Beyond the Concept of Lean Construction: A Prescriptive Rationalizing Model for Pipe Systems Manufacturing in a Petro-chemical Plant.

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Abstract. The economic importance of the Construction Industry (CI) is overshadowed not only by several difficulties but by the lack of innovation in this sector. Notwithstanding that construction and manufactures are part of Industrial Activity; CI does not share the systemic progress of the latter. This research confirms the possibility in CI to increase its efficiency. The main purpose is to develop an operational system that facilitates the rational management of the industrial construction (IC) value chain. The lead researcher designed a software-interface link that allows the transformation of a traditional constructive process into a rational and systematic industrial one. As a result, all areas involved in the construction chain are harmoniously integrated; the whole decision-making process is facilitated by determining what is to be designed, purchased, procured and manufactured and its usefulness for previous and subsequent activities. Both project management and construction benefit from operational costs and inventory reduction as well as opportunity-cost mitigation. The software facilitates project simulation by ordering the isometric drawings of a piping system in an industrial project; timely information allows for more rational decisions about design, purchases, manufacturing, procurement and forecasting overall efficiency in the project. The construction value chain benefits from the application of Supply Chain Management (SCM) and Lean Construction techniques (LC), based on information management and automation. The investigation uses the method of Action Research (AR) for conducting both a professional and a subsequent academic project in the field. The availability of the computer program allowed the relevant simulations in the professional and academic projects. An integral IC process is modelled and simulated, as applied to a real-life pipe installation in a Mexican Petro-chemical plant. CI requires new operational practices so that constructors can rationalize costs, improve quality and reduce delivery times by means of processes control. The proposed construction model can be used to achieve these goals. The study evidences the pertinence and potential benefits of introducing SCM and LC techniques in core areas of IC.

Keywords: Supply Chain Management, Lean Industrial Construction, Mexican Petro-chemical Plants.

1 Introduction

Construction (CI) is one of the largest industries worldwide; contributes to large scale welfare trough important social functions, such as employment, industrialization, infrastructure creation and urbanization. The importance of CI in Mexico is reflected by its size and its great dynamism; with a CAGR of nearly 4%, CI represents over 7.5% of GDP and participates in 66 branches of the Mexican I/O Matrix. Notwithstanding its importance, this sector is overshadowed by many problems. Due to the predominance of traditional fragmented construction processes [1], **[2]**.It´s known in literature that CI exhibits insufficient productivity, budget overruns, delays, low process and products quality, high accident rates and in general, low innovation capacity [3], [4] [5] [6].

Operating Conditions of CI. The greater international competition compels construction companies to rationalize and integrate their processes. In particular IC requires greater control of its processes to guarantee lower costs, enhanced quality, and timeliness completion and delivery [7]. Unlike manufacturing, CI hasn´t improved its productivity and has been flabbergasted [8]. Through constant innovation, the application of techniques in lean manufacturing (LM) and Supply Chain Management (SCM), manufactures improved competitiveness by better adaptation to swift environment changes [9], while the CI continues to rely on traditional and highly fragmented construction models [10], [11], [12].

Why can't CI be considered as just another manufacturing activity? Two of the most important arguments against the potential automation of construction activities are: the specificity of CI and the particular development conditions of its activities. CI incorporates diametrically different projects in terms of size and nature, in addition of heterogeneity in technical and qualification requirements of human resources employed [10], [13]. Although the principles of project implementation seem similar, the scale, peculiarity and complexity of their interactions significantly vary [14], [15], [16]. It is documented that the specificity of construction projects is one of the main axes in the discussion around the adequacy of a systemic approach to CI. Moreover, the same literature seeks to answer questions about the importance of uniqueness in construction, as an argument that supports the permanence of traditional constructive models [7], [2], Laurie Koskela, [17] pioneer of the Lean Construction concept (LC), emphasizes the character of traditional construction methods as parts of conversion procedures, meaning fragmented I/O transformation activities, as of today a perpetuated sectoral vision. In CI, traditional methods adopt a *supply-push* approach, where execution begins in anticipation of customer orders and uncertainty in estimated demand [18]. This perspective evaluates the results of transformation processes as a simple sum of individual components, where those involved, work in parallel; certainly, the goal appears to be: product level maximization and meeting delivery times without hierarchies and pre-established orders. Waste and disorder characterize CI processes where production activities lack their own administrative order; it can be argued that unlike manufacturing processes, the specificity of construction processes and products hinder their repetitive and automated treatment [13], [15], [19].

Purpose of the research. The present research seeks to shed light on the big question: is it possible to apply in the CI, known manufacturing techniques, based on automation, to increase efficiency? If this becomes possible, then it has been suggested that to achieve this goal, construction managers need to define those parts of the process that can be standardized and thus apply tools typical of manufacturing processes, with the purpose of reducing the input-output relationship, reduce costs and delivery times and increase the flexibility and variety of products, providing greater customer satisfaction [12].

The Main Research Question. Under the perspective of a lean philosophy [2], [20], the main question is: How can these activities be rationalized, standardized and integrated, applying SCM techniques? Two complementary quests derive: (i) Can IC be systemically approached and how to make its parts interact to achieve this goal? And ii) How can SCM's own tools be applied and to achieve the integration of the entities involved in the construction chain? As such, these questions were part of a research project conducive, first to the solution of a real-life problem in the installation of a pipe spool system in a Petro-chemical plant in the Gulf of Mexico and subsequently translated into a doctoral dissertation using the Action Research (AR) methodology [21], [22].

Methods. This investigation resorts systematically to AR for the resolution of an organizational problem together with those who experience it directly. The issue here is: How to get beyond the LC concept in IC, and particularly how can it be applied in a real-life example of pipe spool fabrication in a Petro-chemical plant in Mexico? This study is framed in a research program characterized by two concurrent AR projects in SCM and LC. The first is the Core Action Research Project (CARP), where the researcher contributes with management to the solution of a real-life problem, namely: The design of an operating model based on SCM and LC techniques applicable to planning, design, procurement and pre-manufacturing process for the fabrication of pipe spools in industrial plants. The second, the Dissertation Action Research Project, (DARP), where the candidate concentrates on thesis writing, aiming for a distinctive contribution to knowledge in the context of rationalization of construction processes, particularly through the empirical validation of real benefits derived from the applicability of higher level SCM and LC integration techniques in CI.

Results Overview. The investigation confirmed the possibility of applying manufacturing techniques in construction activities based on automation in order to increase its efficiency. As a result of actions derived from the CARP, researchers, proposed a SCM perspective model, for the integral and systemic manufacture of pipe spools; this proposal incorporates a scheme of regulation and controlled planning through a software designed as an IC common interface and is fed by all the elements that relate to it directly through an operating platform.

This model also incorporates the operating philosophy of a more efficient process of producing spools in a manufacturing workshop [23], and provides the basic rational guidelines for calculating a production quota with better results than those obtained with a traditional cell. All the subsequent activities to the manufacture of spools are contemplated again, given their importance for the harmonious integration of the construction process. Finally, the model incorporates the participation of a materials manager, given the massive level of materials that are handled in their operations [24]. These platforms manage the procurement of all equipment and materials from design to project site and are usually developed in-house. This model integrates and streamlines the manufacturing process of pipe spools from the initial design phase to their manufacture and subsequent delivery for subsequent activities; it is able to generate sufficient and necessary metrics to more efficiently manage IC projects allowing the incorporation of SCM tools. Such as: standardization of materials, reduction of inventories, mitigation of opportunity cost, and lean manufacturing techniques, among others.

2 SCM and LT in the CI: An overview of the Literature

The nature of CI. It is not surprising that in the case of construction, poor performance and lack of innovation become worrying in times when customer demand is more demanding and projects become increasingly complex **[25]**, **[26]**, **[27]**. In the recent past, CI has undergone multiple changes, on the one hand, due to an increasing pressure to reduce costs and profit margins and on the other, to the application of multiple initiatives that seek to improve both supplier performance and customer satisfaction **[10]**, **[28]**.

In contrast, industrial production has been able to successfully adapt, while CI has lagged behind. Manufactures, based on a long-term vision, have adopted new forms of production that incorporate increasing productivity management techniques while CI limits knowledge and innovation by relying on traditional models based on short-term productivity **[29]**, **[30]**, **[31]**, **[32]**, **[33].** In construction, opportunity and cost are clear signs of efficiency, however by the very nature of the activity, risk conditions are present and the goals initially set are rarely met. A particular study evaluating 258 infrastructure projects totaling $90 billion across the United States, Europe, Japan and many other developing countries between 1927 and 1998 concluded that the programmed cost surplus exceeded 30% and that customer revenues had been reduced by about 40% **[3]**. Given the reported evidence, well verified by practitioners in the CI world-wide, it is not difficult to say that construction lags continue to materialize in problems such as low quality in its processes and products, malfunction of its value creation chains, lack of industrial safety, non-compliance and delays in deliveries and budget overruns by up to 30% of the original value, to mention just a few of them **[8]**, **[34]**, **[4]**, **[35]**, **[6]**, **[36]**, **[37]**, **[38]**, **[39]**. In general, the risk in construction derives from the effect of variables not controllable by the constructor **[16]**, **[40]**. Among the specific causes of overruns and delays are **[41]**: performance fluctuations of suppliers and subcontractors, pressures to reduce costs and their impact on quality, availability of materials **[42]**, **[43]**, continuous revisions and design changes **[15]**,contractual situations and environmental elements including topographic conditions among others, in coincidence with other research in this regard **[44]**, **[45]**.

CI under the SCM perspective. Within the field of SCM, construction is characterized as an industrial transformation activity that goes beyond manufacturing processes to incorporate uncertainty, complexity and a fast-paced environment **[46]**. Some authors consider that the features of a construction supply chain are: i) product uniqueness; (ii) temporal-space fragmentation of processes and (iii) on-site production **[2]**, while others argue against the notion that features i and ii, are not exclusive of CI, thereby favoring firstly on the argument that even though assembly is contemplated, the manipulated parts are so large that they cannot move through the workstations, so it is the stations that move around the product. And secondly on the fact that the production process is fixed in one place, adding uncertainty in terms of quality, climatological risks and topo-graphical particularities, the interdependence between actors, materials and processes and the conditions in which it is developed, not counting the lags in administrative matters that surround construction projects **[46], [47]**. These situations are jointly reflected in important interaction between processes, which unlike the activities in CI, in other manufactures could be considered as sequential, **[48]**. The SCM perspective of CI begins by recognizing the essence of the processes, where is possible to reduce to a manageable expression the peculiarities of the construction process, delimiting those activities likely to benefit from the application of modern techniques oriented towards efficiency and waste reduction.

Lean Thinking in CI as an alternative to SCM. In academic literature the adaptive application of SCM techniques and lean thinking (LT) in CI seem to be gaining followers in their discourse. The National Institute of Standards and Technology (NIST) **[49]**, defines the concept of lean as: "A systematic approach, in search of perfection, to identify and eliminate waste through continuous improvement, where the product flows in the face of customer demand" **[50]** The LT approach integrates the operational and socio-technical aspects of a value creation system to maximize value and eliminate waste by building accumulated capacities **[51].**

LT and SCM in IC: Where the roads meet. A significant number of academics and practitioners consider that SCM and the lean principles of production are applicable, with adaptations, to the construction industry, despite the fact that initially these practices were designed for repetitive manufacturing activities **[52]**, **[53]**, **[54]**. Thus, the need to solve construction problems and the proven potential of successful application of LT and SCM have led to the creation of a production philosophy initially called "lean construction" **[55]**, initially defined as "the continuous process of eliminating waste, satisfying or exceeding all the requirements and needs of the client, under a systemic approach that integrates the entire value chain, seeking at all times to achieve perfection during project execution." **[56]**. In this study, the rationalization of construction processes in IC considers six basic principles of LT, namely waste reduction, planning and control, customer satisfaction, continuous improvement, cooperative relations and a systemic vision **[52]**. Moreover the proposed model focuses on the application of five techniques that will allow systemic problem solving: i) Streamlining processes and reducing waste **[57]**; ii) lean production flow for the manufacture of pipe spools as opposed to a traditional spool manufacturing process **[23]**; iii) stabilization of the process and reduction of uncertainty. This requires uncertainty minimization in the chain by means of greater demand predictability **[58]**, **[59]**, **[26]**; iv) standardization of materials and use of a Just-in-Time model **[43]**, **[58]** and v) long-term supplier agreements for lean procurement **[43]**, **[56]**, **[60]**.

3 Methods: Building an IC prescriptive model trough AR

The application of AR in this study, required extensive experience in the operational and administrative environment of IC: the condition of business, the structure and dynamics of operating systems and the theoretical foundations of such systems, avoiding the inherent bias of the experience of researchers in this sector. The initial knowledge brought into the research included the experience of more than 29 years in the development of large industrial projects and the search for solutions to problems rooted in the verified chaos in the practice of construction and its documented evidence in the literature.

The Core (CARP) and the Dissertation (DARP) Action Research Projects

The subject of the CARP study. A real project of state IC developed in the Gulf of Mexico by the international Construction Company (CC).

Data Collection. Through direct involvement, the researcher collected information not normally found in the project's documentation; the direct responsibility in project execution, led the researcher to delve into the perspective of the use of traditional construction methods and to verify the problems actually involved. Finally, the quantitative and qualitative analysis permitted the objective dimensioning of the problem of cost overrun (similar figures close to those in other studies **[40]**), non-compliance with delivery time (delivery delays due to re-work, lack of inputs and budget problems), in addition to the uncertainty sources inherent in this type of projects and increase waste in pipe procurement and material management, situations that can be readily extrapolated to other CI activities.

Researchers Involvement in the pipe spool system manufacturing in the CARP
The pipe spool system is the largest and most complicated process of IC projects: together with pre-manufacturing, these activities were selected for the study **[61]** to demonstrate their rationalization potential. These activities share with manufactures, potential benefits from waste reduction, shortening of construction times and improvement of the work environment **[52]**.

The research team inquired on the following processes: manufacture and installation of piping spools; procurement, management of design as part of integral environments in project execution. As a result, one of the researchers developed a general prescriptive model and the software that rationalizes these processes. This software-interface allowed the mapping and control of such activities as design, procurement, pre-manufacture, monitoring and control, administration, among other disciplines, and then through simulation of time execution, efficiencies, costs, data and additional information, visualized the results of two type of scenarios: one with a traditional construction system and other-under different efficiency levels- with a *demand-pull* manufacturing perspective, including SCM and LT techniques that can be applied in other industrial operations.

The Dissertation Action Research Project (DARP). The experience obtained in the CARP and the confirmation of the potential benefits of applying the proposed rationalization model and the software-link initially designed for pipe spool systems management was generalized to other processes in IC, in order to complete the dissertation process of one of the research team participants. A more general prescriptive model was proposed and was tested on project documentation activities. Specifically, it was applied in one of the most important management processes in IC, being it the generation and maintenance of the Master Document List (LMD) or Master Document Report (MDR) and the Control Level Schedule (CLS): The model was tested on cross-checks, both internal and external; resource management; production control (document production); interaction with other disciplines; budget overruns and changes to the execution schedule.

4 The Proposed Operational Model under the CARP

As a result of the actions in the CARP, Figure 1 displays the diagram of both the traditional and the new flow proposed in this model, for the manufacture of pipe spools. In response to one of the most important problems daily detected, the proposal substantially improves the coordination of flows of activities, communication and information, in all instances of the construction process within CC. The difference between the proposed and the traditional model, is that this original process incorporates a regulation scheme and controlled planning through a piece of software that works as a common interface and is fed by all the elements that relate to it directly through an operating platform. It also incorporates the operating philosophy of a more efficient process of producing spools in a manufacturing workshop **[61]**, providing the basic guidelines for estimating a more rational production quota.

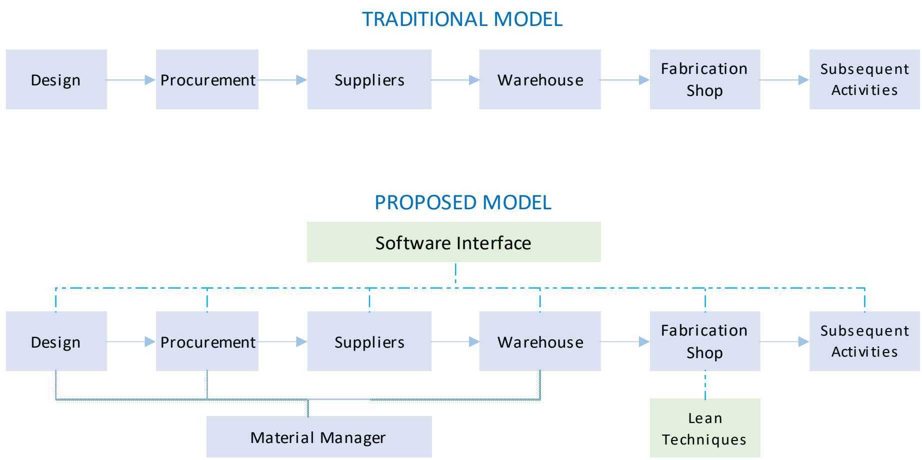

Fig. 1. Traditional and Proposed Process Flows

Given the massive level of materials that are handled in the CC, the model incorporates the participation of a materials manager. These platforms handle the procurement of all equipment and materials from design to project site and are usually developed in-house. This prototype integrates and streamlines the manufacturing process of pipe spools from the initial design phase to their manufacture and subsequent delivery for other activities; It generates the necessary metrics for efficient management of large IC projects, using SCM tools such as: materials standardization, inventories and waste reduction, lessening opportunity costs, and lean manufacturing techniques implementation.

Pipe spool manufacturing. The manufacture of pipe spools is a crucial phase in an IC project. A spool is regularly composed of pipes and fittings (elbows, flanges and fittings). In spools manufacturing, the typical operation includes the following activities: cutting, beveling, assembly, welding, quality control, stress relief, hydrostatic testing, painting or any other coating. In the manufacture of spools, each one is unique and must be identifiable throughout the process **[61]**. A spool manufacturing workshop is like any other shop; the difference resides that here each product is unique and the product family is very extensive; the productivity of cutting, assembly and welding is affected by many factors such as the diameter of the pipe, its weight, its configuration, the material and the welding procedure among other elements.

Information Requirements for the Model. The information required is contained in the isometric drawings: line number, diameter, type and quantities of material, item numbers as well as other data and information for process control. Each operational area provides and collects standardized data through the software-interface. The units of measurement considered are: *Diametrical inches of weld.* One diametrical inch is the process control unit in a pipe pre-fabrication workshop. This data is obtained from the quantity of all welding joints or joints multiplied by the diameter of the pipe or fittings being considered. For example, welding a flange and an elbow, both 3 inches in diameter, involves 3 diametrical inches of weld. *Surface.* This is expressed in surface units and implies the total area that each spool has to be coated, painted and sand-blasted or surrounded by thermal insulation. *Linear footage.* The control of the installation of the pipe is usually carried out in linear terms, although there are other control units such as field joints. For control purposes each isometric drawing carries the total number of linear meters of each item

Simulation exercise with the proposed model. The selected project was developed in the Gulf of Mexico, is owned by the Mexican State and consists of the design, procurement, construction and commissioning of two catalytic gasoline desulphurization plants of 20,000 standard barrels per day to produce Ultra Low Sulfur gasoline, ULSG-1 and ULSG-2 Plants. This project also includes two amine regeneration units (Regeneration Absorption Circuit), pumping equipment, elevated burner for the burning of low-pressure gas and acid gas, separation tanks, seal tanks, and pumping equipment to dispose of separate hydrocarbons and bitter water at battery limits. The plants are designed to process 20,000 BPSD of bitter catalytic gasoline with a TFE of 230 °C, each, with 10% overdesign, and with a minimum load of 12,000 BPSD, each, with continuously operating runs of 36 months (minimum). The function of CDHydro/CDHDS+

plants is to desulfurize bitter catalytic naphtha, minimizing olefin saturation, reduce the total sulfur content to produce light gasoline and heavy gasoline product with a sulfur content of 10 ppm by weight with minimal octane loss.

Simulation Data Input. The programmed time period is 56 weeks; 2,100 Isometric Drawings in two buildings (ULSG1/ULSG2); four quadrants per building and 58 pipe spool systems. Operational data follows: five production cells in operation; 160,841 men hours; a performance of 568 men-hours/Diametrical Inches; 625 Man-working hours/week per production cell; labor and machine costs were respectively 12 USD/men-hour and 7 USD/machine-hour. All the materials considered for the simulation of this model are considered for diameters of 4, 6 and 8 inches: 35,756 Linear Meters of Pipes and 15,776 accessories.

Simulation Scenarios. Four different continuous efficiency scenarios were contemplated in the simulation; many elements are identified to affect the behavior of a work cell to achieve programmed productivity: as lack of personnel, equipment failures, absences, quality failures, among many others; in the simulation these cases were not considered. The case scenarios included in this exercise were 100%, 85%, 70% and 55% of the expected efficiency, in each of the cases.

Software-link. The software interface has been written in the Visual Basic programming language. Net 2010. The database is designed and developed in Microsoft Access 2016; uses the Microsoft Net Framework and operates through a Windows 7 or higher OS

Simulation Results.
Performance Metrics. Although the different efficiency scenarios were defined at 100%, 85%, 70% and 55% respectively for each case, the final corresponding simulated efficiency considered by the software in each scenario was on average 98.3%; 83.4%; 68.2% and 53.4%. The reason for this difference being that conveyed production is a function of the isometrics reported as manufactured. The units of control are isometric drawings containing one or more spools that have different production values: (diametrical inches, dimension, surface, among other characteristics) ; by feeding the software with the nominal production value in diametrical inches to be manufactured under different scenarios, the isometric drawings -previously ordered- whose sum of diametrical inches is close to the amount entered in the software are selected, to then read the data and produce the corresponding information.

Production Metrics.
Execution Time. Table 1 displays the time values under different scenarios. In the first scenario (100%) there is a difference between the planned time (56 weeks) and actual execution (57 weeks) equivalent to 2% or 5 days of deviation from the original plan). As mentioned before, for this case the efficiency is 98.3% and that remnant of 1.7% in the production average brings as a consequence 5 days difference with original plan. Operating with an average efficiency of 85% implies wasting a fifth of resources (21%), which double (46%) if we lower only 15 percentage points more in our efficiency (70%)

until we reach an already excessive amount of 88% of the additional time if we operate at 55% of our efficiency.

Table 1. Modelled Execution Times

#	Concept	Plan	Scenarios			
			100%	**85%**	**70%**	**55%**
1	Total execution weeks (Readings or events)	56	57	68	82	105
2	Difference with plan	-	2%	21%	46%	88%
3	Delays (days)	0	5	82	180	341

Modelled Production. The average production obtained in the model is reflected in Table 2. Since the number of work cells expected to execute in the expected time is equivalent to 4.6 of them and their individual production capacity corresponds to 1,100, it is then considered that the nominal production capacity of the total working cells or cluster is equivalent to 5,060 diametrical inches produced per week. In the 100% simulated efficiency scenario, the average cluster production is 4,966 diametrical inches produced weekly. Its standard deviation is 99.78, reflecting a dispersion of readings relative to the mean of only 2%. It is noteworthy that the standard deviation of the 85% scenario rises to 10%. However, in this scenario the average production is 4,163 diametrical inches, divided into 68 readings or events (or execution weeks). In this case, the first 67 of the 68 readings obtained maintain a similar behavior in terms of their average production except the last one, which is only 23% with respect to this and is represented by the 970 diametrical inches produced in reading number 68, which is practically the remnant of the diametrical inches to be manufactured in the last event. If we omitted to count this reading or event number 68 to calculate the standard deviation of the 67 shots, it would be only 3%, similar to those obtained for the scenarios of 70% and 55% with 3.452 and 2.696 diametrical inches respectively.

Table 2. Modelled Production

#	Concept	**Scenarios**			
		100%	**85%**	**70%**	**55%**
1	Average Production (PdE)	4,966	4,163	3,452	2,696
2	Standard Deviation	99.78	401.93	116.31	83.17
3	Dispersion	2%	10%	3%	3%

Modelled Labor Data. Table 3 displays man-hours. The total number of scheduled man-hours to be consumed is 160,841. In the 100% scenario there is a surplus of 2% of total hours consumed, reflecting the additional 5 days that the cluster worked caused by the average production of 98.3% explained above. This figure represents 2,977 man-hours that have been wasted and cost approximately $3,000 (if we value the cost of man-hour at $12) in the most convenient scenario. For labor, $389,000 would be wasted in the 85% efficiency scenario; $892,000 in the 70% scenario; and an extremely high figure of $1,692,000 on stage, with only 55% efficiency.

Table 3. Modelled Labor Consumption

#	Concept	Scenarios			
		100%	**85%**	**70%**	**55%**
1	Total man-hours consummed	163,818	193,274	235,175	301,875
2	Difference with schedule	2,977	32,433	74,334	141,034
3	Surplus % of man-hours due to inefficiency	2%	17%	32%	47%

Modelled Inventories Data. The inventory of materials includes, beside unit costs, those of their procurement, storage, insurance and security costs, as well as the cost of their maintenance and obsolescence. In the simulation only, the unit value of the good or item is considered, table 4 displays the inventories expense. The universe of materials amounts to $2,044,442 US dollars

Table 4. Modelled Inventories Expenses

#	Concept	Scenarios			
		100%	**85%**	**70%**	**55%**
1	Execution weeks (readings or events)	57	68	82	105
2	Average expense per reading (USD)	$35,866	$30,065	$24,932	$19,470
3	Standard deviation	3,706	4,270	2,634	2,194
4	Dispersion	10%	14%	11%	11%

In the 100% efficiency scenario the average material purchase per batch is $35,866 USD with a standard deviation of 3,706; a 10% dispersion with respect to the average. In the 85% scenario, the above mentioned 68th reading is present; its effect causes the expense to fall to $30,065 USD, with a standard deviation of 4,270 and 14% dispersion with respect to the average. If this reading is omitted, the dispersion ratio would be 11% just like that obtained in the remaining scenarios of 70% and 55% efficiency. Graph 2 exhibits the cost behavior of inventories under different efficiency scenarios. The ordinate axis represents the expense value in USD and the abscissa axis the elapsed weeks.
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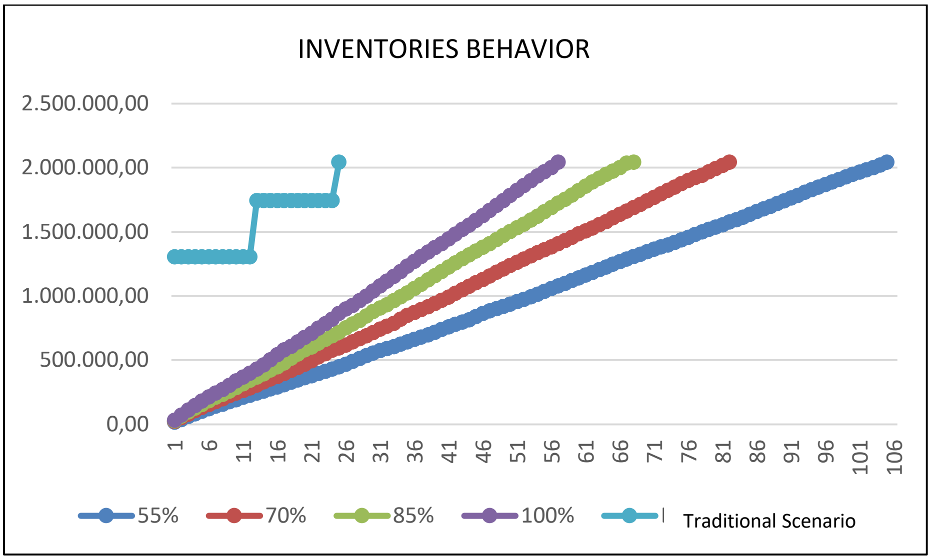

Fig. 2. Inventories behavior for each efficiency scenario

Actual results from the Gulf of Mexico IC Project (Background Information) The scheduled execution plan for this specific IC project was 56 weeks, while the actual execution time expanded to 145 weeks. This difference implies that CC operated the project at an efficiency range between 40 and 45%. The total cost of the project exceeded the approved budget on 77%; the labor cost by 63%; the scheduled man-hours by 60% and the cost of materials by 72%.

5 Final Words

As a result of the CARP project, this study carried out a simulation of the behavior of the proposed prescriptive rationalization model in a real-life IC state project in the Gulf of Mexico. Actual inputs and other pieces of information allowed researchers to analyze the pre-manufacturing of spools in the project. This exercise allowed the comparison between the traditional construction model and the results of the application of a proposed rationalization model that incorporates an important component of articulation of information flows, SCM techniques based on a *demand pull* operation scheme, the reconfiguration of the prefabrication workshops of spools, improvements in the procurement systems, monitoring of inventories of materials and other products and the continuous measurement of operation indicators in terms of efficiency and productivity, re-jobs, delivery times, costs, inventory management and other sources of waste. The research contributed to generate empirical evidence in large-scale projects, not only about its potential, but about verifiable beneficial effects of the application of rationalization models using techniques associated with SCM and LC in this country. As per data in the results subsection, the operation of CC under the most pessimistic efficiency, that is 55%, represents an improvement of the actual efficiency range of 45%, with the consequent positive contrast of metrics in terms of inventories, delivery times and opportunity costs. The Model contributed with a positive solution to the original question of the research: The introduction of techniques of supply chain management (SCM) and lean construction (LC) in the formation of an alternative construction model to the traditional one, is not only possible but contributes to cost reduction, quality improvements, and shortening delivery times and budgetary control in large scale IC projects.

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