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Material supply planning and management model for social housing projects in a construction company

Modelo de planeación y gestión del suministro de materiales para proyectos de vivienda de interés social en una constructora

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Abstract

This article addresses the development of a model for the material supply planning and management in the construction industry, using System Dynamics, supported by AHP supplier selection methods, evaluation and monitoring with ABC classification, all mediated by Vensim data analysis software. The supply management in the construction industry is studied and analyzed based on a collaborative model between suppliers and builders, under the CPFR model and the integration of the Last Planner System, which contributes to optimize the use of resources that allow completing all social interest housing (VIS) construction projects. The model simulates the impact and performance produced in the collaborative system, compliance with planning and profitability in VIS projects, appropriate selection, and supplier evaluation and monitoring. Finally, this model allows those who make strategic decisions in VIS projects to identify the most critical variables, assess their contribution, and make the right decisions to eliminate waste due to waiting time.

Keywords: *Social interest housing (vis), construction company, supply, last planner system, supplier, provider, collaborative logistics*

Resumen

Este artículo recoge el desarrollo de un modelo para la planeación y gestión de materiales en la industria de la construcción, mediante el uso de Dinámica de sistemas, y el apoyo de metodologías de selección de proveedores AHP, evaluación y seguimiento por clasificación ABC, todo ello mediado por el software Vensim para el análisis de datos. La gestión del abastecimiento para el sector de la construcción se estudia y analiza a partir de un modelo colaborativo entre proveedores y constructores, bajo el modelo CPFR y la integración del sistema de control Last Planner System, que contribuye a optimizar el uso de los recursos permitiendo llevar a feliz término todos los proyectos de construcción de viviendas VIS. Se simula en el modelo, la afectación y el desempeño que produce en el sistema colaborativo, el cumplimiento de la planificación y la rentabilidad en los proyectos de vivienda de interés social VIS, una adecuada selección, evaluación y seguimiento de proveedores. Finalmente, el uso de este modelo permite a quienes toman las decisiones estratégicas en los proyectos VIS, identificar las variables más críticas, valorar su contribución y tomar las decisiones acertadas para eliminar los desperdicios por pérdida de tiempo.

Palabras clave: Vivienda de interés social (VIS), Constructora, Abastecimiento, *Last Planner System*, Proveedor, Proveedor, Logística Colaborativa

1. Introduction

The construction industry in Colombia accounts for 6.5% of the GDP, according to the 2017 report of the Colombian Chamber of Construction (Camacol); however, this high GDP percentage comes along with a low productivity in the global construction industry. For the construction company involved in the case study, the numbers for 2019 are the following: from 13852 projected units, 12329 were handed over within the schedules agreed with the customers, thus generating an 89% compliance.

A previous study of 2015 to 2018 established that the critical causes delaying the property delivery include the following.

- *Interruption of the flow of resources, 75%*
- *Change in the specifications due to modification of the standards, 12%*
- *Extemporaneous design changes, 10%*
- *Delays in paper work and permits to initiate the activities onsite, 3%*

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The supply chain of a construction company must deal with several work fronts simultaneously, which demands a synchronization level that is agile enough to allow fluidity and flexibility to guarantee the fulfilment of the goals agreed.

As the study shows, the lack of synchrony in the works supply chain implies a delay and standstill of the project, which may lead the customer to desist from buying the property due to delays and incurred losses.

This paper aims at providing a methodology that removes the mudas due to waiting time within construction companies, thus contributing to substantially improve the customer service, optimize the companies' resources and improve the productivity indicators, which in turn improve the decision making process of the administrative district in the planning of the materials procurement and handling operations. Therefore, the authors will rely on System Dynamics, with methodologies such as supplier selection and AHP evaluation (Analytic Hierarchy Process), and ABC supplier classification, thereby considering that each project receives certain supplies and obtains certain outcomes that significantly affect their environment in several ways.

Finally, and thanks to the simulation, the paper allows identifying the different tasks, links and operations that generate waiting time, its causes and consequences and how they can be solved to ensure the achievement of the agreed goals.

1.1 Lean Construction Philosophy

According to the Lean Construction Institute (LCI), "Lean Construction is a philosophy aimed at the production management in the construction industry, initially developed by Japanese car manufacturers. Its main objective is to reduce and remove all activities that do not add value to the project, while optimizing those that add value. It is focused mainly on creating specific tools applied to project execution processes and a good production system that minimizes waste" (Consuegra, 2018).

The model is based on the philosophy developed by Toyota at the end of the 20th Century, which consists in eliminating from the different phases of the processes all the tasks that do not add value and generate costs (Leal Vegas, 2020). For its implementation, execution and control, the LCI establishes eight waste categories: Unused Talent, Inventory, Motion, Waiting, Transportation, Defects, Overproduction and Extra-processing. The identification, measurement and control of each one of these factors allows establishing continuous improvement plans aimed at perfecting the customer service.

The three main Lean Construction processes that allow increasing the efficiency are:

- *Transformation: minimizes or eliminates the flows, understood as the path of materials until they are installed onsite.*
- *Planning: defines criteria and strategies to achieve the project objectives.*
- *Control: ensures that each task will be carried out in the planned sequence (Leal Vargas, 2020).*

For a better implementation and control of this model, the LCI recommends using the following tools:

1.2 Last Planner® System

The Last Planner System was first developed in the 1980's, was strengthened and regularized in the 1990's following the consulting work of Glenn Ballard and Gregory Howell in the industrial construction sector (Pasquire, 2021).

The Last Planner System is an efficient project planning methodology that modifies the scheduling and control process by reducing the uncertainty and variability through the implementation of the Lean Construction philosophy (Fernando Cerveró and María Jesús Lledó, n.d.).

This planning system seeks efficiency and it is based on a "pull" system, which allows a production control that is different from the traditional one. Planning involves weekly work plans and requires the commitment of the project team with planning and control (Sipper and Bulfin, 2010).

The Last Planner System has two important distinctive features. First, planning should be a collaborative process carried out through a negotiation between all the stakeholders participating in the process and guaranteeing its execution. This enables the availability of all the planning data of the tasks.

The other characteristic of the Last Planner System is that it is done inversely in the frame of the pull session, starting with the big picture of the completed work, and setting forth what is needed to arrive at the end point. Consequently, it is possible to completely visualize the critical path of the project in a way that is clearer and more realistic (Fernando Cerveró and María Jesús Lledó, n.d.).

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The objective is that all tasks contemplated in each phase are executed, thereby preventing delays in the housing production.

- *Master Project Plan*

According to the work of (Alpízar, 2017), it is the first general planning of the housing construction project, which establishes the tasks to be done, their order and execution time, according to the data flow; a budget is also defined to achieve the objectives.

- *Intermediate Planning (Lookahead)*

It is the second planning level, which consists in analyzing each task according to the master project plan. Alpízar (2017) establishes that the tasks can be developed according to the execution time and dates and the work flow sequence. This work plan covers a period of 4-12 weeks, since the tasks are executed in the short-term.

In order to define these tasks a pull session is needed with the team formed by the representatives and/or managers of the project site. The objective of this meeting is getting to understand the tasks and thus generate value for each phase. Therefore, they make the planning of the tasks easier, given their knowledge and integration with other collaborators of the construction company and contractors to establish the logistics support tasks, thus guaranteeing the availability of human resource, machinery, materials and/or tools. According to Alpízar (2017), the main definitions of the pull session are:

- *Duration definition*
- *Task definition*
- *Identification of constraints*

Following the above concerning the pull session, (Alpízar, 2017) indicates that constraints should be prepared, where actions are taken to minimize and/or remove the constraints to guarantee the development of the tasks. It should be clear that, if the constraint is removed, the affected task is now ready to be accomplished, which is known as preparation and involves the following steps:

- *Verify the response times.*
- *Pull: requirements to suppliers concerning the specifications of materials, machinery and/or tools required for each one of the project's operational construction processes.*
- *Accelerate: if the response has not been generated and the response times are too long.*

1.3 Tasks Made Ready (TMR)

According to Alpízar, after removing the constraints on the proposed tasks, the latter must pass onto a list of activities that are ready for their execution, which is called "tasks made ready". In this front, the tasks are contextualized from "should" to "can" be developed on the Lookahead Planning. It should be kept in mind that tasks can present delays, but they should not affect the critical path, or there may also be advances in the general schedule.

1.4 Weekly schedule

In the last level, the weekly schedule is a little more detailed concerning the task execution, and it is developed by project coordinators and technical interns. Tasks are assigned according to the tasks made ready and the flow of processes above the work schedule, but it also considers the related criteria in Figure 1.

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Definition	***Definition***	***Sequence***
Tasks are completely defined, as well as the materials to be used and other resources. Additionally, it should be considered that, if it is scheduled, the weekly plan can be achieved.	*Tasks are made ready because materials are available and previous related tasks are already executed.*	*The task is within the sequence of the processes above the activities already executed.*
Size		***Feedback or Learning***
There is the capacity to fully perform the task.		*If the task was not completed that week, it establishes the causes to be able to end it.*

Source: Self-prepared

Figure 1. *Task prioritization criteria*

The information of the tasks is filled in the form before initiating the week to set the planning. Tracking is performed at the end of the week in relation to execution dates, actual compliance, whether the task was ended or not, and the causes for non-compliance, which helps measuring the performance of the Last Planner System.

1.4 Weekly Planning Meeting

The planning of the activities for the week is defined in weekly meetings, according to the provisions in the Last Planner System methodology. The attendance and participation of the stakeholders is essential to guarantee the control and execution of the tasks. The objectives of the meetings are:

- *Analyze the indicators concerning the progress made, especially PAC.*
- *Analyze non-compliance causes and constraints that have not been removed.*
- *Establish improvement actions to mitigate and/or remove non-compliance causes.*
- *Establish the next activities to be developed according to the Lookahead Planning and the tasks made ready.*
- *Analyze the objectives on the achieved performance.*

2. Research methodology

The purpose of the designed methodology is to define the integral model for planning and material supply management for VIS projects, whose main objective is to ensure the tasks' execution and the proper flow of resources in the operation. This is achieved by integrating the supplier management through a multi-criteria selection model that applies the selection matrix of the AHP method, evaluation by ABC classification, collaborative logistics and alliances connected with planning management through a Lean Construction methodology using the Last Planner System. It should be considered that the integration of the three phases are interrelated, not in a cyclic way, but rather based on the needs of the master project plan (see Figure 2).

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Integral model for planning and material supply management for social interest housing (VIS) projects							
Phase 1. Supplier Selection	*a. Define expert panel and selection criteria*	*b. Prepare pairwise comparison matrix*	*c. Apply AHP method*	*d. Identify valuation of alternatives according to scale*	*e. Define decision matrix*	*f. Establish decision matrix for alternative comparison*	*g. Select alternative (Supplier)*
	DEFINE SUPPLIER						
Phase 2. Supplier Evaluation and Tracking			*Display ABC supplier classification*		*Establish supplier evaluation and tracking scale according to ABC classification*		
		ESTABLISH SUPPLIERS TO BE DEVELOPED					
Phase 3. Collaborative supply chain and strategic alliances with suppliers			*a. Focus on compliance with delivery time and quality*	*b. Make change towards collaboration*	*c. Define activities of collaborative system and alliances by CPFR*	*d. Definition of measurements of processes and results*	*e. Start-End agreements*
			f. Joint business plan	*g. Create materials requirement plan*	*h. Identify/ Solve / Collaborate exceptions to the materials requirement plan*	*i. Order generation*	*j. IMPROVED MATERIAL DELIVERY TIMES*
Phase 4. Last Planner System		*a. Make pull planning of tasks*	*b. Establish monthly planning (intermediate)*	*c. Analyze constraints*	*d. Make weekly planning*	*e. Execute weekly control and planning meetings*	*REDUCED DAYS OF DELAY*
			IMPROVEMENT OF SOCIAL INTEREST HOUSING DELIVERY TIMES				

Source: Self-prepared

Figure 2. *Integral model for planning and material supply management for general VIS projects*

Phase 1. Supplier Selection

This phase develops the rating method, formulated through the Analytic Hierarchy Process (AHP), which includes the following stages:

a) ***Definition of expert panel and selection criteria.*** *A group of company experts is formed with the aim of analyzing and defining criteria for the supplier selection. For the case study in the construction company, the panel established the following criteria for selecting the suppliers of the company: delivery times, process, acknowledgement in the market, solvency, environment, quality of the material, location and administrative districts of the supplier.*

b) ***Preparing a pairwise comparison matrix.*** *After defining the evaluated criteria, a comparison matrix applying the parameters established in the Saaty scale, is prepared (see Table 1).*

Table 1. *Pairwise comparison matrix*

	Pairwise Comparison Matrix						
	Solvency	***Market Acknowledgement***	***Quality***	***Price***	***Location and Administrative District***	***Environment***	***Delivery Time***
Solvency	*1*	*3*	*1/5*	*1/5*	*2*	*1/5*	*1/5*
Market Acknowledgement	*1/3*	*1*	*1/7*	*1/7*	*1/3*	*1/5*	*1/5*
Quality	*5*	*7*	*1*	*1*	*3*	*2*	*2*
Price	*3*	*3*	*1*	*1*	*3*	*3*	*1/3*
Location and Administrative District	*1/2*	*3*	*1/3*	*1/3*	*1*	*1/3*	*1/5*
Environment	*5*	*5*	*1/2*	*1/3*	*3*	*1*	*1/7*
Delivery Time	*5*	*5*	*1/5*	*3*	*5*	*7*	*1*

Source: Self-prepared

c) Application of AHP method. *Weighted criteria are established by mathematical calculations. The result is the priority vector and the consistency ratio (CR%); the case study obtains a value of 7.12%. According to the theory, if the CR% is below 10%, it can be inferred that the matrix is reliable and consistent. This indicates that the most representative criterion is delivery time and the least important is market acknowledgement (see Figure 3).*

Delivery Time	*01*	*31.69%*
Quality of Materials	*02*	*25.36%*
Price	*03*	*17.12%*
Environment	*04*	*12.15%*
Solvency	*05*	*5.50%*
Location and Administrative District	*06*	*5.39%*
Market Acknowledgement	*07*	*2.79%*

Source: Self-prepared

Figure 3. *Weighted scores for supplier selection criteria*

d) Identify valuation of alternatives according to scale. *Sets the scale for each criterion and by group of experts for the decision-making process (see Table 2).*

Table 2. *Criteria rating scale*

Scale	***Solvency***	***Market Acknowledgement***	***Quality***	***Delivery Time***	***Location and Administrative District***	***Environment***
1	*Solvency ratio below 0.50*	*Company consolidation in the market less than 6 months*	*Below 93%*	*Much higher than the market standard*	*The supplier location is in a different city than the project, with only one office and does not have administrative transportation*	*The material has a very contaminant impact on the environment*
2	*Solvency ratio below 1.0*	*Company consolidation in the market between 6 and 12 months*	*Between 93% and 94%*	*Higher than the market standard*	*The supplier location is in the project city and has a weak administrative support*	*The material has a contaminant impact on the environment*
3	*Solvency ratio below 1.50*	*Company consolidation in the market between 1 and 3 years*	*Between 95% and 96%*	*Market standard*	*The supplier location has between 2 and 3 offices in the project city and has a standard administrative support*	*The material has no impact on the environment*
4	*Solvency ratio 1.50*	*Company consolidation in the market between 3 and 6 years*	*Between 97% and 98%*	*Lower than the market standard*	*The supplier location has between 4 and 6 offices in the project city and has a good administrative support*	*The material contributes to mitigate the environmental contamination with certification*
5	*Solvency ratio higher than 1.50*	*Company consolidation in the market over 7 years*	*Over 99%*	*Much lower than the market standard*	*The supplier location has national coverage and a very good administrative support*	*Has innovation materials, researches, and environment certification seals*

Source: Self-prepared with information from the construction company

e) Definition of the decision matrix. *After consolidating the data regarding the alternatives of evaluated suppliers, a decision matrix is generated to define the most adequate group of suppliers to make strategic procurements of materials.*

f) *Establishing the weighted standardized decision matrix.* *In order to build the weighted standardized decision matrix, the priority vector resulting from multiplying the value of each criterion by the weight assigned by the expert panel, should be calculated.*

g) *Selecting alternative (Supplier).* *Once the final scores of the evaluated suppliers are obtained, they are ordered according to the scale established by the expert panel, with the aim of choosing the best options to purchase the supplies needed for the construction company projects (see Table 3).*

Table 3. *Supplier selection scale*

SCALE	SUPPLIER SELECTION
1	Does not comply
2	Unsatisfactory
3	Fair
4	Good
5	Excellent

Source: Self-prepared

Phase 2. Supplier Evaluation and Tracking

This phase develops an evaluation and tracking scheme based on the ABC classification of suppliers, with the aim of defining the participation and weight for rating the supplier performance. Therefore, the following stages are established:

a) *ABC supplier classification.* *Here, the supplier classification is grouped into three categories, considering their percentage (%) on the total purchase volume of the past year. In order to establish each ABC classification category, the proper intervals should be organized from the highest to the lowest purchase value. Column A shows the suppliers covering 80% of the total purchase value, column B, 15% of the total purchase value, and column C, 5% of the total purchase value.*

b) *Supplier evaluation and tracking scale according to ABC classification.* *A 3x3 pairwise comparison matrix is developed with the Analytic Hierarchy Method (AHP), with the aim of analyzing the impact of shortage on the project activities and the relationship between purchase value criteria, conflict level, and material procurement complexity (see Figure 4).*

CALCULATION OF CONSISTENCY AND OWN VECTOR, WEIGHT, OF SUPPLIER EVALUATION AND TRACKING CRITERIA					
	Pairwise Comparison Matrix				
	Purchase Value	Conflict Level	Material Procurement Complexity	Criteria Weight	
Purchase Value	1	1/2	1	Purchase Value	26%
Conflict Level	2	1	1	Conflict Level	41%
Material Procurement Complexity	1	1	1	Material Procurement Complexity	33%

Source: Self-prepared with rating of company experts

Figure 4. *3x3 pairwise comparison matrix for defining I,J criteria for the supplier evaluation phase by ABC classification*

c) *Define scale.* *A rating scale from 1 to 5 is currently defined, with the following performance levels for evaluating the suppliers, using the ABC methodology (see Table 4).*

	CRITERIA					
SCALE	Business Relationship	Conflict Level	Material Procurement Complexity	A	B	c
	Indicates the level of compliance with contractual agreements	Indicates the amount of novelties presented that affect the materials supply	Indicates the level of difficulty to obtain the product on the market	Supplier performance measurement representing 80% of the purchases	Supplier performance measurement representing 15% of the purchases	Supplier performance measurement representing 5% of the purchases
1	Total breach of contract	Very high conflict level	Very high complexity	Very low performance	Very low performance	Very low performance
2	Considerable breach of contract	High conflict level	High complexity	Low performance	Low performance	Low performance
3	Partial breach of contract	Medium conflict level	Medium complexity	Fair performance	Fair performance	Fair performance
4	Moderate breach of contract	Low conflict level	Low complexity	Good performance	Good performance	Good performance
5	Total compliance with the contract	No conflict level	Slight complexity	Excellent performance	Excellent performance	Excellent performance

Source: Self-prepared

Table 4. *Criteria and scale for supplier evaluation and tracking*

The scores are obtained from the operations with the previously indicated formulas, which consider a scale of results from 0 to 25 points, and the performance is measured according to the following ranges:

**21 to 25 points Excellent*
**16 to 20 points Good*
**11 to 15 points Fair*
**6 to 10 points Unsatisfactory*
**0 to 5 points Does not comply*

The evaluations are made on a monthly basis and if the supplier does not obtain a score higher than 16 points, it is replaced by another one with a rating higher or equal than 4, which indicates that it is good in the supplier selection phase.

It is very important to map the tasks that make up a master project plan and the typical activities of a social interest housing (VIS) project, in order to establish the influence of the group of materials on each task that is part of the production process in those projects.

Phase 3. Collaborative Logistics and Strategic Alliances with Suppliers

The tool of Collaborative Planning, Forecasting and Replenishment (CPFR) is based on the fact that companies relying on a supply network generate win-win relationships, where there is no competition between isolated supply systems. Rather, the core idea is to collaborate by linking all supply systems that generate collaborative systems and alliances between the supplier and the company. This generates greater profits for the company, strengthens the development of suppliers, and aims at fulfilling the customers' requirements of adequate quality and delivery time.

The tool diagram includes the following development phases:

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a) ***Focus on compliance with delivery time and quality.*** *Currently, the compliance indicator for housing delivery is around 89% and this means that the company fails to receive 96000 million Colombian pesos annually, due to the interruptions in the flow of materials towards the projects.*
b) ***Definition of the total performance rating scale for the collaborative system and alliance.*** *The result is generated by the supplier selection (35%), evaluation of the supplier performance (35%), technology investment factor (17%), collaborative system development factor (13%), which are measured in a scale from 1 to 5, where 1 does not comply and 5 is an excellent performance of the collaborative system and alliance.*
c) ***Change towards collaboration.*** *In this stage, the necessary strategies and resources are developed to succeed in replacing the traditional scheme of business relationships for a new one that changes the viewpoint and interrelations between suppliers, company and customers.*
d) ***Definition of the activities of the collaborative system and alliance by CPFR.*** *Training provision for an expert group in all aspects related to legal and operational regulations to achieve the best performance of the suppliers. Additionally, a knowledge management group is created, in charge of tracking and consolidating the lessons learned, good practices, feedback, improvements and innovations that strengthen the collaborative system and alliances, according to Figure 5.*

CPFR Model – Collaborative Planning, Forecasting and Replenishment			
1. Definition of the measurement of processes and results			*4. Create demand forecasts*
	2. Start-End Agreements	*5. Identify / Solve / Collaborate exceptions to the demand forecast*	
3. Joint business plan			*6. Order generation*

Adapted from (Chávez and Torres, 2012)

Figure 5. *CPFR Model*

a. ***Definition of the measurement of processes and results.*** *This stage of the model displays the compliance goals regarding delivery time, quality of supplies and prices, as well as the impact that an unfavorable performance of these items may generate on the project development. The supplier-company partnership should ensure that the jointly-set objectives are complied with, because the raison d'être of the collaborative system and alliances is to achieve the following objectives:*

- *Reduce the lead-time of deliveries and guarantee the quality of the supplies.*
- *Increase the percentage (%) of the compliance indicator for on-time deliveries in VIS projects.*
- *Reduce the current average of days of delay.*
- *Succeed in positioning the compliance of the master project plan above 90%.*
- *Achieve better unit prices in the procurement of supplies.*
- *Mitigate the conflict levels that may affect the fulfillment of the objectives.*
- *Ensure a prompt procurement of supplies and avoid delays that may aggravate the non-compliance with the master project plan.*

Phase 4. Last Planner System

This methodology is combined with a technological tool that allows planning, coordinating and controlling the execution of the VIS construction projects by integrating the traditional Gantt interface with a complement that enables to manage the data record and the visual management. This allows establishing the progress percentage of each task and the factors interrupting them, as well as the gap between the base line and the real executed percentage of the works schedule, according with Figure 6.

Project scheduling	*Establishes the milestones to be executed in the housing construction project*	
		SHOULD
Phase scheduling	*Defines each task according to project phases*	
	Can be done	
Intermediate planning	*Identifies constraints and commitments for the tasks*	
	Will be done	
Weekly work plan	*Identifies constraints and commitments for the tasks*	

Source: Self-prepared

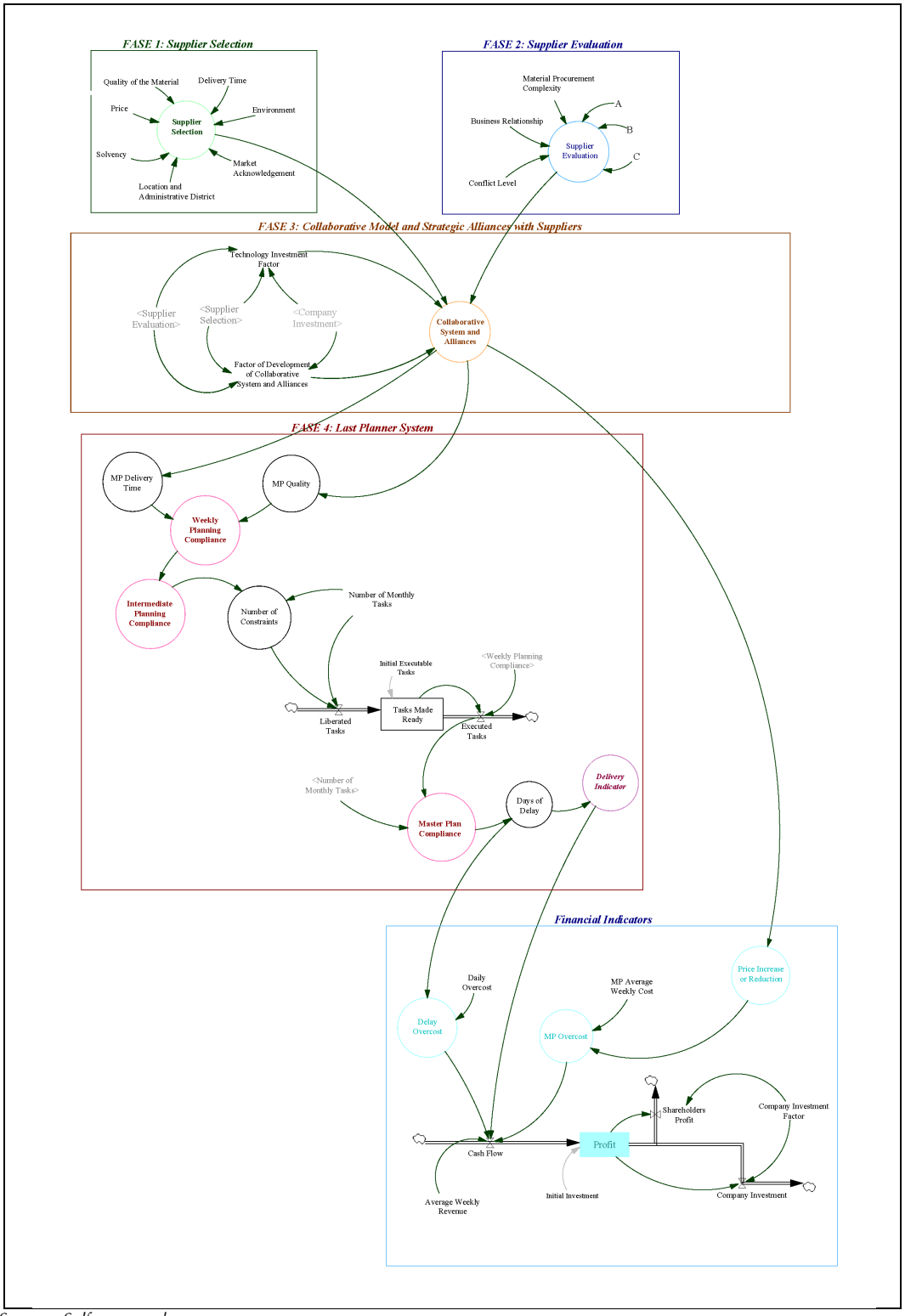
Figure 6. *Planning sequences*

- ***Pull planning of activities****. A pull planning is presented, where the first phase is consolidated with the milestones that define how the project tasks should be executed in the next 22 months. The purpose of the meetings is to analyze the information of the master schedule in the Gantt chart, which is located in the dashboard, where tasks with their corresponding fact sheet are located. Next, the list of tasks with the execution path by weeks is gradually created, in order to track and control the master project plan to find possible gaps between the scheduled progress and the actual one.*
- ***Monthly Planning (Intermediate).*** *The monthly plan, usually known as intermediate planning, contains all the tasks that should be developed during the month, according to each phase of the master project plan. To define these tasks, a monthly planning meeting is held with the Project Manager, the technical interns and the administrative group, with whom a task dashboard is established according to the specified sequence. These meetings are necessary for coordinating the material and equipment supply process with the suppliers, human resource, specifications of contractors and required information.*
- ***Analysis of constraints.*** *The factors preventing the task execution during the scheduled weeks can be overcome with adequate tracking and control; therefore, a dashboard is made to identify these constraints. It should be kept in mind that, in order to decide the removal or mitigation of constraints, Phase 1 "Select supplier by multi-criterion method of Analytic Hierarchy Process (AHP)" must be integrated with Phase 2 "Establish collaborative model and strategic alliances with suppliers through CPFR (Collaborative Planning, Forecasting and Replenishment)", with the aim of ensuring the availability of resources in the estimated time and quantities, thus improving the productivity of the operations management system of the construction company. Accordingly, the tasks can be liberated to allow their execution according to the flow of the Master Project Plan.*
- ***Weekly Planning****. This planning is built with already liberated or possibly liberated activities. Therefore, it relies on the technological tool through a dashboard with a Gantt chart, where tasks are broken down according to the master project plan and previously held meetings. The activities liberated from the constraints will be referred to as tasks made ready, thus forming an inventory of the flow to be executed on their set dates.*
- ***Weekly control and planning meetings.*** *Prepare tracking and control of the executed activities and decide the planning of the next activities based on the inventory of tasks made ready, according to the measurements in the dashboard of indicators and the progress of each Gantt chart generated with the Power BI technological tool. Considering the analyses produced by Power BI, the pending tasks are reviewed and distributed in the times set according to the workflow sequence and the constraints removal. The meetings should be held on a weekly basis during the project execution and a great commitment with the attendance of all stakeholders should be generated, with the aim of improving the productivity and getting the task done on schedule.*

3. Resentation of the product

The model is built by means of System Dynamics and it is composed of four interconnected phases, which generate the proper framework to define the causal relationships between the system components. The model is recursive, since the optimal performance of each phase depends on obtaining the maximum efficiency of the initial values and variables established for each component. Therefore, the greater the efficiency of the phases, the greater the overall efficiency of the model, as well as the productivity increase and the company profits. The logic of the software used for preparing the model allows simulating, analyzing and enhancing the obtained results. Consequently,

it is possible to recreate real execution situations of housing projects, thus adopting the best course of action in the face of adverse results. This serves to avoid losses by delayed deliveries and overcosts associated to greater investment of resources, which affect the earnings for duly complying with the delivery dates agreed with the customers (see Figure 7). The scheduled phases of the model are detailed below.



Source: Self-prepared

***Figure 7**. Integral model for planning and material supply management for VIS projects*

The following premises are considered for the formulation of the model:

- *The weights assigned to the criteria are defined by an expert panel, which seeks to optimize the supplier selection, considering the supplier rating scale from 1 to 5 applied by the construction company.*
- *The criteria affecting the supplier evaluation are the following: conflict level, business relationship, material procurement complexity, A, B, C weighting derived from ABC classification by annual purchase volume. The scores for the previously mentioned variables applies a scale from 1 to 5.*
- *Phase 1 "Supplier Selection" and Phase 2 "Supplier Evaluation" are connected with the variable of "Collaborative System and Alliances". It should be highlighted that the performance of the aforementioned system depends on an optimal management of the supplier selection and a proper tracking and evaluation of the suppliers. On the other hand, the Collaborative System and Alliances receives a 0.7% reinvestment from the profits generated by the company, calculated in million Colombian pesos (COP). This company investment is allocated as follows: 56.7% to the technology investment factor and 43.3% to the development factor of collaborative system and alliances.*
- *The calculation of the value that the Collaborative System and Alliance rating adopts in a given simulation, is based on the values of the own variables of the technology investment factor, the development factor of collaborative system and alliances, and the supplier evaluation.*
- *In the model, the delivery time is a function of the path of the days of delay established in each category, where the longer the delivery time, the lower the score. It should be noted that a lower score in the supplier selection tool has a negative impact on the performance of the Collaborative System and Alliances.*
- *The score for raw material quality is another input that considerably affects the performance of the Collaborative System and Alliances.*
- *The calculation of the Weekly Planning compliance is based on the tasks carried out and considers the fulfillment percentage (%) of delivery times and quality of the materials.*
- *The compliance with the intermediate planning takes into account the fulfillment percentage (%) of the execution of the master project plan by means of a scale proposed by the expert panel, based on the efficiency percentage (%) obtained from the weekly planning.*
- *The fulfillment percentage (%) of the master plan is calculated as the ratio of the number of executed tasks to the planned monthly tasks (100%).*
- *The indicator for days of delay is calculated based on the fulfillment percentage (%) of the master project plan. Therefore, the lower the fulfillment percentage of the master project plan, the higher the number of delay days.*

The delivery indicator is calculated by dividing the estimated housing delivery percentage by the percentage of actual current delivery, according to the times established by the levels of service agreed with the customers and stakeholders involved in the projects.

4. Analysis of results

The following results were obtained when running three scenarios with the model proposed by the Vensim software, with values of 3 = fair, 4 = good and 5 = excellent, according to the scale defined in Table 3 (see Table 5).

Table 5. *Results of simulation scenarios in Vensim*

RESULTS OF SIMULATION SCENARIOS			
Criteria	***Scenario 1***	***Scenario 2***	***Scenario 3***
Market Acknowledgement	*3*	*4*	*5*
Location and Administrative District	*3*	*4*	*5*
Solvency	*3*	*4*	*5*
Environment	*3*	*4*	*5*
Price	*3*	*4*	*5*
Quality	*3*	*4*	*5*
Delivery Time	*3*	*4*	*5*
Supplier Selection Score	*3*	*4*	*5*
Criteria	***Scenario 1***	***Scenario 2***	***Scenario 3***
Business Relationship	*3*	*4*	*5*
Conflict Level	*3*	*4*	*5*
Material Procurement Complexity	*3*	*4*	*5*
A	*3*	*4*	*5*
B	*3*	*4*	*5*
C	*3*	*4*	*5*
Supplier Evaluation Rating	*9*	*16*	*25*
Variables	***Scenario 1***	***Scenario 2***	***Scenario 3***
Average Technology Investment Factor (million COP)	*257*	*155*	*168*
Total Technology Investment Factor (78 weeks) (million COP)	*17,746*	*12,234*	*13,238*
Average Weekly Development Factor of Collaborative System and Alliances (million COP)	*144*	*128*	*138*
Total Development Factor of Collaborative System and Alliances (million COP)	*10,715*	*10,150*	*10,917*
Average Weekly Score Collaborative System and Alliances	*3*	*4.3*	*5*
Average Weekly MP Delivery Time (days)	*17*	*12*	*9*
Average Weekly MP Quality (%)	*74*	*84*	*95*
Average Weekly Planning Compliance	*72*	*78*	*95*
Average Weekly Intermediate Planning Compliance	*82*	*86*	*97*
Number of Monthly Tasks	*160*	*160*	*160*
Average Weekly Number of Constraints	*28*	*19*	*5*
Average Weekly Master Plan Compliance (%)	*82*	*86*	*96*
Average Weekly Days of Delay	*24*	*19*	*4*
Average Weekly Delivery Indicator (%)	*73*	*83*	*97*
Average Weekly Delay Overcost (million COP)	*706*	*546*	*325*
Average Weekly Raw Material Overcost (million COP)	*411*	*-205.25*	*-821*
Average Weekly Cash Flow (million COP)	*36,694*	*39,155*	*42,385*
Average Weekly Profit (million COP)	*40,899*	*39,017*	*42219.82785*
Average Weekly Company Investment (million COP)	*256.3400967*	*273.1203544*	*295.5388481*
Average Weekly Profit (million COP)	*36370.43038*	*38743.56329*	*41924.30506*

Source: Self-prepared

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In scenario No. 1, the variables of the first two phases of the model present the following values corresponding to the current situation of the company. The supplier selection criteria take the value of 3 = fair, the set of criteria of the supplier evaluation adopt a value of 3 = fair, thereby obtaining an overall evaluation rating of 9 points, which is equal to fair. Consequently, an overall performance of the collaborative system and alliances of 3 = fair is generated, and the fulfillment of the master plan scores 82% with 24 days of delay. Finally, a 36370 million COP annual profit is produced.

Regarding scenario No. 2, the supplier selection criteria are rated with 4 = good and, in the supplier evaluation, the set of criteria adopt a score of 4 = good, thereby obtaining an overall evaluation rating of 16 points, which is equal to good. The previous results produce a 4.3 rating of the collaborative system and alliances, thus achieving an overall good performance for the company. Therefore, the average fulfillment of the master plan reaches 86% with 19 days of delay. Finally, a 38743.6 million COP annual profit is produced.

In scenario No. 3, the supplier selection criteria take the value of 5 = excellent, the set of criteria of the supplier evaluation is also rated with 5 = excellent, thereby obtaining an overall evaluation rating of 25 points, which is equal to excellent. Consequently, the overall performance of the collaborative system and alliances is rated 5 = excellent, which gives the best results for the company, because the average fulfillment of the master project plan is 96% with only 4 days of delay. Finally, a 41924.3 million COP annual profit is produced.

When comparing scenario No. 1 corresponding to the current situation versus scenario No. 3 or optimal situation, there is a 32% improvement in the compliance with the weekly planning, going from 72% to 95%. Consequently, the fulfillment of the weekly planning increases by 17%. When adopting the collaborative logistics and alliances with suppliers regarding their selection and evaluation, the constraints are reduced by 81%, thus causing an impact of 96% on the master plan compliance and a 17% improvement with regard to the current fulfillment rate.

For this reason, when analyzing the indicator for days of delay, a reduction of 83% is evidenced, and the delivery indicator for VIS housing improves by 32%, thus generating a 54% reduction of the overcost due to delays. It should be highlighted that this reduction is equivalent to 381 million COP and increases the cash flow by 16%, which represents an increase of 5691 million COP. The latter generates a profit over 3% with an increase of 1321 million COP; thus generating a 15% profit growth, which means 41924.3 million COP annual according to the results obtained in the model.

5. Conclusions

The proposed model integrates planning management, collaborative logistics and alliances, and supply assurance with supplier partnerships.

The limitation of this model is that it only applies for social interest housing (VIS), because different variables are involved in high-income or institutional projects, which were not envisaged in the construction of the model.

It is important to add that the model is a scenario simulation tool that allows reducing the gaps between scheduled work progress vs real progress and delivery times by optimizing the supplier selection and evaluation to mitigate shortage. This ensures the uninterrupted flow of supplies towards the work site in the adequate times and quality, thereby searching the best negotiations with supplier partnerships. However, it does not guarantee that a 100% efficiency will actually be achieved in productivity, operation and overcost reduction.

Considering the above, it is important to bear in mind that the success of the total execution of the master project plan also depends on continuous improvement. This means dealing with the lessons learned during the project execution to reduce the final delivery time, increase the cash flow and the profits to ensure the sustainability and growth of the company

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