Valuation of coefficients affecting modeling factors in the optimal organization structure design problem in make-to-order operations

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ABSTRACT

This paper addresses the valuation of coefficients that affects the organizational structure design model in a make-to-order (MTO) operation environment. A mathematical model was presented to aid an operations manager in an MTO environment to select a set of potential managerial layers to minimize the operation and supervision cost. This model examines the span of control (SOC) problem and provides a quantitative approach to the organization design problem and is intended for applications as a design tool in the make-to-order industries. With a given Work Breakdown Structure (WBS) for any specific project, solving this model leads to an optimal organization structure design. In order to solve this model, it is necessary to determine the coefficients for modeling factors. These factors consider allocation tasks to workers, including complexity and compatibility of each task with respect to workers, and the requirement of management for planning, execution, training and control in a hierarchical organization. An implementation of this model was made with a particular group of companies resulting in the selection of a feasible span of control for this type of organizations.

Keywords: Span of control, Organizational Design, Hierarchical Organization, Assignment Problem, Make-to-order

1. INTRODUCTION

This paper presents an analytical model for analyzing hierarchical organizations. It considers various factors that affect the requirement for supervision and formulates them into an analytical model which aims at optimizing the organizational design. This decision includes allocation tasks to workers, considering complexity and compatibility of each task with respect to workers, and the requirement of management for planning, execution, training and control in a hierarchical organization. The model is formulated as a 0-1 mixed integer program. The objective of the model is minimum operational cost, which is the sum of supervision costs at each level of the hierarchy and the number of workers assigned with tasks. This model addresses the span of control (SOC) problem and provides a quantitative approach to the organization design problem and is intended for applications as a design tool in the make-to-order industries. Each project-based company may have to frequently readjust its organizational structure, as its capability and capacity shifts over time. It could also be applied to functionality based companies as an evaluation tool, to assess the optimality of their current organization structure.

The objective of this paper is to determine a method to quantify the factors that determine the allocation of jobs to workers (level 0), and those related with supervising time, divided into the following factors: planning, control, execution, and training. In order to do this, the level of importance between the factors has to be determined, and a quantitative range has to be identified with which it is possible to make an objective measurement that can be incorporated in solving the mathematical model proposed. This part of the research was conducted through the study of the activities of people who have supervisory duties. For this purpose, data were collected from four different Information System (IS) companies in the city of Chihuahua, Mexico.

2. Problem Description

This research focuses on a study of the organizational structure design problem in the MTO operation environment, aiming at developing a quantitative model and a practical solution for this problem. The model considers all direct work planned for the operation in a planning horizon and managerial activities required to run the operation, including planning, training, control, and execution. The design process begins with decomposition of each work into elemental work units (called OP), and assigning each OP to direct resources (machine and worker required) in relevance to work complexity, resource competency (skill and proficiency), and their compatibility. It then moves to organizing the required resources into groups, sections, and departments, forming a hierarchical management structure. It assumes work can be decomposed into a hierarchy of standard OPs, of which specifications, requirements and methods have been formalized for each OP type. It further assumes management effort for each managerial activity is measurable and is unique for each company, depending on the experience and expertise it has and tools and techniques it uses to run the operation.

Formally, the problem can be described as follows: A set *J* of jobs and a set of *G* different processing workstations are given. Each job *(J)* is described by its processing time for the tasks to be completed, the skills needed for the job, the level of each skill (factor complexity) and compatibility according to the information given to the workstations. The objective is to find a set of workstations (G) to schedule the jobs (J) in such a way that the utilization of each workstation could be maximized and to find the SOC needed for this Work Breakdown Structure (WBS) while maintaining the minimum cost of supervision. The number of SOC formed depends upon the number of workstations (G) considered in an instance and also depends on the factors identified for supervision: planning, control, execution and training.

3. Mathematical Formulation

Below is the mathematical model proposed for the organizational structure design problem for the MTO operation environment and the parameters used in the mathematical formulation:

- w_{nj}: the unit cost coefficient for section *j* at level *n*
- β_i: the processing time for job i, $i \in I$
- r_{oj}: the capacity of the working group j, $j \in J$
- α_{ij}: the complexity factor when job *i* is assigned to group *j*
- p_{nj}: the planning factor for section *j* at level *n*
- c_{nj}: the control factor for section *j* at level *n*
- t_{nj}: the training factor for section *j* at level *n*
- e_{nj}: the execution factor for section *j* at level *n*
- f_{nj}: the capacity of section *j* at level *n*
- n_{ij}: the compatibility factor when job *i* is assigned to group *j*

The decision variables used in this model are given below:

- $z_{ij} = \begin{cases} 1 \text{ if job is assigned to group j} \\ 0 \text{ otherwise} \end{cases}$
- $y_{0jp_0} = \begin{cases} 1 \text{ if group j with section } p_0 \text{ at bottom level is occupied} \\ 0 \text{ otherwise} \end{cases}$
- $y_{njp_n} = \begin{cases} 1 \text{ if section j with section } p_n \text{ at level n is occupied} \\ 0 \text{ otherwise} \end{cases}$

The mathematical formulation for the problem under study is presented below:

Min $\sum_{n=1}^{N}\sum_{j=1}^{J} w_{nj}\, f_{nj}\, y_{njp_n} + \sum_{j=1}^{N} y_{ojp_0}$ $(\forall j \in J), (\forall n \in N)$ (1)

Subject to:

$\sum_j z_{ij} = 1$ $(\forall i=1\ldots m)$ (2)

$\sum_i \beta_i\, \alpha_{ij} z_{ij}/n_{ij} \leq r_{0j}\, y_{ojp_0}$ $(\forall j=1\ldots n)$ (3)

$\sum_j r_{oj}\, y_{0jp_0}\left(\rho_{ij} + c_{ij} + t_{ij} + e_{ij}\right) \leq \sum_j f_{ij}\, y_{ijp_1}$ $(\forall i=1\ldots m)$ (4)

$y_{ojp_0} \leq \sum_{p1} y_{1_{p0p1}}$ (5)

$\sum_j f_{n-1,j}\, y_{n-1,jp_{n-1}}(\rho_{ij} + c_{ij} + t_{ij} + e_{ij}) \leq \sum_j f_{nj}\, y_{njp_n}$ $(\forall i=1\ldots m)$ (6)

$y_{n-1,jp_{n-1}} \leq \sum_{pn} y_{np_{n-1}p_n}$ (7)

$(z_{ij}, y_{0jp_0}, y_{njp_n}$ binary, $(\forall j \in J), (\forall i \in I)$). (8)

In this formulation the objective function (1) has two elements: the direct cost of supervising and the number of working groups. Constraint (2) ensures each job (operation type) is assigned to only one direct labor group. Constraint (3) ensures each direct labor group has a finite capacity, all job assignments are limited by the capacity of each labor group. Constraint (4) and (6) ensures the total managerial work requirement of its child units cannot exceed the finite capacity imposed on the parent unit. Constraint (5) and (7) ensures that each child unit must have a parent unit. The constraint sets (8) impose the binary restrictions on the decision variables z_{ij}, y_{0jp_0} and y_{njp_n} , respectively. A commercial software system, LINGO, was used to help validate the proposed binary integer model, study its behavior, and explore its computational limits. Extensive experiments were conducted to validate the model with practical problems and evaluate the impact of changing the complexity and compatibility parameters at level 0 and managerial-related parameters for planning, training, execution, and control at the higher levels (Mena & Chen, In Editing (Online ISSN 1943-670X))

4. Complexity and compatibility factors (level 0)

The objectives pursued with the following method are based in two points: (1) determining their existing workers' OP-Types and skill levels, and (2) assigning the workers to their complexity and compatibility factors at an appropriate level regarding the jobs. The method for assessment of the complexity and compatibility factors at level zero is based on the information of a job proposed to the company which consists of the jobs to be completed, the OP-Type, and the level of skill (required to complete each job). The theoretical foundation for this method is based on the analysis of workers' skills, and makes a comparison with respect to the skills required for a particular job. The following figures show the steps needed for this process. The proposed model is partially built on the one developed by Depuy et al. (Depuy, 2006).

On the left side (worker), the first step is to identify the skills (OP-Types) of the worker. Once the different skills of each worker have been established, the next step is to determine, based on technical tests, the level of each skill. On the right side (job), the OP-Type and required skills of each job are defined. Next step is to determine the required skill level of each job. In order to assign a skill relationship between jobs and workers, it is necessary to design a skill relationship table. For this table, the first step is to determine how many levels are required (e.g., novice, intermediate, expert), and the numerical relationship between the different combinations (e.g., novice-novice, novice-intermediate, novice-expert).

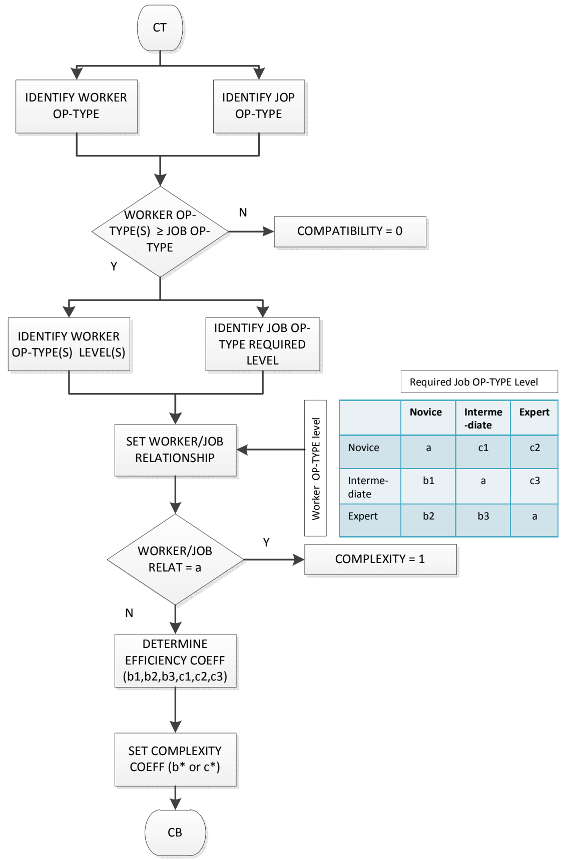


Figure 2: Method for complexity factor

The compatibility factor, as shown in the following figure, verifies the compatibility and then assigns a value to this factor updating the relationship between a job and a worker.

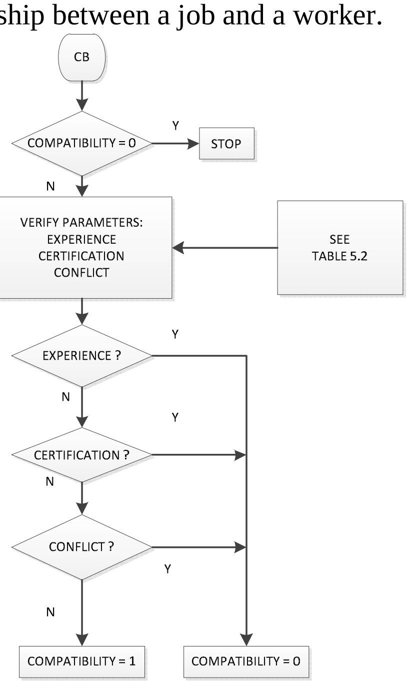


Figure 3: Method for compatibility factor

Some questions must be made regarding the compatibility factor between worker and job assignments. Compatibility values consider only close to 0 and 1, in such a way that the model assigns jobs to workers only when compatibility is equal to one. When compatibility is close to zero, the model assigns a very large number for the processing time of that activity and does not assign that activity to that individual worker. The no-compatibility factor is used when a worker does not have the appropriate level to perform a job. The result of this method is the development of a model that provides an assignment of workers to jobs, such that the total skills gap is minimized.

5. Primary dimensions of supervision work (level 1 to n)

In this section, the objective is to construct an instrument for providing a measure of organizational factors (planning, execution, training, and control). This develops a more extensive model that assigns workers to supervisors, in such a way that the total cost required achieving all the jobs is minimized. From examination of the literature on Organization Theory (Meier & Bohte, 2003), (Theobald & Nicholson-Crotty, S., 2005), four primary dimensions of supervision work were defined: (1) planning, which is concerned with process, product standardization in the organization, initiation, preparation, resource allocation, and scheduling; (2) control, which is concerned with the extent to which good project management control is employed, such as monitoring, coordinating, decision making, dissemination, dispatching, and performance evaluation; (3) training, which is concerned with effective training tools such as lecturing, coaching, guiding, and discussing in the organization; and (4) execution, which is concerned mainly with the alignment of organization objectives, problem solving and implementation. These definitions are going to be translated into operational definitions, and developing the methods and results of scaling the supervisor work variables. The theoretical foundation for this method is based on the analysis of the relevant activities related to each factor, and the identification of instruments for measure. This method is partially based on the work of Khaled et al. (Khaled, 1995) for measuring organizational maturity. The following figure shows the general steps:

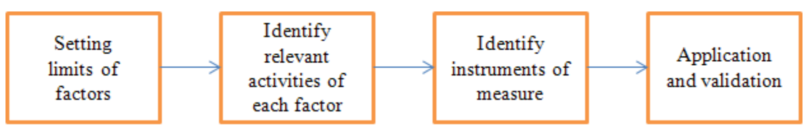


Figure 4: Method for supervisor factors

5.1 Setting limits for the factors

In the model, if the sum of the factors (constraints 4, 6) is equal to one, then that implies that supervision at level 1 requires the same quantity of time than the worker at level 0. On the other hand, if the sum is less than one, this implies that the supervision time required is less than the operating time of the group; therefore, a supervisor can have more than one subordinate as shown in the following figure.

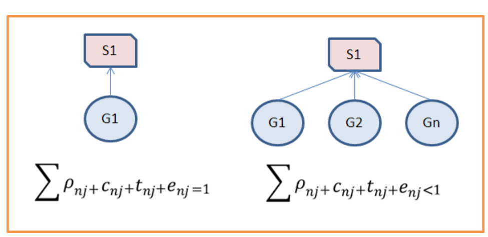


Figure 5: Impact of sum of factors in SOC

As shown in Figure 6, a method was developed to identify the boundary of each of the factors within the constraints indicated.

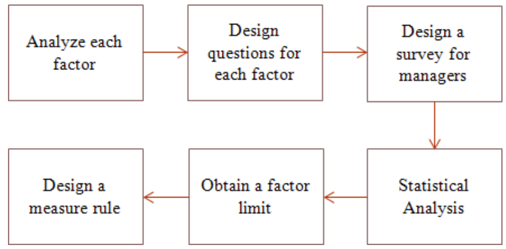
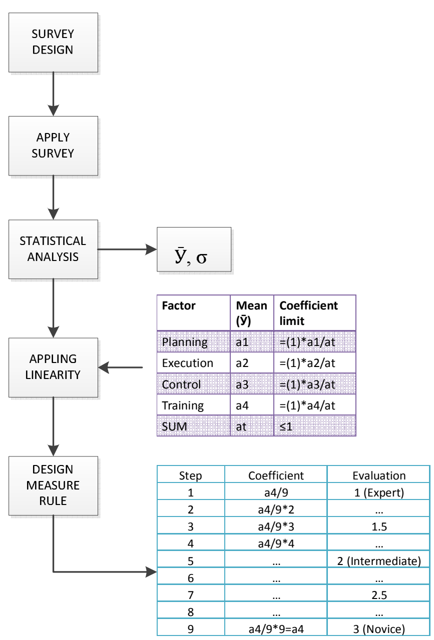


Figure 6: Factors between level 0 → 1

The first step in the previous model includes the analysis of each factor according to the type of industry. Planning, control, execution, and training could have different meaning in different types of industries. In order to know the importance level of each factor within the company, a survey with different questions regarding each factor was designed. The survey was applied to all supervisors and managers in the company and the results were analyzed using statistical software (in order to obtain mean, standard deviation, and relevant parameters). If for a particular type of business, the importance of each factor was the same, then the limit would be 0.25 for each (in such a way that the sum of the four factors equals one: 0.25 + 0.25 + 0.25 + 0.25). Otherwise, applying linearity to the results, a factor limit is obtained. Once the factor limit is known, a measure rule could be designed adjusting the minimum and maximum number of subordinates, in such a way that the rule is according to the SOC for each particular industry. In order to show how this process works, data were collected in four IS companies and 30 supervisors (within these companies) in the city of Chihuahua, Mexico. The next figure shows how to design a measure rule: once the survey that establishes the level of importance of each of the supervisor factors has been designed and applied, the next step is to get the mean (a1, a2, a3, a4) and standard deviation of each factor. The next step is to get the sum of the means values (at), and assuming that the sum of the coefficients must be less or equals to one, applying linearity the coefficients limits could be obtained (equals a*/at). Each of the instruments, in order to valuate supervision effort, used in this process, has an evaluation from one (expert), two (intermediate), and three (novice). The coefficient limit at level three (novice) will be the mean value of each factor. In order to get the measure rule, the number of steps must be established and from there the measure rule could be designed dividing the coefficient limit by the number of steps with regular increments (as shown in figure).



Factor	Mean (ȳ)	Coefficient limit
Planning	a1	=(1)*a1/at
Execution	a2	=(1)*a2/at
Control	a3	=(1)*a3/at
Training	a4	=(1)*a4/at
SUM	at	≤1

Step	Coefficient	Evaluation
1	a4/9	1 (Expert)
2	a4/9*2	…
3	a4/9*3	1.5
4	a4/9*4	…
5	…	2 (Intermediate)
6	…	…
7	…	2.5
8	…	…
9	a4/9*9=a4	3 (Novice)

Figure 7: Design of measure rule

5.2 Identification of relevant activities

Once the coefficients limits of each factor have been identified, it is necessary to establish the relevant activities for each factor in order to identify possible instruments to measure the required time of supervision effort. From definitions found on the work of Iyigün (Ïyigün, 1993), Raishi (Raisch, 2008), Annand et al. (Anand, 2006), and Hales (Hales, 1986) the principal activities for the planning, control, training, and execution factors were defined. The next steps in this process, after the activities were identified for each factor, are focused on the following processes:

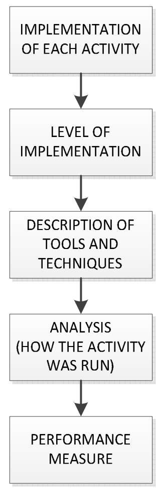


Figure 8: Activity implementation process

5.3 Application and validation

This section provides the procedure of the field test used, and a brief description of how variables were measured, the data analysis procedures, and discussion of the results of the study. Supervisors, who might be a work manager, an area superintendent, or some other administrator, were first contacted by a letter addressed to the general manager of each IS company. Field work began with interviewing them at length, and interviews were conducted with standard schedules listing the data desired. This instrument is used as part of the software process diagnosis and improvement services that the IS companies provided. The study was specifically conducted to confirm the patterns found in the literature with the organizational practice (Price, 2007) and to collect data that are useful for measuring the factors of planning, control, training, and execution.

In order to apply and validate this method, a sample of 30 supervisors and managers of the Information Systems (IS) companies were given a survey to determine the importance assigned to each of the factors within that particular organization type. The use of a semantic differential scale (Al-Hindawe, 1996) for all the items in the survey was proposed. The first part of the validation consists in setting the limit for the factors involved, and an analysis of the survey instrument employed was made using the statistical software SPSS version 17 for Windows Vista. The interview consisted of twenty questions, five of them related to each factor in random order and on a scale of 1 to 5 (1. Strongly disagree, 2. Disagree, 3. Neither agree nor disagree, 4. Agree, 5. Strongly agree) that the supervisor has with respect to each question. Applying linearity to the value found for average for each of the factors and assuming that the sum of the limits must be less than or equal to 1, the limit for each of the factors identified were obtained. The previous quantification shows that the factors have different hierarchy between each of them, where the planning and execution were of significant importance of 0.26, the control factor limit was 0.25 and a training factor of 0.23. The following table shows the values obtained for each factor:

Table 1: Quantitative limit of each factor

Factor	Mean	%	Limit
Planning	3.7	26.24	0.26
Control	3.54	25.11	0.25
Training	3.24	22.98	0.23
Execution	3.62	25.67	0.26
Sum	14.10	100	1

The next step for validation purposes was to measure the utilization of each of the instruments identified. To validate this information, a study with 20 randomly selected supervisors was conducted. The analysis was carried out to identify how activities are performed for each factor. A standard measurement of 1 to 3 for all the instruments was used, where 1 is the full utilization of the instrument, and 3 when the instrument is not known. As noted in the factors for the level 0, the analysis of the supervisor factors must be made by the next person higher in command to avoid, at least to the level *n-1*, a self-assessment process. The objective is to assess the number of subordinates that should be expected (on average). The study consisted of an interview with each supervisor where the evaluator collected data regarding the use and knowledge that each supervisor has in each of the formats identified. Scales were constructed to define the variables operationally. These measured the degree of a particular factor present by linking together a number of items that could be used to measure that factor.

Once the limit of the factors and the evaluation of each supervisor have been established, the next step was to determine the value of each factor that can be assigned to the supervisor. Applying linearity and using the following rule the value of the coefficient for each factor was calculated, as shown in figures 9 and 10.

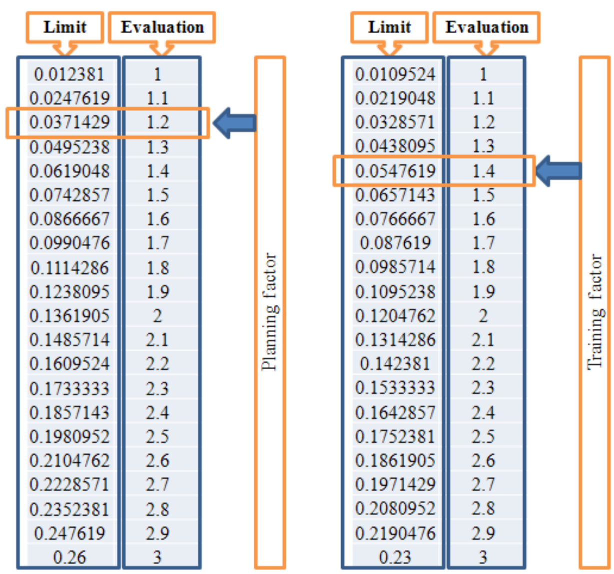


Figure 9: Evaluation of planning and training factor

Execution factor

Limit	Evaluation
0.012381	1
0.0247619	1.1
0.0371429	1.2
0.0495238	1.3
0.0619048	1.4
0.0742857	1.5
0.0866667	1.6
0.0990476	1.7
0.1114286	1.8
0.1238095	1.9
0.1361905	2
0.1485714	2.1
0.1609524	2.2
0.1733333	2.3
0.1857143	2.4
0.1980952	2.5
0.2104762	2.6
0.2228571	2.7
0.2352381	2.8
0.247619	2.9
0.26	3

Control factor

Limit	Evaluation
0.0119048	1
0.0238095	1.1
0.0357143	1.2
0.047619	1.3
0.0595238	1.4
0.0714286	1.5
0.0833333	1.6
0.0952381	1.7
0.1071429	1.8
0.1190476	1.9
0.1309524	2
0.1428571	2.1
0.1547619	2.2
0.1666667	2.3
0.1785714	2.4
0.1904762	2.5
0.202381	2.6
0.2142857	2.7
0.2261905	2.8
0.2380952	2.9
0.25	3

Figure 10: Evaluation of training and control factor

With the data found and replacing in the following constraint:

$$\sum_j r_{oj} y_{0jp_0} (\rho_{ij} + c_{ij} + t_{ij} + e_{ij}) \leq \sum_j f_{ij}\, y_{ijp_1}$$

For an 8-hour workday, the constraint results in the following equation:

8 hrs * (.037+.059+.054+.049) = 8 hrs * (0.199) = 1.592 hrs.

This relationship indicates that the working group only requires 1.59 hours of supervision. Supervisor factors that affect each level must be calculated for each working group independently. If the working groups were homogeneous (same factor value for each group), then in the previous constraint the number of groups directed by each supervisor can be calculated with the following equation:

$$n_{groups}\ (8)\ (0.199) \leq 8(1)_{supervisor}$$

$$n_{groups} \leq \frac{8(1)\text{supervisor}}{(8)\ (0.199)} \sim 5 \text{ groups}$$

Under these conditions, one supervisor could manage up to five working groups (workers). In the extreme case, where a supervisor obtains an assessment of one (perfect score) in all measuring instruments, it involves the following equation:

$$n_{groups}\ (8)\ (.045) \leq 8(1)_{supervisor}$$

$$n_{groups} \leq \frac{8(1)\text{ supervisor}}{(8)\ (0.045)} \sim 20 \text{ groups}$$

It is important to note that these results and tables of weights are relative to a particular type of organization and cannot be taken as the basis for any company. In any new design, the method must begin with the evaluation of the limit that the factors could take in order of the relevance of each factor related to the company and also the assessment made in measuring instruments.

6. Conclusions

From an examination of the literature of Organization Theory, four primary dimensions of supervision work were defined: planning, control, execution, and training. These concepts were then operated by generating instruments measuring various aspects of the primary dimensions. The results found in this paper, regarding the SOC within the Information Systems (IS) companies, were consistent with the practice that those companies currently have between four and eight operators in charge for each supervisor and also the SOC found in the literature review. This method can give some guidelines to determine how a supervisor may be responsible for more working groups. The evaluation of each factor must be analyzed, and from this assessment, it must be determined how it can improve the performance for each factor involved. The SOC can also identify managers who need further training by measuring their performance. One of the main contributions of this quantification of factors was to determine an appropriate method to increase the number of subordinates considering the analysis and study of the factors involved.

The results of the SOC in this paper are consistent with the ones found in the literature review. The number of subordinates founded in the work of Van Fleet et al. (Van Fleet, 1977) with an average SOC of five and also Entwisle and Walton (Entwisle, 1961) with an average between 5 and 7. The only author that mentions a maximum SOC is Udell (Udell, 1967) with 30 subordinates. For this particular application case, the SOC suggested is (around) five with a maximum SOC of 21.

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