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Decisions in hierarchical production planning: goals, heuristics and bias

Decisiones en la planificación jerárquica de la producción: metas, heurísticas y sesgos

Leopoldo ARIAS-BOLZMANN [1]; William Fernando AGURTO Antón [2]; Ángela María CHÁVEZ Coronel [3]; Ricardo PANTOJA Retamozo [4]; Antonio PINTO Ticona [5]

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Content

ABSTRACT:
An experiment emulates a hierarchical production planning environment with the aim to determine the effect of goal setting on the production scheduler's performance with regard to lot sizing costs. Some heuristics and biases influencing the production scheduler's decision-making were detected. Reiterative behavioral patterns and the use of statistical parametric procedures found that goal setting reduces the production scheduler's cost dispersion, making the results more predictable, but there's no influence on performance. Production schedulers often use representativeness and availability heuristics and, the more frequent biases affecting the production scheduler's decision-making process are related to subjective probability setting and loss aversion.
Keywords: Hierarchical Production Planning, Goals, Heuristics, Biases.

RESUMEN:
Un experimento emula el entorno de planificación jerárquica de la producción, buscando determinar el efecto del establecimiento de metas sobre el desempeño de los programadores de producción, en lo referente a los costos relacionados con la elección del tamaño de lote. Se buscó detectar algunas heurísticas y sesgos que influyen en la toma de decisiones. La observación durante el experimento y el uso de métodos estadísticos paramétricos, permitió inferir que las metas impuestas a los programadores de producción consiguen aminorar la dispersión de los costos obtenidos, haciendo más predecibles los resultados, pero no influyen en el desempeño. Las heurísticas más utilizadas por los programadores de producción son las de representatividad y de disponibilidad. Los sesgos que con mayor frecuencia afectan las decisiones de los programadores de producción están asociados al establecimiento subjetivo de probabilidades y aversión a la pérdida.
Palabras clave: Planificación jerárquica de la producción, metas, heurísticas, sesgos.

1. Introduction

In the production environment, the hierarchical operational planning is named “hierarchical production planning (HPP)” (Bitran & Tirupati, 1993; Hax & Candea, 1984; Hax & meal, 1975). It is characterized by the use of the aggregate planning methodology, which is a process that defines the levels of capacity, production, subcontracting, inventory, shortage, and even price in a specific time frame. Its goal is to meet the demand and to maximize profits (Chopra & Meindl, 2008). Thus, the decision-making process is separated in time frames and a responsible person is assigned to each time frame. However, this simplification is affected by human factors, since individuals do not necessarily make strictly rational decisions. Depending on the context, they make biased judgments in an attempt to shorten the decision-making process (Robbins & Judge, 2009). In addition, according to the literature related to decision-making (Arrow, 2004; Goodwin & Wright, 2004; Kahneman, 2003; Robbins & Judge, 2009; Tversky & Kahneman, 1974, 1981), it can be inferred that individuals make rationally limited decisions and use heuristics.

Research studies related to the HPP model have been developed for many years (Bitran & Tirupati, 1993; Hax & Candea, 1984; Hax & meal, 1975; Schneeweiβ, 2004; Söhner & Schneeweiss, 1995; Thomas & McClain, 1993); the majority assumed that decision-making in the environment of production administration is strictly rational. There was no evidence of studies that considered the limited rationality, heuristics, and biases as part of the HPP models, or the human factors, such as (a) confidence and (b) motivation. There were no experimental quantitative studies comparing the results obtained through HPP models and the results that could be obtained from the reality. Altough, there are operations management studies that use a behavioral approach (Bendoly, Donohue, & Schultz, 2006; Davis & Kottemann, 1994; Gasser, Fischer, & Wäfler, 2011).

The planner-scheduler relationship was also analyzed in the HPP context. It was noted that the objectives related to the cost reduction of the production planner and scheduler might not be compatible due to the process of aggregation and disaggregation of information in both levels (Bitran, Haas, & Hax, 1982; Bitran & Tirupati, 1993; Hax & Meal, 1975).

The review of all these definitions led to state the purpose of this research: Study the behavior of production schedulers in the HPP context in order to identify heuristics and biases related to the frequent stress circumstances during the decision-making of the production lot size. This research is relevant because it pioneers in the study of production schedulers’ behavior in a HPP environment in Peru. It also has an advantage over the other studies in the field: the participants directly work in the productive environment and most of them work as a production planner or scheduler.

2. Literature review

Companys and Corominas (1998) noted, in regard to production, that it is the transformation of goods and/or services in other goods and/or services of greater utility. They also stated that the production process requires certain inputs, such as human labor, energy, materials, money and information, and, as part of a more general system, the interaction with other processes is needed: accounting, financial, commercial, etc. This approach is very similar to that proposed by D'Alessio (2012), who modeled the organization as an entity composed of five functional units: finance, operations, marketing, human resources and logistics. Productive resources (the "7Ms": labor, machines, materials, methods, environment, mentality and currency) to reach the objectives of quantity, quality and costs of the good and / or service that takes place within a set period. However, Hax and Candea (1984) proposed that production is the process of converting raw materials into finished products that can be obtained in appropriate quantities, in the agreed time, with the required quality, and at a reasonable cost if the process is effectively managed, this definition will be used in this research study.

Production planning can be simply defined as the determination of the capacity needs according to the estimates of the demand and the existing bottlenecks (Companys & Corominas, 1998). A more detailed view has been given by D'Alessio (2012), who proposed the division of production decisions into three dimensions consistent with the four managerial functions described by Robbins and Coulter (2010b): (a) planning Productive operations, related to forecasts, location and sizing of the plant, product planning and design, process planning and design, plant planning and design, and work planning and design; (B) the organization of productive operations, closely associated with the scheduling of operations and logistics; And (c) management and control of productive operations, which has to do with setting quality and cost targets. Among these three dimensions, the organization of productive operations and the direction and control of productive operations are those that are more related to the definitions of planning and production programming that this study seeks, but do not have the desired approach.

A broader perspective was provided by Anthony (cited in Bitran & Tirupati, 1993), who classified the productive environment decisions in three levels: (a) strategic decisions related to the policies, investments, design of facilities and logistic systems; (b) tactical decisions aimed to conceive a production plan through the aggregation of resources in a specific time frame; and (c) more detailed operational decisions that require disaggregating the information (Bitran & Tirupati, 1993) and involves facing the daily issues encountered in a productive environment. Thomas and McClain (1993) took these three decision levels as a basis and they defined production planning as the process of making tactical decisions and developing the production schedule as the process of making operational decisions. These concepts were used as a basis in this research.

The mathematical models designed to support the production planning process have been developed at a software level and they have two main approaches: (a) the monolithic approach, and (b) the hierarchical production planning (HPP) approach. With regard to the monolithic models, Hax and Meal (1975) indicated that there were no analytical methods or information processing methods available to optimize the whole production administration system. They also mentioned the advantages of the HPP model and, considering the risk of failing to achieve optimal solutions, they established a series of conditions to maintain the required optimality, although it could not be completely guaranteed. It was also noted that HPP models prevail over the monolithic models as a result of its logical harmony in the organizational charts and decision-making flows; hence, the HPP model was used as a basis for this study.

According to Nahmias (2009), aggregate planning has to do with the decision of how much staff to hire, and in the case of companies belonging to the productive sphere, is also related to the decisions of quantities and combinations of goods to produce. According to the author, aggregate production planning can also be called macro production planning.

Bitran and Tirupati (1993) introduced a more specific process approach for aggregate production based on two activities: (a) aggregation of items into families and the allocation of the capacity of resources for those families; and (b) the development of forecasts about the variability of the demand in the medium term and not in the short term, in order to focus on the higher costs and on the most important resources. The succession of aggregation and disaggregation processes in the operational and tactical production decision levels consists of an exchange of information typical of the HPP environment (Bitran et al., 1982; Bitran & Tirupati, 1993; Hax & Meal, 1975) that, as stated by Hax and Candea (1984), can generate stress among the parties because there are certain functional differences in these levels: (a) the degree of responsibility and interaction, (b) the scope of the decisions, (c) the level of detail required in the information, (d) the time frame necessary to materialize the consequences of the decisions, and (e) the degree of risk and uncertainty associated with each decision.

This research used the definition of production aggregate planning given by Bitran and Tirupati (1993), considering the possible stress situations in the tactical and operational levels of Hax and Candea (1984).

Studies have been carried out that contemplate the importance of the human factor in the decisions that are made in the productive environment, and although they are not many, they have been enough to recognize a new field in the theory of the administration of the operations: The management of operations under the behavioral approach.

Besides, Bendoly, Donohue and Schultz (2006) recognized that, in operations management with a behavioral approach, there is a gap in the operations techniques and in the rules followed by the individuals in practice. One of the reasons for this difference is the individuals who are influenced by several personal and social agents. The authors suggested that these agents should be considered when generating the assumptions in the operational models, which can be classified into three categories: (a) intentions, which reflect the model's precision with respect to the goals established for the decision makers ; (B) actions, referring to the rules or behaviors shown by the participants involved in the model; and (c) reactions, related to the responses shown by the participants to changes in parameters in the models.

Loch and Wu (2005) shared the same perspective, indicating that there is a gap between the theory of operations management and the way people in that environment solve their problems, making evident the need to incorporate the tools of the field of Organizational behavior (the psychology of individual decision-making and their respective deviations from the normative theory of decision-making, and the influence of group dynamics, emotions and culture on the interactions that take place between the actors Of all operational processes) to the mathematical rigor and the scientific methods characteristic of the classic models of the administration of the operations (both theoretical and experimental).

This study will try to describe some of the actions of the production programmers based on the reactions that have to the presence or absence of a production goal imposed by a production planner, in a situation characterized by the high confidence, and in the Cultural environment.

In relation to the production planning with a behavioral approach, Davis and Kottemann (1994) conducted two experiments and realized that the bias called "illusion of control" made individuals overestimate the capabilities of a computational tool called "what-if analysis" in comparison to other tool with a better performance. The authors were able to notice during the experiments the myopia of some participants (decisions based on immediate consequences).

Gasser, Fisher and Wäfler (2011) conducted a study of the production planners' behavior in their actual work environment from a naturalistic decision-making perspective. They found that all of them used their previous knowledge and experience related to production and the organization's business.

On the other hand, there were no studies including the coordination between the production planner and the scheduler in the HPP context that covered the potential stress in their objectives,

Since there are no studies that include the coordination between the production programmer and the production planner in the HPP context that contemplate the potential emergence of tensions between their objectives (neither abroad nor in Peru), it is necessary that this study addresses the theory of the behavior of the programmer to contribute to the development of the theory of administration of the operations under a behavioral approach, specifically in the production planning, since the deviations of the decisions regarding the optimal solutions of the rational models in that environment can have a strong impact on the financial performance of organizations.

Decisions are choices made between two or more alternatives (Robbins & Judge, 2009). However, while such a definition seems to be simple, the theories developed around decisions are rather vast and complex.

According to Hansson (1994), decision-making theories can be categorized as normative (dealing with how decisions should be rational) and descriptive (dealing with how decisions are actually made).

Simon (1986) proposed as the definition of rational decision the consistent choice of an alternative that maximizes utility within specific constraints, which is perhaps the most commonly used concept of rationality in the development of mathematical models until now.

In practice, optimality depends on the problem model that the decision maker uses (Arrow, 2004), which is consistent with the framing of decisions proposed by Tversky and Kahneman (1981) and Goodwin and Wright (2004, p. 357). It is also necessary to consider that people generally tend to simplify complex problems in order to understand them easily, a fact that does not allow them to process all the information they need to optimize, being satisfied with obtaining satisfactory and sufficient solutions (Simon, 1955; Kahneman, 2003), Ie acceptable or reasonable, even if they are not optimal (Robbins & Judge, 2009). This process of simplification is what is known as limited rationality, also called bounded rationality.

Decision-making can also be subject to heuristics and biases: (a) a heuristic is any strategy that simplifies the complexity of a problem to facilitate its understanding in order to obtain satisfactory and sufficient solutions, but not necessarily optimal. This definition is related to the bounded rationality term (Kahneman, 2003); and (b) the biases, according to Tversky and Kahneman (1974), are non-randomized errors that distance a rationality solution and can occur when using any heuristics.

There are three heuristics related to the estimation of probabilities and to the prediction of future values (Tversky & Kahneman, 1974): representativeness, availability, and adjustment and anchoring, each associated with their respective biases. Goodwin and Wright (2004) analyzed other additional biases and suggested a methodology of subjective probabilities in order to minimize the negative effect of introducing bias in the decision-making process. This study shares the positions of Goodwin and Wright (2004) and Tvesrky and Kahneman (1974). It is considered that the use of heuristics might affect the production schedulers' decisions. Zand (1972) stated that, in regard to confidence, the conscious regulation of dependency from another person may vary according to the characteristics of that other person, the activity, and the context. It is a crucial factor for an effective problem solving. A very similar concept of trust was proposed by Mayer, Davis and Schoorman (1995), who indicated that teamwork generally involves interdependence, so that people depend on others to achieve their own goals and organizational goals.

Finally, in regard to the goals, Locke and Latham (2006) noted that they work only as motivating agents, and their effect on individuals' performance depends on whether they already have the knowledge and the necessary skills to perform the activity. Gollwitzer (1990), using a cognitive approach, differentiated two processes for the goals: (a) set goals, which is related to the individuals setting their goals; and (b) search for goals associated with the behavior that individuals show when carrying out actions to achieve their set goal. Given the importance of confidence and goals in the decision-making process, these factors will be considered in this study.

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3. Methodology

Chapter 2 text According to Hernandez, Fernández and Baptista (2010), this is a descriptive research that uses a quantitative approach with an experimental design. Which is convenient because it will allow discovering if the establishment of a goal has influence in the behavior of the production programmer, and if the heuristics that he uses change by this fact, or they remain the same. In addition, the longitudinal trend design will record the consistency of decision-making and its relationships with other instrument parameters over time, such as costs, demand distribution, capacity constraints, experience, and horizon of planning, with which it will be possible to quantify the strength of these relations and their influence in the selection of the batch size of production and in the confidence level.

The study used an instrument to emulate the HPP environment considered as a laboratory experiment, since the subjects participated in their working environment using specific software for this purpose, with which the independent variables were controlled. The variables will be analyzed in two ways:

• Between the groups: the independent variable (the final inventory goal proposed as a suggestion by the production scheduler for the production scheduler) will be intentionally manipulated in two degrees (presence-absence), having a moderating variable (high confidence between Production scheduler and production scheduler) to determine its effect on production costs; and

• Within the group: it will be verified if there is a correlation between the five independent variables (related to the behavior of the programmer and the heuristics used when making their decisions) and the dependent variable (to produce more than the demand, which is a behavior associated to the forecast).

The planning frame lasted four quarters with five periods each, i.e., it took 20 decisions with respect to the production lot size. Likewise, the decisions were made throughout three independent planning frames: the first for training and familiarization with the interface, while the second and third for measuring the cost performance to define the winner of the incentive.

The population consisted of individuals who worked directly or indirectly in the production planning environment of Sociedad Minera Cerro Verde S.A.A—a Peruvian mining company—and its contractors (approximately 450 individuals as of September 30, 2013) in the department of Arequipa, Peru. The samples were selected for the two groups: 47 individuals for the experimental group, from which 34 were experienced in planning and scheduling, while the remaining 13 were not; and 46 individuals for the control group, from which 31 were experienced in planning and scheduling, while the remaining 15 were not. A result of each group was removed because it included statistically atypical values: the costs clearly did not tend to look for a minimal result. The groups consisted of 46 individuals in the experimental group and 45 in the control group.

The instrument was developed based on the HPP model with the anticipation process proposed by Schneeweiβ (2004) and Söhner and Schneeweiss (1995), simplified to a single product and adapted to include the cost of lost sales. Four computer programs were used to create the final interface of the experiment: Gusek version 0.2.15, a free optimization software (Bettoni, 2013); Microsoft Excel 2010 (Microsoft Corporation, 2013); Matlab R2012a (Mathworks, 2013); and z-Tree version 3.4.2 (University of Zurich-Department of Economics, 2013).

3.1. Research hypothesis

The goals have the potential to influence the individuals' performance and, therefore, the type and quality of the decisions made (Locke & Latham, 2006). This led to the formulation of the following hypothesis: (1.1) There is a difference between the costs obtained by the production schedulers who are instructed by the planner to achieve the inventory goal at the end of each quarter and those who are not instructed.

In addition, given the fact that the majority of decisions in the production administration environment are of human nature and that such decisions are often biased by the existence of heuristics (Goodwin & Wright, 2004; Tversky & Kahneman, 1974), this leads to the following hypotheses that we want to verify : (2.1) if the relationship between capacity and demand increases, the production scheduler will tend to choose a production lot bigger than the demand of the period; (2.2) if the relationship between the inventory and the demand decreases, the production scheduler will tend to choose a production lot bigger than the demand of the period; (2.3) if the production scheduler experienced a previous stock shortage, he will tend to choose a production lot bigger than the demand of the period; (2.4) the trend of the production scheduler to choose a production lot bigger than the demand of the period will decrease as time passes in the scenario (session), i.e., as the periods pass in such scenario; and (2.5) the distribution of the probabilities, related to the demand in the quarter that the production scheduler receives as information, influences his choice to produce a lot bigger than the demand of the period.

3.2. Independent and dependent variables, comparison between the groups

The only independent variable that was manipulated was the inventory goal at the end of each quarter. This was included in the planning frame and it was provided only to the experimental group. The dependent variable was the total cost incurred by the scheduler based on the decisions made. The costs of maintaining an inventory, the costs of lost sales, and preparation costs of the production line were included. This cost was compared with the deterministic minimum total cost of a HPP mathematical model. The deviation was measured with respect to the optimal response.

3.3. Moderating variable, comparison between the groups

The selected variable was the level of confidence at the beginning of the experiment. It was assumed that there was a close relationship of trust between the planner and the scheduler at the beginning of the experiment and it was induced through some instructions in the instrument.

3.4. Independent and dependent variables, comparison within the groups

The independent variables were the following: Relationship between capacity and demand, represented by the demand/capacity quotient; the relationship between the initial inventory of the period and the demand, represented by the initial inventory/demand quotient; the prior experience of stock shortage, represented by a dichotomous one-value variable if there is a stock shortage in a previous period and, if that is not the case, a zero value; the current period of decision, where each of the twenty periods within a scenario is an ordinal variable; and the distribution of the demand in the quarter, that is a nominal variable that can have three categories: high, average, or low. The dependent variable was the production, which must at least be equal to 120% of the current demand, since it is the least detectable.

The following assumptions were made: the participants will not have difficulties in following instructions and understanding the HPP model terminology; the distributions of the demand only have three categories: high, average, and low, randomly selected at the beginning of each quarter; everything that the scheduler requests to produce is what is produced; the lost sales are not recoverable in subsequent periods; the preparation costs of the production line, unit costs of inventory maintenance, and the unit costs of lost sales are constant throughout the experiment. The quantitative analysis was performed using parametric statistical techniques, using Microsoft Excel 2010 statistical package and the Real Statistics add-in version 2.7.1 for Microsoft Excel 2010. The results were corroborated with Minitab 16 statistical software. In addition, to check for differences among the cost dispersions obtained by the schedulers of the control group and the experimental group, the F-test and t-test were used to verify if there is a difference between the cost means obtained by the production schedulers of the control group and the experimental group, both at a 95% confidence level. The binary logistic regression was used to study the production scheduler's behavior in regard to produce a lot size bigger than or equal to 120% of the demand of the period. Hence, the following items were observed to verify the internal validity and confidentiality of the instrument: The initial equivalence of the groups with regard to their previous experience in planning activities and in their current field, through the random selection of the participants of each group and the equivalence during the experiment, avoiding the potential sources of invalidity mentioned by Hernández et al. (2010,

p. 130), such as history, instrumentation, and compensation. Furthermore, the intrinsically well-controlled design of the instrument enables to generalize the results and replicate the experiment in other populations of the production environment. The external validity and confidentiality can also be inferred.

4. Results

Costs decreased as participants progressed throughout the three sessions. The mean of the production cost in the experimental group was slightly lower than the mean of the control group. On the other hand, it was observed a decreasing trend of the standard deviations of the production costs obtained by the experimental group and the control group. This indicates that the dispersion of production costs decreased as the participants progressed throughout the sessions. In turn, the standard deviation of the experimental group was lower than the deviation of the control group in the three scenarios. A one-tailed F-test was performed for the respective variances. The results showed that the cost variance of the experimental group was lower than that the variance of control group in the three scenarios.

Table 1
One-tailed F-test for the cost variance difference

	Group					
	Control (*n*=45, *df*=44)		Experimental (*n*=46, *df*=45)			
Variable	*M*	s^2	*M*	s^2	*F*	*p*
Costs						
Scenario 1	7.45	13.13	6.84	6.84	1.92	.016
Scenario 2	5.54	10.08	4.53	3.19	3.16	.000*
Scenario 3	2.91	9.77	2.65	2.39	4.08	.000*

Note. Means are in thousands and variances in millions. *p<.001.

The difference between the cost variances was confirmed; therefore, the two-tailed t-test was used for two samples of unequal variances in order to test hypothesis 1.1. The hypothesis could not be rejected at a 95% confidence level. See Table 2.

Table 2
Two-tailed t-test for the cost mean difference

	Group								
	Control (n=45,df=44)		Experimental (n=46,df=45)						
Variable	*M*	s^2	*M*	s^2	s_p^2	*df*	*t*	*p*	*d*
Costs									
Scenario 1	7.45	13.13	6.84	6.84	9.95	89	0.93	.358	0.19
Scenario 2	5.54	10.08	4.53	3.19	6.59	89	1.86	.068	0.39
Scenario 3	2.91	9.77	2.65	2.39	6.04	89	0.49	.625	0.10

Note. Means are in thousands and variances in millions.

4.1. Hypotheses testing in regard to the scheduler's behavior

The results of the binary logistic regression analysis for the dependent variable were: the scheduler's decision to produce a lot bigger than or equal to 120% of the demand of the period showed that the factors (independent variables) with a significant influence in this analysis are: (a) the relationship between capacity and demand (OR = 5.26, $p < .001$), (b) the relationship between the initial inventory and demand (OR = 0.57, $p < .001$), (c) the stock shortage s2 in the three previous periods (OR = 1.95, $p < .001$), (d) the current decision period (OR = 0.94, $p < .001$), and (e) the probability distribution of the demand in the quarter (OR = 1.60, $p < .001$). The obtained values provide the necessary evidence to validate the hypotheses 2.1, 2.2, 2.3, 2.4 and 2.5.

5. Discussion and implications

Chapter 4 text It was determined that the planner sets an inventory goal at the end of each quarter, which implies that the production schedulers obtain a lower cost dispersion and it makes the decisions made more predictable. Furthermore, biases were detected throughout the experiment; these affected the production schedulers' decisions to define the production lot size. The biases were the following: The disregarded information related to the probabilities to predict an outcome; the misunderstanding of the randomness associated with the representativeness heuristic (Tversky & Kahneman, 1974); the allocation of high probabilities to recent family situations, which relates to availability heuristic; aversion to the loss, explained by the prospect theory and myopic loss aversion. In addition, this research study has contributed to the operations management field with a behavioral approach, since it was confirmed that the goals, heuristics, and biases have significant implications in the decision-making process in the context of HPP, although there is no evidence to affirm that the goals improve the production scheduler's performance because, apparently, the effect of the heuristics and biases is stronger when making decisions. In general, they have the potential to influence any area of the organizations. Experience seems to have an important role in the scheduler's decision-making process, since the heuristic of myopic loss aversion (Benartzi & Thales, 1999) was detected in the experiment, which confirms this assertion. There were also limitations, such as the main input, i.e., the decision made by the production scheduler in regard to the production quantity, which denotes the simplicity of the experiment. There were other aspects that the production scheduler had to face in order to make decisions, which should be considered in future research studies. Similarly, the obtained results depended on the unit costs of inventory maintenance, preparation of line, and sales losses since they were considered as fixed costs for the whole experiment. If modified, the results would be different.

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1. Researcher Professor in CENTRUM Catholica Graduate Business School, Pontificia Universidad Católica del Perú. PhD in Business Administration from Oklahoma State University. MBA from University of St. Thomas. Bachelor's degree in Administrative Science from Universidad de Lima, Peru. Contact e-mail: lariasb@pucp.pe

2. MBA from CENTRUM Catholica Graduate Business School, Pontificia Universidad Católica del Perú. Mechanical engineer from Pontificia Universidad Católica del Perú. Contact e-mail: williamf.agurto@pucp.pe

3. MBA from CENTRUM Catholica Graduate Business School, Pontificia Universidad Católica del Perú. Architect from Universidad Nacional De San Agustin, Peru. Contact e-mail: a20114044@pucp.pe

4. MBA from CENTRUM Catholica Graduate Business School, Pontificia Universidad Católica del Perú. Contact e-mail: rpantojar@pucp.pe

5. MBA from CENTRUM Catholica Graduate Business School, Pontificia Universidad Católica del Perú. Contact e-mail: apintot@pucp.pe

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