Industry 4.0: A Real-Time Cyberphysical System to execute the Just-in-Time Philosophy in Lean Construction

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Abstract

For nearly 40 years there has been a significant lack of studies and innovation regarding construction processes and its productivity. Poor planning, low coordination of elements, multiple changes, high fragmentation of activities and manual collection of information cause high levels of uncertainty, inefficiency and waste in this sector. Although Lean Thinking (LT) has incorporated its philosophy in construction to improve productivity and reduce waste, no significant or effective results have been achieved to mitigate these problems.

Artificial intelligence (AI) technologies have been designed to impulse and leverage human capacities by using new arrays of data and information for complex problem-solving and decision-making process. The implementation of new environments such as Cyberphysical Systems (CPS) make Industry 4.0 a significant contributor for the transformation of construction industry.

Powered by a software-interface link designed by the researcher which transforms a traditional constructive process into a rational and systematic industrial one, the CPS framework presented herein is an expert system which creates bi-directional coordination between cyber models and the physical construction of a project. This tool can create different scenarios of prediction based on actual operational level inputs which can altered in a short-term basis. This is an integrated real-time AI model for industrial construction projects that can supervise simultaneously process of key activities such as design, chain-supply and construction by collecting and extracting its data suiting the Just-in-Time and Lean-Thinking operations.

Keywords: *Industry 4.0, Artificial Intelligence, Cyber-Physical System, Lean Construction, Just in Time*

1 Introduction

Most construction projects go over budget due to scheduling issues, poor planning, and lack of adequate information at the initiation phases of a project. This invariably reduces the output of each worker and hence productivity of the entire project [1]. For organizations to meet ever increasing customer demands and survive in an environment where change is inevitable, it is crucial that they offer more reliable delivery dates and control their costs by analyzing them on a continual basis.

AI technologies help organizations to reduce latency in making business decisions, minimize fraud and enhance revenue opportunities. However, within the corporate world, AI is widely used for complex problem-solving and decision-support techniques in real-time business applications [2]. The emergence of AI systems is now moving state-of-the-art one step further towards the usage of expert systems to enhance the monitoring and control of both batch and continuous processes [3].

The Fourth Industrial Revolution (Industry 4.0) is reshaping and transforming the construction industry, bringing it into an intelligent era. However, the major issue of intelligent construction is integrating multiple technologies to create more potential opportunities rather than their fragmented application. The traditional project management mode requires the construction scheme to be made in as much detail as possible in the planning stage [1]

With the deep integration of industrialization and informatization, a new ecosystem, namely the Cyberphysical System (CPS) has emerged, which unprecedentedly entangles the network and physical worlds. This has initiated a new era of real-time communication and cooperation between value network participants, including devices, systems, organizations, and people [4].

The purpose of this CPS is to depict an expert and distributed system of a lean construction Just-in-Time model which can provide a real-time interface performing monitoring, simulations and forecasting to control the processes involved in the execution of industrial construction.

2 Basis model

This cyberphysical system is powered by a prescriptive rationalizing model for a pipe-systems manufacturing process which incorporates a software-interface link designed by researcher. The Piping System is always the most complicated area, and it usually compounds the critical path in industrial construction projects [5]. This software-interface link allows the transformation of a traditional constructive process into a rational and systematic industrial one. Figure 1. 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, supplied and manufactured and its usefulness for previous and subsequent activities.

Software-interface philosophy

The philosophy of the software focuses on the actual capability of fabrication in a shop and its resulting real-time productivity will determine the forecasted scenarios for termination. Operation of software is divided in two phases. First, when the planning of work takes place, initial input includes information contained on design (piping drawings), start and finish dates and projected productivity. This software will provide the required amounts of labor, work cells and material consumption forecast to comply with the projected termination date.

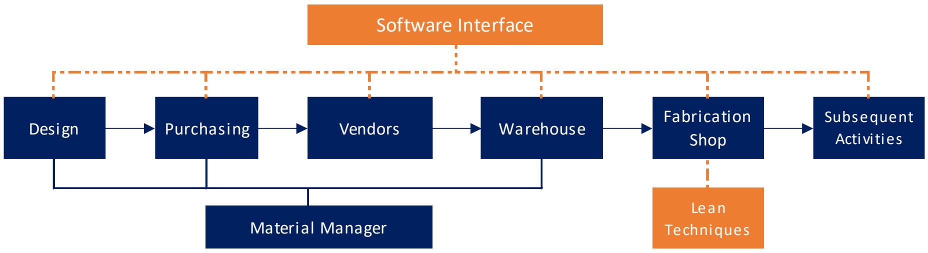

Figure 1. Rationalizing model

Second phase starts once the fabrication is being executed. Input implies the actual production and workforce of shop. Software will provide the projected scenarios based on resultant productivity along with the forecasted material consumption for its purchasing. Figure 2 shows basic philosophy of software-interface.

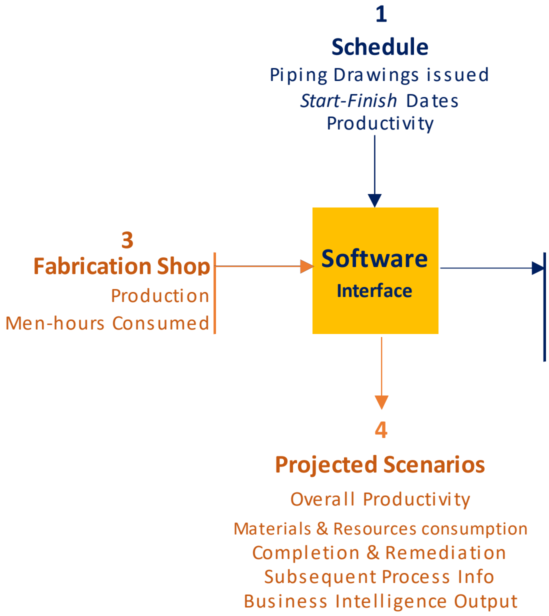

Figure 2. Software-interface philosophy

Integration of software-interface link in construction process

Figure 3 depicts how the software-interface links all areas involved in the fabrication process of piping spools. The sequence of such interaction is shown step-by-step and implies the input and output of data required per each element of the system.

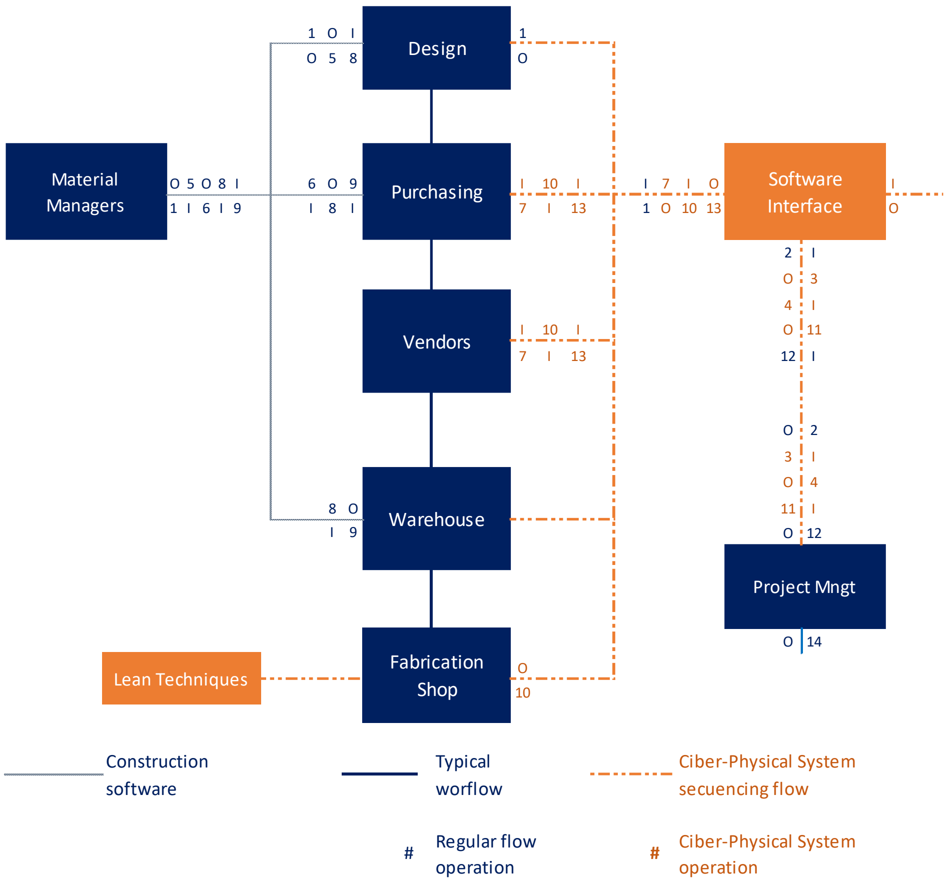

Figure 3. Software-interface sequence diagram

Software features

Algorithms contained in this software-interface were written in Visual Basic programming language Net 2010. Database has been designed and developed in Microsoft Access 2016; It uses Microsoft Net Framework and an operative system Windows 7 or superior.

3 Scenarios of Simulation

Four different scenarios of productivity were simulated through this software. The performance of productivity in each case is continuous, keeping such ratio from the beginning of fabrication up to the conclusion of activities. No stabilization period, noise or variations in performance is considered. Noise can be interpreted as lack of personnel, equipment breakdown, quality fails, among others. The simulated scenarios contemplate 100%, 85%, 70% and 55% of productivity in each case.

Simulation results: Material consumption estimates

The results obtained in the fourth different simulations are shown in Chart 1 below. Readings correspond to the number of weeks forecasted according to each productivity ratio.

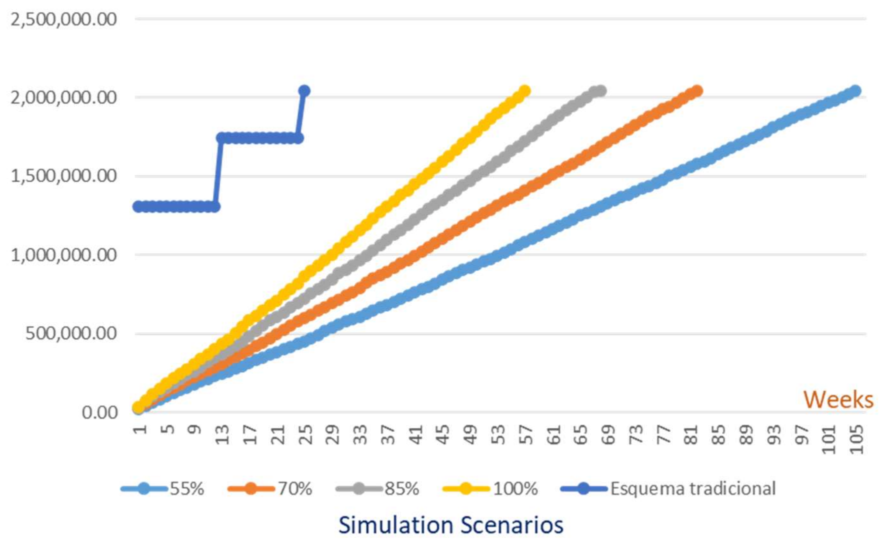

Chart 1. Result of simulations and cost opportunity

The average expenditure in each case scenario implies a market-price cost given to every component of a spool-pipe (Piping and fittings). Performance of weekly average expenditure in each case and reading is shown in Chart 2:

#	Concept	Simulaton Scenarios			
		100%	**85%**	**70%**	**55%**
1	Execution Weeks (Readings)	57	68	82	105
2	Reading expenditure average (USD)	\$35,866	\$30,065	\$24,932	\$19,470
3	Standard deviation	3,706	4,270	2,634	2,194
4	Ratio	10%	14%	11%	11%

Chart 2. Weekly expenditure of forecasted material consumption

Just-in-Time philosophy and the construction industry

The Just-in-Time philosophy focuses on providing the adequate materials, adequate quantities and adequate quality of products just in time for the production process [6]. In other words, it means to provide whatever is needed now it is needed [7].

According to Akintoye [8], quantities of material are to be delivered on a periodical basis at jobsite subject to the requirements of work requirements. Quantities are to be precise and delivered in small portions to assure low inventories. Contractor will have to determine quantities according to the production plan, schedule and notification to vendors. This is the main goal of the Just-in-Time philosophy.

However, a very strong impediment to achieve JIT philosophy on construction companies is the lack of standardization of materials. This can be understood as the need of less space for material storage and a small lot of materials must always be present at the jobsite [9].

Results obtained from the software-interface simulation proves that this philosophy can be achieved in a planned way. The software-interface provides a precise work schedule in which a material or a group of materials are to be required at site.

Projections of the simulated scenarios are shown in a weekly basis, but they can be depicted daily or in any other convenient fraction of time. Forecast of task completion produced by the software-interface will behave in the same fraction of time but in the real world of construction, its logistics differs greatly than manufacturing. The product of construction is done at its destination while manufacturing is a repetitive process performed in a specific facility and can be removed after its final assembly [10].

Lean Procurement

Procurement of materials is one of the basic principles for the Just-In-Time philosophy [8]. This is a new concept for most of the construction companies worldwide. With this software-interface, Vendors are involved on early and subsequent stages of materials planning, knowing in advance the quantities, specifications and precise dates to be required at jobsite through long-term supply contracts.

This software-interface has been designed to execute a benchmarking process for purchasing materials or heavy equipment. Selection of a vendor will be based on cost, delivery time or any other parameter defined by the Buyer.

7 Spool-pipe fabrication and subsequent production processes

A stated above, spool-pipe fabrication is one of the most complicated areas in industrial construction. However, this is just another piece of a big puzzle. More subsequent activities are to be scheduled after this process such as coating, hydrotesting. Installation, instruments installation, etc. Based on the scheduled termination of activities provided by the software-interface, subsequent areas are profoundly benefitted because it provides them precise information to schedule purchasing, workforce, materials requirement as well as start and finish dates.

Chart 3 shows seven sub-sequent activities after spool-pipe fabrication and the concepts that can be forecasted and scheduled accordingly.

8 Software-interface algorithms for sub-sequent activities

Like with the pipe-spool fabrication, philosophy of software for sub-sequent activities bases on the actual capability of fabrication or installation in shop or jobsite. Its resulting real-time productivity will determine the forecasted scenarios for completion. Since these activities are linked one after another, any delay in fabrication will automatically affect the sub-sequent process, like a chain reaction.

Construction design

Design plays a very important role in construction. Not only because it reflects on drawings and documents its scope of work, but it also determines directly and indirectly the path for success or unsuccess of a project.

#	Sub-sequent Process	Purchase & Activity Projections
1	Spool-pipe Fabrication	Piping
		Fittings
		Consumables
2	Coating	Sand Blast & Coatings
		Thermal Material
3	Spool-Pipe Installation	Support Fabrication
		Field Fittings
		Gaskets & Bolting
		Consumables
		Scaffolding
4	Hydrostatic Testing	Consumables
5	Manual valves & instrumentation	Design*
		Purchasing
		Storage
		Installation
6	Loop Check	Consumables
7	Project Start-Up	Vendors Field Assistance

Chart 3 Sub-sequent activities after spool-pipe fabrication

Industrial construction involves different multi-disciplines: civil, structural, mechanical and electrical equipment, piping systems, control systems, among others [5]. A poor design can affect a project in many ways: lack of quality and control of its activities will derive on purchasing of unnecessary or excess of materials and equipment, poor performance of final product, facilities or equipment, delays in procurement and fabrication, or even client dissatisfaction.

The product of *Design* is in general, drawings, datasheets, specifications, cross-checks, documents, etc. Different and very diverse resources are necessary to produce them such as engineers, designers, supervisors, computers, software, etc. Design, as any other production activity needs to be planned and executed effectively so that project can meet expectations of contractors, vendors and clients. Activities of Design shares the same problem of construction: high fragmentation, lack of coordination between disciplines, delays, etc.

The software-interface of this CPS integrates activities and documents of the different disciplines to be issued in a project. It executes algorithms to control the processes activities of construction design. Prior to such calculations, software-interface creates a *Document Master List* (DML) so that every production unit is tracked over the whole process and is capable to provide a Level 5 Schedule. This represents the capability of planning *Design* activities on a *day-to-day* basis.

Design process control Philosophy

The philosophy of the software-interface to control *Design* process activities is like the piping control fabrication process: the actual capability of *Design* and its resulting real-time productivity will determine the projected scenarios for termination. Here, several constraints and document interaction are considered in basic algorithms, depending on the precedence of each document according to *Design* disciplines. Figure 4 shows the constraints and interactions of *Design* documents.

Operation of software is divided in two phases. First, when the planning of work: initial input includes information contained on the Master Document List MDL, start and finish dates and projected productivity. Software will provide the required workforce, work cells and resources forecast to comply with the projected termination date. Figure 5 shows the basic figure for software-interface philosophy.

Cyber-physical System architecture

Figure 6 depicts the overall architecture for a cyber-physical system that integrates the elements of an industrial construction project. Central piece of integration is the software-interface that links all participants through individual terminals and every terminal is a bi-directional line of communication provide and receive data or information from the whole system, processes and activities on a real-time basis at a Level 5 schedule.

Key elements of an industrial construction project involved on this CPS are: Desig; Supply Chain (Purchasing, quality surveillance, shop fabrication, vendors and warehouse), Construction, Project Controls, Document Controls and Information technologies.

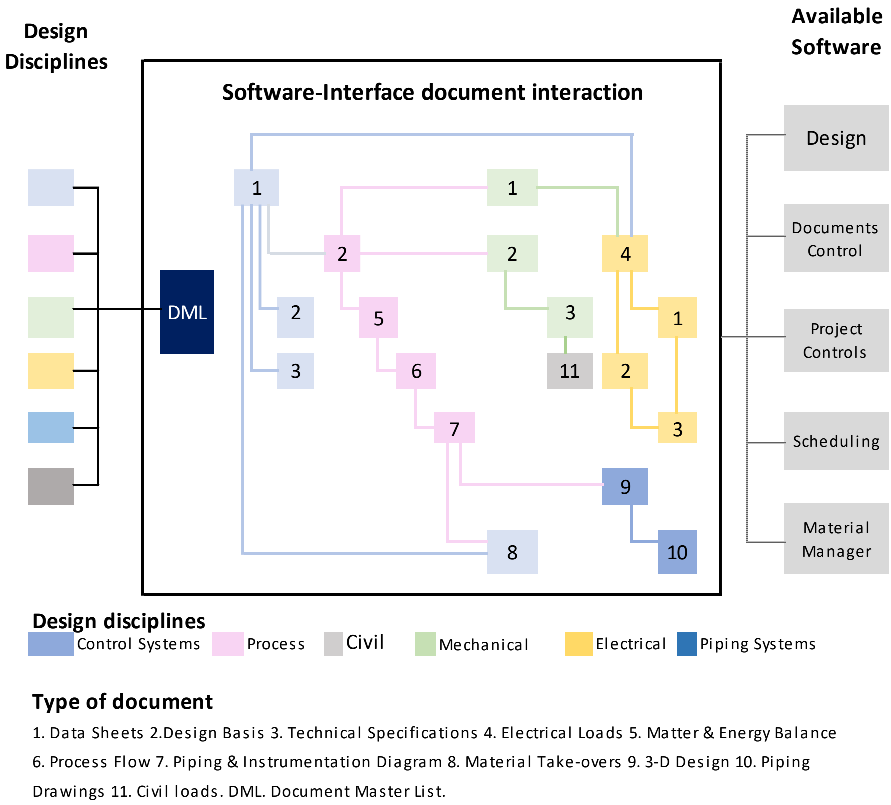

Figure 4. Software-interface document interaction

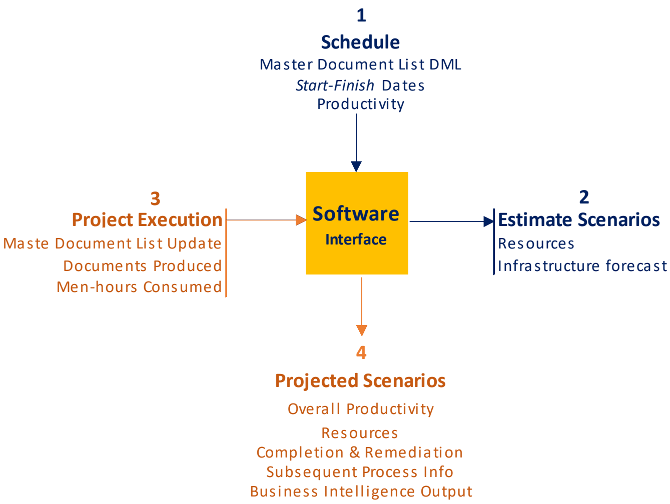

Figure 5. Software-interface document interaction

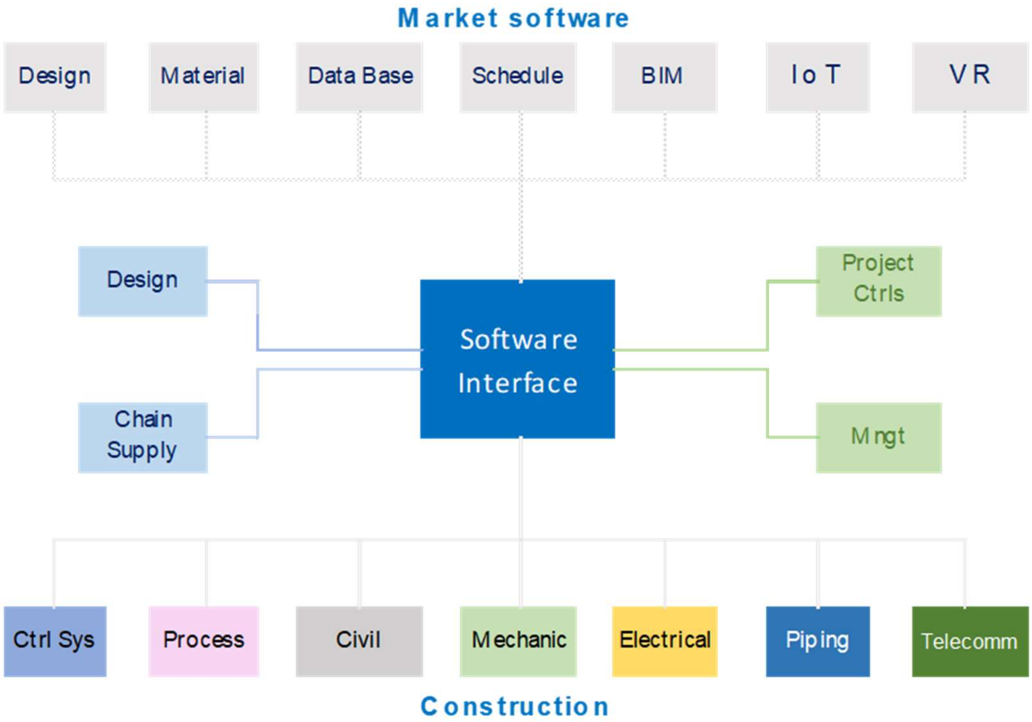

Figure 6. Cyberphysical System architecture

Commercial software associated

Software-interface of this CPS can communicate with commercial software used by the elements of a regular construction project. Sofware for Design, Database, Material Managers, Document control, Management, Internet of Things (*IoT)* or Building Information Models (*BIM)* can interact, exchange and validate data and information on a real-time basis.

4 Conclusion

The Cyber-Physical System presented herein provides monitoring, precise forecasts and the decision support to adjust the plans of a construction project. This is based on the actual situation and performance of its activity processes. The prescriptive model contained in this CPS can provide dynamic scheduling and control of activities process to improve productivity and reduce waste, which is consistent with the *Just-in-Time* philosophy.

This CPS framework depicts a prescriptive and innovative rationalizing real-time, lean-construction model designed to synchronize harmonically all elements and their processes, bringing along a new era in the Construction Industry.

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