COMPARING AHP AND ANP SHIFTWORK MODELS: HIERARCHY SIMPLICITY V/S NETWORK CONNECTIVITY

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Summary *The Objective of this presentation, is to show a comparison of models and results between two different but complementary methods applied to the real Shiftwork problem. The first is an application of AHP in a very large problem (more than 400 terminal or cover criteria, and more than 500 overall criteria), this was a 18 months work with 22 different experts involved to build a Shiftwork Asset, that may be applied to almost any kind of shift in different type of work and enterprises. The second one is an extension, built after completeness of the first model. This time we used ANP instead of AHP, with a very good knowledge of the problem as an advantage, so we were able to synthesize the model, capturing almost all the existing interrelations. At the end, this paper has as a main objective to be able to compare the benefits and costs of both ways of doing the modeling process as well as to compare the final results obtained in both systems AHP & ANP.*

1. Describing The Problem

As a global introduction, we want to point out the relevance and impact of having a structuring, ranking and deciding support tool to help in the complex problem of choosing a shiftwork system for a company (in this case a mining company), and for a Country (legal aspects and international trades). With this in mind, we would like to point out the next three statements:

- The technological development of the last 100 years has won to the nature many light hours. But this advantage, linked with the need of keeping a 24 hours continue productive process, has compelled us to force our biology, and this is not for free.

- Right now, circa 25% of the world population is working in some kind of continuum shiftwork squeme (24x7).

- The International Free Trade signed by Chile and the EEC, US and South Corea, will force us to observe in detail our own working laws and the agreements with the International Confederation of Workers as well. This will imply a reordering inside the working organizations in Chile, in terms of competitiveness and the management of people's quality life.

The Analytic Hierarchy Process (AHP) for decision-making uses objective mathematics to process the inescapably subjective and personal preferences of an individual or a group in making a decision. With the AHP, we construct hierarchies that have a first level of strategic or political criteria, then expand each one of these criteria, as branches, into more specific subcriteria until we reach the terminal criteria, the behavior indicators.
By the other hand, the Analytic Network Process (ANP), is a mathematical extension of the AHP theory. Here feedback process and all kind of relations are allowed. The ANP has clusters of elements connected

in networks rather than elements arranged in levels. You can connect any element to other elements that influence it. Once the model is built, we make judgments on the influencing elements with respect to the element they influence. Then, computing the supermatrix limit (eigenvector), we derive ratio scales (metric) that are internally located in a stochastic supermatrix (matrix of matrices). Finally, it prioritizes in a form that reflects all the different interactions between clusters, nodes and alternatives. This process has a higher level strategic hierarchy that controls all the benefit, cost, risk and opportunity subnets, that the specific shiftwork problem may need.

The main idea is to compare the AHP with the ANP results, to point out what benefits does each system have and how we can use them to complement the answers for very complex problems, where very complex stand for: many criteria of different sources, many actors of different types and many relations among the criteria.

To accomplish the last statement, we need to create a multicriteria decision making model based in a network of relations and feedback to support the process of choosing the best shift in the mining sector in Chile. This decision may be defined in the following sentence.

Global Objective (GOAL): To choose the best shiftwork system for a mining Company in Chile, that offers the best balance between the impacts reduction due shiftwork systems and the Company or Country competitiveness increase, while keeping a good quality life for the workers.

The shiftwork selection problems is a very complex one, mainly because of influences from different fields (biological, psychological, anthropological, economical and mathematical). His complexity level is such, that it has never been faced in a complete and integrated vision so far. In fact, up to date the only solutions that appear in the literature for this kind of problems are by one side, limited to very specific cases with a very fractioned vision (linked to one specific field) and with very little applicability in the real world general problems. And by the other side, we can only find some general solutions without any kind of mathematical background, just purchase software oriented, quite dangerous to people that may not be aware about where do these systems came from.

As a first step, we need to fully understand the problem. This will be carried out through the alternatives explanations (the shifts), in the third table column. To be more explicit about the shift explanation and at the same time be more explicit about the problem difficulty, we will enclose in parenthesis a qualitative appreciation of each specific shift characteristic. We have to point out that the parenthesis enclosed appreciations are for a general scenario, since their specific behavior will change depending on the criterion being measured and on the environment in which the problem is immerse. For instance, lets consider the 7x7 shift, where 7 working days in altitude environments is a negative factor for psychological (mental) aspects and negative also for working charge aspects, but it is very positive for the physiological adaptation of the body to the altitude situation (biorhythm adaptation). Even more, this shift has another positive characteristic, since it leaves at least half of the year week-ends free to be used with the family, and it also allows to easily calculate the future dates of work and of course the future dates out of work.

Another example of shift explanation is the 7 week shift: this is a 6 working days shift (negative) with only one day off (very negative), 8 hours per day (positive), starting at 5:00am (extremely negative), with a counterclockwise rotation (very negative), which means that the shift has time perception flowing against the natural sense, changing in a night - evening – morning order. After 6 working cycles in this shift the worker has a 5 days in and only 2 days off cycle (negative). A big disadvantage of this shift is beginning his working hours in the worst moment of the day (from the alert level and possibility to fall asleep point of view). Additionally, the worker never has a full week-end to spend with his family. By the other hand, it offers a very positive situation, since the worker is at home daily, with enough hours in good conditions as to build a good family link and able to give a “father presence”, important issue specially when children and youngsters are present.

The last descriptions are complex and represent just a part of the many different sources variables (points of view) that have to be assessed on these problems, without forgetting the multiple interactions this variables (criteria) have.

In this case, we ranked just 4 shifts (from a universe of about 70).

Alternatives Descriptor	Code	Shift Description
D7/H12/E8/Wednesday	7x7	Weekly system (positive), 7 days in (negative), 7 days off (positive), 12 hours per day (negative), starting every Wednesday (positive) at 8:00am (positive),
D7/H8/AH/E5/x7 weeks	7 Weeks	Weekly system (positive), 6 days in (negative), 1 off (negative), for 6 cycles. The seventh cycle has only 2 days off (negative). Counterclockwise rotation (night, evening, morning) (negative), 8 hours per day (positive), starting at 5:00am (negative).
D4/H12/E8	4x4	Not weekly system (negative), 4 days in (negative) and 4 days off (positive), 12 hours per day (negative), starting at 8:00am (positive).
9x3/AH/E8/NTML(5)	9x3	Not weekly system (negative), 9 days in (negative), 3 day off (positive), counterclockwise rotation (night, evening, morning, free) (negative), 8 hours per day (positive), starting at 8:00am.(positive).

Table 1: Alternatives, Codes and Descriptions

2. The Models

Now, we have to evaluate each shift to determine which is best and how much better is one from the other (cardinal ranking). This issue, is accomplished in both systems (AHP & ANP), first in the AHP model using the Shiftwork Asset customized to the Company and environmental restrictions. In this case, the conditions are: no altitude component and the camp (where the workers live) near to the working place.

Part of the Shiftwork Asset displays is showed now, software used for the shifts prioritization in the AHP formulation.

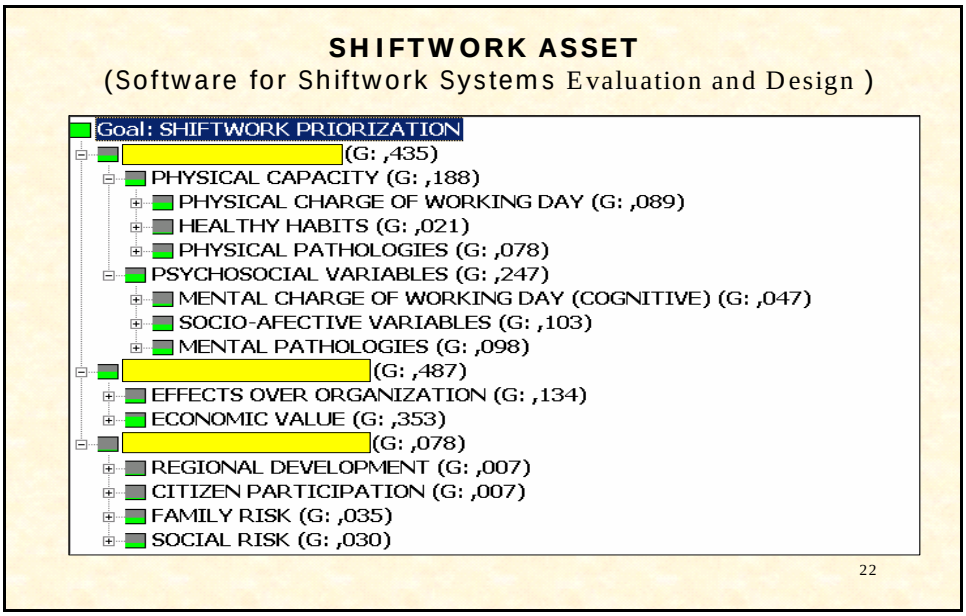

Figure 1: The Shiftwork Asset: a general software for shiftwork systems evaluation and design

Here, in the construction of the model, special care must be taken in order to avoid (as much as possible), the different feedback relations. This was one of the causes for the huge number of criteria in the model, since one criterion may appear several times in the model, considering the different views and hence the necessary assessments that the criterion may posses. In fact, we discovered a set of 33 indexes that were found repeatedly in the model in order to consider the different views (like a gem giving a different reflection index for each cutting (face), but having a global overall index of refraction). Those indexes represent the shift's characteristics, and combining them almost any desired shift can be built.

Whit this concepts in mind, the ANP version of this problem was built, but now considering in an explicit way all the internal and external existing relations. Of course, the criteria (nodes) interpretation changes a little due to the ANP comparison form, which differs from the AHP case in the way that criteria influence or is influenced by the others, and hence how the questions must be asked. In any case, the characteristics set remained practically unchanged.

In the next two figures (Figures 2 and 3), the strategic hierarchy is shown, in its graphical (by software) and matrix representation. In fact, it is not exactly a hierarchy, because inner and outer dependence relations exist (observe the circular arrows and the double arrow in and between second and third levels).

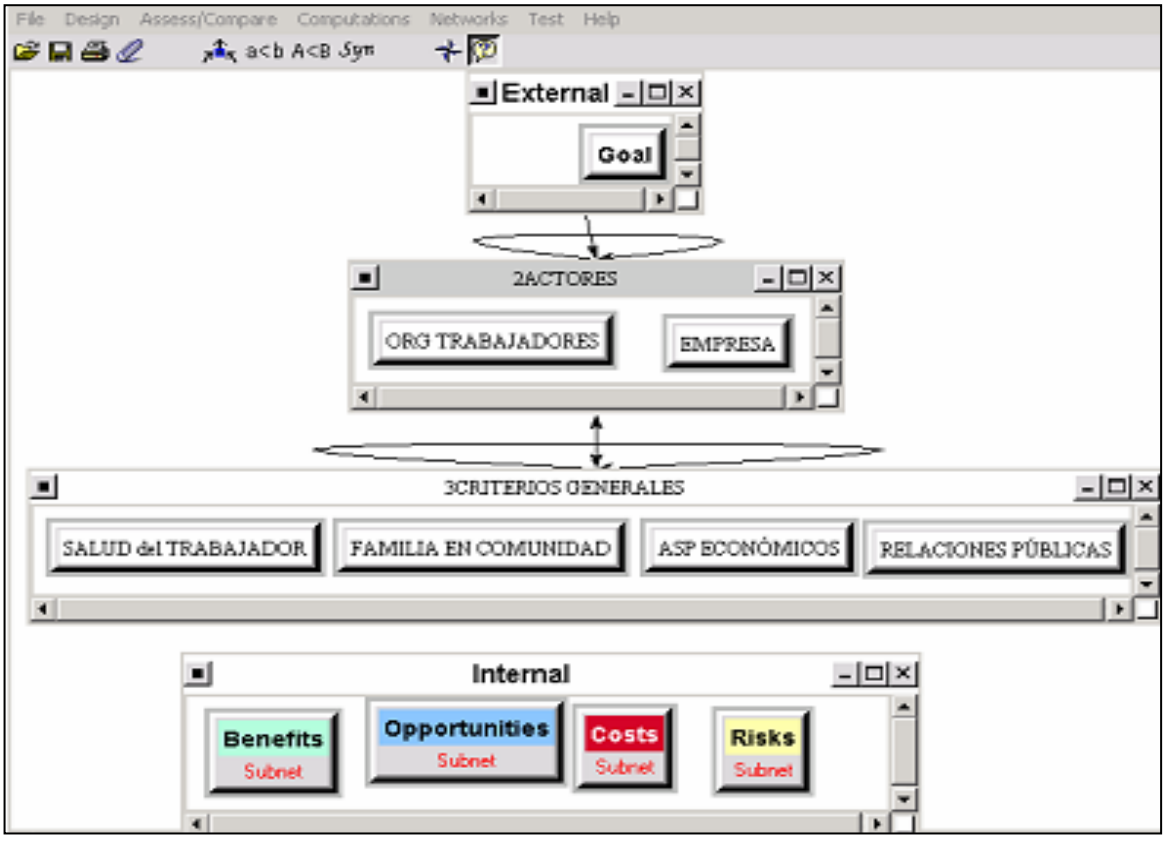

Figure 2: The Strategic Hierarchy: Combining benefits, opportunities, costs and risks

The second level criteria (actors level) are: workers organizations (mainly unions) and the Company (CEO's plus main stakeholders).

The third level criteria (global interest criteria) are: workers health (mental and physical), family as a community member, economical aspects (related with investment, workers and company's productivity,

incomes, etc..) and public relations (of the Company with the social environment and how is it perceived by the community).

It is easy to deduce that this criteria keep a strong dependence among themselves, for instance, we can't think in the workers health conditions without thinking in the lateral effects over the public relations criteria, as well as the economic aspects and the develop of the family and the community to which they belong to. In other words, they work in a whole interactive and integrate form.

From the strategic hierarchy (and acting as alternatives) 4 hanging subnets are found: benefits, opportunities, costs and risks. This subnets have a set of control criteria above, clustered in a hierarchy form called "control hierarchy". Inside this control hierarchy, we find many subcriteria controlled by criteria, the subcriteria may have many different dependence relations between them, so they are clustered conforming a subnet of cluster and nodes. This subnet hangs belongs to some of the criterion of the control hierarchy, which belongs to one of the four "alternatives", which in turn belongs to the strategic hierarchy located in the main top of the model (the main model).

Note: the excessive "belongs", was a way to represent and communicate the many relation forms one variable may have (degrees of connectivity).

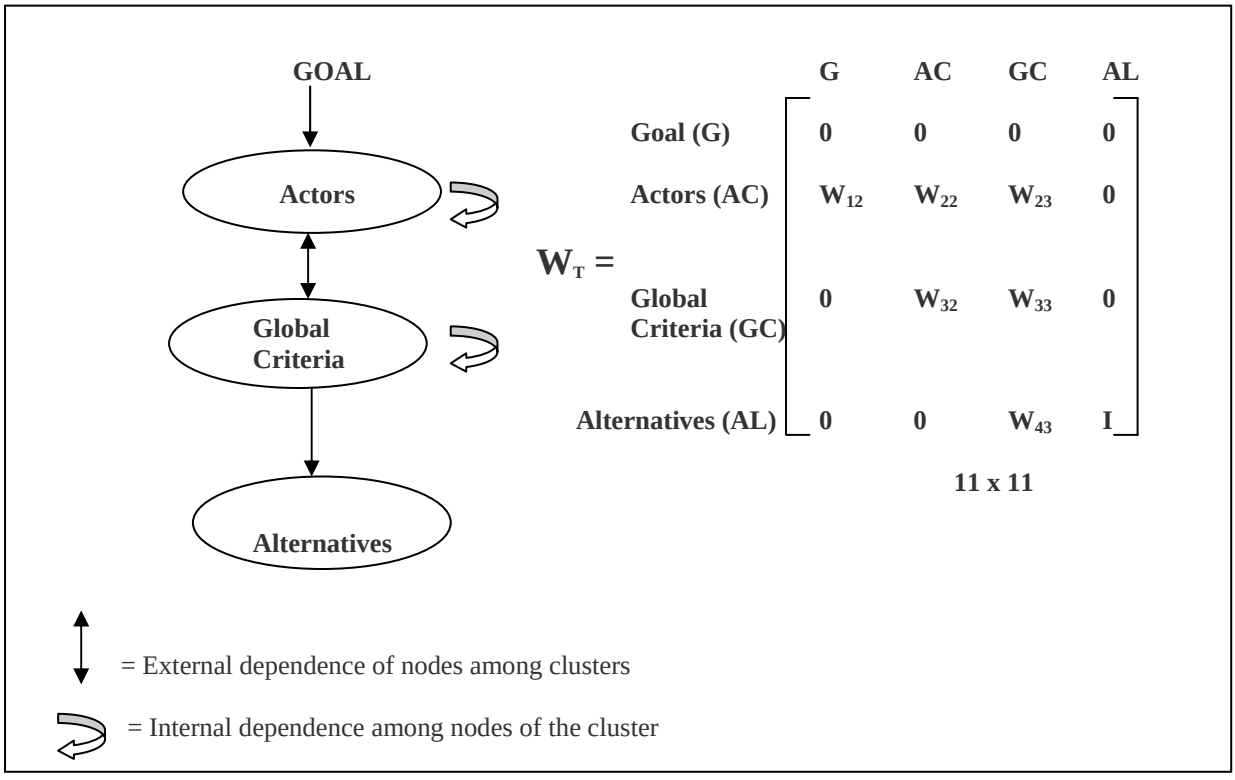

Figure 3: Strategic Hierarchy Matrix Representation

Note1: W_T (11x11), represents the global network Supermatrix , which captures all the strategic hierarchy (main model).relationships.

Note2: W_{12} (2x2), W_{22} (2x2), W_{23} (2x2), W_{32} (4x4) W_{33} (4x4), W_{43} (4x4), and I (4x4) (the alternatives identity matrix), are the matrices that capture the local node interactions, intra clusters (internal dependence) and inter clusters (external dependence).

Next, one of the four control hierarchies of the ANP model is shown, corresponding to the Benefits alternative of the strategic hierarchy. (Figure 4).

Just like the strategic hierarchy, this is not actually a hierarchy, since an inner dependence relationship exists (circular arrow in control criteria cluster), between the time quality and quantity criteria, in the second hierarchy level. The relation is originate by the dependence of the time quality from the time quantity, as it is impossible to have one without the other. So, the time quality is a function (depends) of the time quantity.

The first level (goal) criteria, represent the benefits in terms of relax time. This is measured by two criteria, time quality and time quantity, each one having its own subnet. One of this subnets (Time Quality) can be appreciate in Figure 5, where the alternatives are found. They are measure in a relative form in terms of their contribution to the control criterion Time Quality.

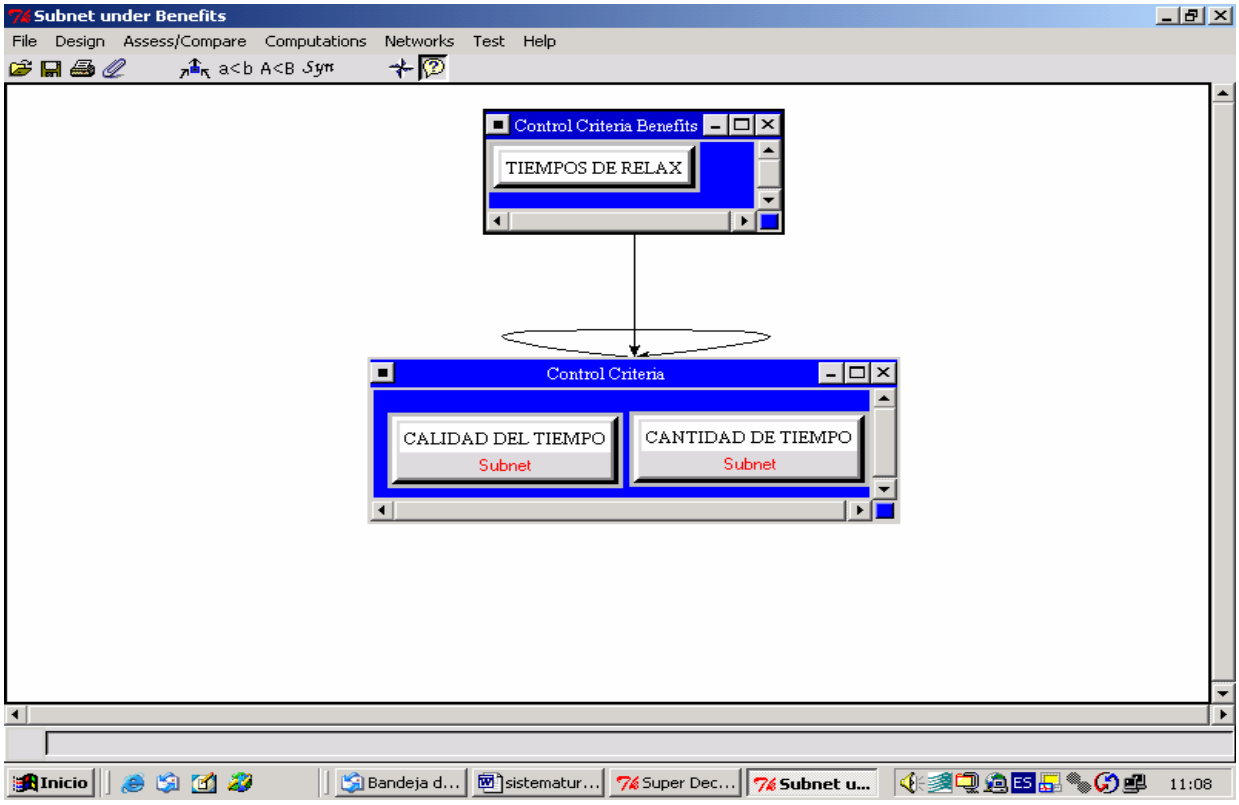

Figure 4: The Benefits Control Hierarchy

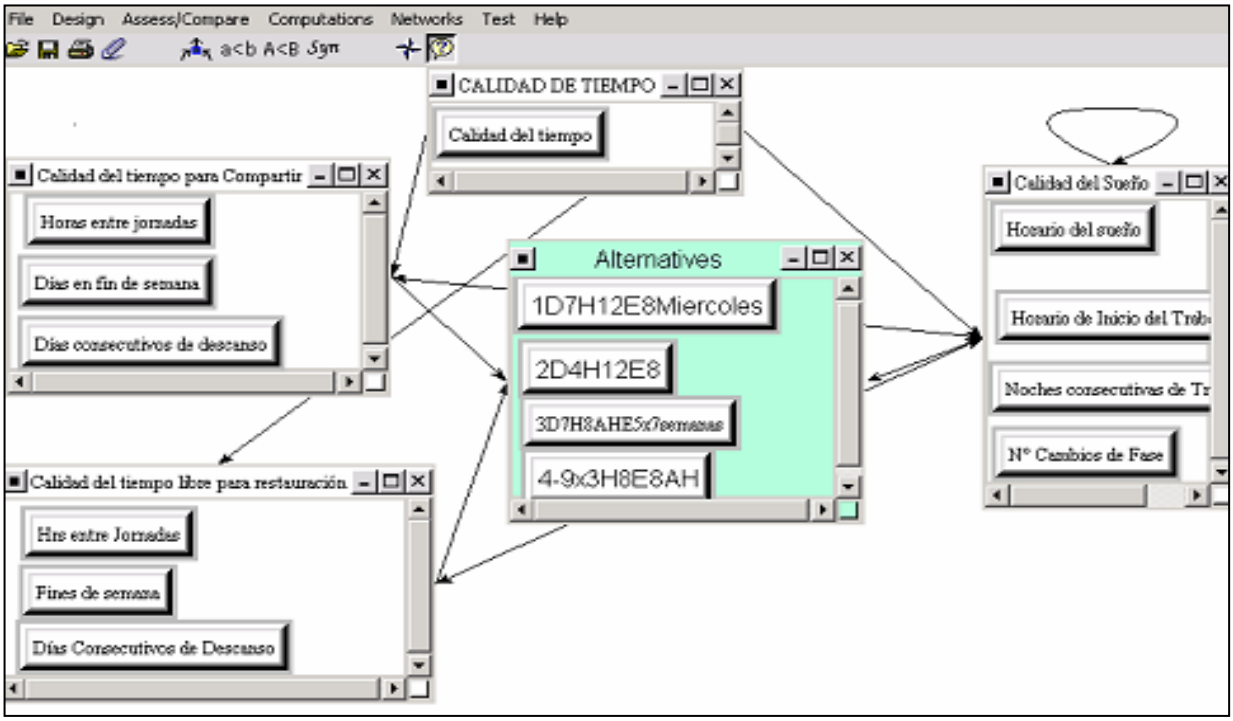

Figure 5: The Time Quality Subnet

In Figure 5, three clusters are responsible of the time quality measurement of the alternatives:

- Sharing free time quality, with the following nodes:
  - Free hours during working days
  - Free days during week-ends
  - Consecutive days off
- Recovering free time quality with the following nodes:
  - Free hours during working days
  - Number of week-ends
  - Consecutive days off
- Sleeping time quality with the following nodes:
  - Starting sleeping time
  - Starting working time
  - Consecutive working nights
  - Number of changing phases (rotations)

Dependencies:

Internal dependencies:

In this model, there is one internal dependence among the nodes of the sleeping time quality cluster, since the starting sleeping time is affected by the nodes: starting working time, consecutive working nights and the number of changing phases.

External dependencies:

There are few external links: the Sharing Time Quality cluster linked with the Sleeping Time Quality cluster, and the Recovering Time Quality cluster linked with the Sleeping Time Quality cluster.

These dependencies are related with the following nodes: Starting sleeping time, since it is affected (and affects), by the external nodes: Free hours during working days, Free days during week-ends and number of week-ends. The explanation of this is, that the quality of the workers sleeping hours will affect (and will be affected by) the quality of the time (composed by his working days and week-ends hours) devoted to the family and to his physical and mental restoration.

3. The Models Results and its Comparison: (The AHP Simplicity v/s The ANP Connectivity)

Once the ANP model was completed, the results were compared with the AHP ranking for the same 4 shifts, both mechanism gave the same answer: 7x7 shift is the best.

The following table (Table 2) shows the decision metric (ranking) for each model (ANP & AHP), both measured in the ideal mode. AHP against standards (rating mode), and ANP in comparison alternatives mode (relative measurement).

Shifts	ANP (relative/ ideal mode)	AHP (rating/ ideal mode)
D7/H12/E8/Wednesday (7x7)	1	1
D4/H12/E8 (4x4)	0.970	0.953
D7/H8/AH/E5/x (7 weeks)	0.565	0.591
9x3/AH/E8/NTML (9x3)	0.707	0.562

Table 2: AHP – ANP Ranking Comparison Table

Then, the Haddamar product was used in order to know how close the results were. Both decision metrics ANP and AHP, for the four shifts alternatives evaluated.

With the Haddamar product is possible to build a compatibility /incompatibility index for two decision metrics, having the tolerance threshold approximately in 10% (index of 90% or more means compatible).

Doing this, the Incompatibility index became equal to 0.011 and hence, the Compatibility index among the decision metric vectors became equal to 98.9%, which means that the two metrics are very close. (In spite of, we got one reverse order between the third and fourth shifts). This closeness show that the decision (to choose the 7x7 shift), is the best one (for both methods).

At the same time, the scenario analysis, the sensitivity and stability solution analysis as in the marginal analysis has showed that the 7x7 is the best shift. Only when the risks model (pessimistic vision), has an important weight, the 7x7 became the 2nd best option (for a little difference), behind the 4x4 shift alternative.

4. Final Conclusions:

The ANP modeling process replaces the many criteria of the hierarchy by a proper network relationship "*connectivity*" between elements and clusters, so the problem is represented in a closer way to what occurs in real life. We note that almost similar good results were obtained with the AHP model as with the more realistic ANP model. This was due mainly to our comprehensive AHP model of more than 500 factors that comprises the Shiftwork Asset Software.

The ANP modeling process provides a way to explicit all the relationships among variables, reducing significatively the gap between model and reality.

The way that ANP deals with the relations among variables (through pair comparisons), helps to drive the attention to a given connection at a time, allowing a more accurate and comprehensive analysis.

The abstraction level needed to build hierarchy models requires an extraordinary effort to identify and handle the multiple interrelations between components that the real problem has. In the shiftwork AHP model developed by Fulcrum Engineering, it took almost one year of work to isolate each factor (approximately 500 criteria in total for the largest one), checking that interrelations and feedbacks were properly handled. Instead in the ANP modeling, this task was much easier, considering that it allows to represent interactions in a explicit, graphical and direct way. As a consequence, the model developing time was dramatically reduced. This advantage is particularly important in complex problems which deal with biological, psychological or/and anthropological matters.

The AHP and ANP analysis capacity (scenario analysis, benefits, Opportunities, Costs and Risks analysis, tendencies, dominance, stability and sensibility), turn out to be a very powerful mechanism to validate results and increase participants confidence on them. This kind of analysis and synthesis provides the consultant, analysts and decision makers a powerful framework, transparent, complete, practical and with models close to reality, that allow them to face complex and "super" complex decisions in many different areas (medical, economical, social, psychological, legal, etc..) of human society.

As problems turn more and more complex in this global world, the necessity for adequate methodologies and tools increases significatively in a daily bases. The AHP and his mathematical extension the ANP (to better capture the complexity of reality) are here to help.

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