of the authorization for construction	3%	4%	2%	1%	2%		16%		2%
Elaboration of the detailed project	31%	22%	26%	19%	55%		49%		27%
Contract of the contractors	7%	6%	0%	22%	2%		15%		6%
Execution of the foundations	8%	13%	7%	6%	5%	X	4%	=	8%
Assembly of the walls beams and pillars	10%	13%	9%	14%	6%				11%
Assembly of the flagstone and roofs	11%	6%	12%	9%	6%				10%
Installation of the hydraulic and electric parts	12%	8%	10%	11%	8%				10%
Execution of the external finishing	4%	9%	10%	7%	6%				8%
Execution of the internal finishing	4%	9%	14%	7%	6%				10%
Attainment of license	1%	4%	0%	1%	2%				1%

Figure 17 – Matrix with the activity's weight to build a house considering the previous criteria.

The result of the method application in the considered example shows the coherence and viability of the method once the results presented in Fig. 17 allow to conclude that:

- The Criteria Costs is considered the most critical in this example. However, its weight could vary enormously in function of the premises and existing restrictions for the project as lack of financial resources, execution urgency, lack of specialized workers, etc.

- Coherent with the concepts of integrated product development, the scopes defined in the preliminary stages really affect strongly the remain process and all of its alterations.

Generally, it is easy to verify that the elaboration of the detailed project is one of the most important items in a house construction project being the guide to define scope, costs, Schedule and human resources.

6. CONCLUSIONS

The method shows to be technically viable once its supplied results are coherent, however it is clear that it is necessary to stress the method in order to confirm its virtues and to correct any imperfections that can exist in its concepts.

The great virtue of the presented method is, in fact, its ability to join some already well appraised techniques widely employed and accepted in the enterprise and academic environment to form a coherent and concise model, helping to stress the principles of the presented method.

The fact that turn it possible to get different values from the criterion's weights comes from the need to quantify the subjective criteria and relationships, the balance given to the process, etc. It makes very important to evaluate this method through a well-prepared team with well-defined concepts and, after all, consolidate all results in a matrix.

As a forthcoming work, interesting results could come from the possibility to stress the method applying it in other case studies including real cases.

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8. RESPONSIBILITY NOTICE