Why construction productivity initiatives fail to deliver significant improvements?

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Abstract

Popper's (1972) analytical process of conjecture and refutations highlight how a problem begets a solution that engenders new problems. Efforts, in theory and practice, to increase construction productivity at the strategic level (project delivery systems, internal and external project planning), the logistic level (scheduling theories and lean construction theories and practices) and the tactical level (work task/time studies and value stream mapping) have failed to yield significant improvements. This paper summarizes and links the systemic nature of construction to the three organizational levels in a historical perspective of productivity's strengths and weaknesses.

Structured literature review is used to identify and analyze published research regarding construction productivity at the above-mentioned three levels (Motwani et al. 1995). Sketches of organization and project models are created. These models are based on independent, dependent and interdependent variables uncovered in the literature review. The models use organization and process description language to feed a project simulation that in turn will feed a future meta-project Monte-Carlo simulation expected to generate massive quantity of data. The data will be tested internally and externally through case studies and verified against actual projects, organization and productivity theories and the experience of project personnel.

KEY WORDS: productivity, project delivery systems, scheduling, work breakdown structures, time-task studies, strategic, logistic and tactical

Introduction

Karl Popper (1972) analytical process of conjectures and refutations serves as a framework to analyze how the perceived problem initiates a quest for tentative theories and error elimination as a way of solving an identified problem. However, the result is a new version of the problem or an unintended problem.

This paper analyses state of the art initiatives for significant, reliable and permanent industry wide increases in construction productivity. Unreliable productivity in construction is major problem calling for a solution. The theories and technologies employed to address this issue generate new problems prelude for future solutions-problems cycles.

Why is this relevant? All of our current problems at finding ways to increase construction productivity, as it has happened in manufacturing, have failed to achieve their intended targets, Fernández-Solís (2008). Therefore we need to keep finding solutions albeit those that do not create other problems. Furthermore, sometimes we anticipate that the state of the art solutions that may be able to change drastically the current paradigm, Howard, et al. (2003), the aim of this paper.

Methodology

The methodology is based on the following abbreviated method of Popper's method of conjecture and refutations (Fig. 1).

$$P_1 \rightarrow TT_1 \rightarrow EE_1 \rightarrow P_2 \rightarrow TT_2 \rightarrow EE_2 \ldots$$

Figure 1. Popper's Analytical Process of Conjectures and Refutations

P_1= Original Problem
TT_1= Tentative Theory
EE_1 = Error Elimination $\Rightarrow$ **S_1=** Solution
P_2 = Emerging Problem

This paper simplifies Popper's method by combining tentative theory and error elimination and call it solution, see Fig. 2.

$$P_1 \rightarrow S_1 \rightarrow P_2 \rightarrow S_2 \rightarrow P_3 \rightarrow S_3 \rightarrow \ldots$$

Figure 2. Modified Popper's Analytical Process of Conjectures and Refutations

The method of conjectures and refutations is a novel gateway into critiquing current theories by challenging the finding of a solution that does not in itself create a problem. From Popper's theory we can paraphrase the following hypothesis: *All problems seek solutions that, however, create new problems.*

The problems and solutions are identified, selected, studied and summarized by using a structured literature review (SLR) methodology on published research on the topics. SLR is a systematic methodology to map, catalogue and rank existing and found critical literature central to the research in a rigorous and systematic manner, Armitage and Allen (2008).

The SLR used a set of key words for each topic and five search engines. The found research set on the topic was narrowed down by using a set of rubrics that required a minimum number of citations, be part of the Texas A&M University Construction Science Department set of 25 preferred journal publications and the selected journal has an equally robust set of references.

Discussion

The topic is limited to vertical (building) construction, the area of expertise of the author. The aim is to establish a building construction productivity topic starting point, highlight the problems encountered and solutions enacted that then created a new problem and so on up to the current condition. The topical focus is construction efforts for increasing productivity at the strategic, logistic and tactical stakeholder organizational levels, Fernández-Solís and Rybkowski (2015), see Fig. 3.

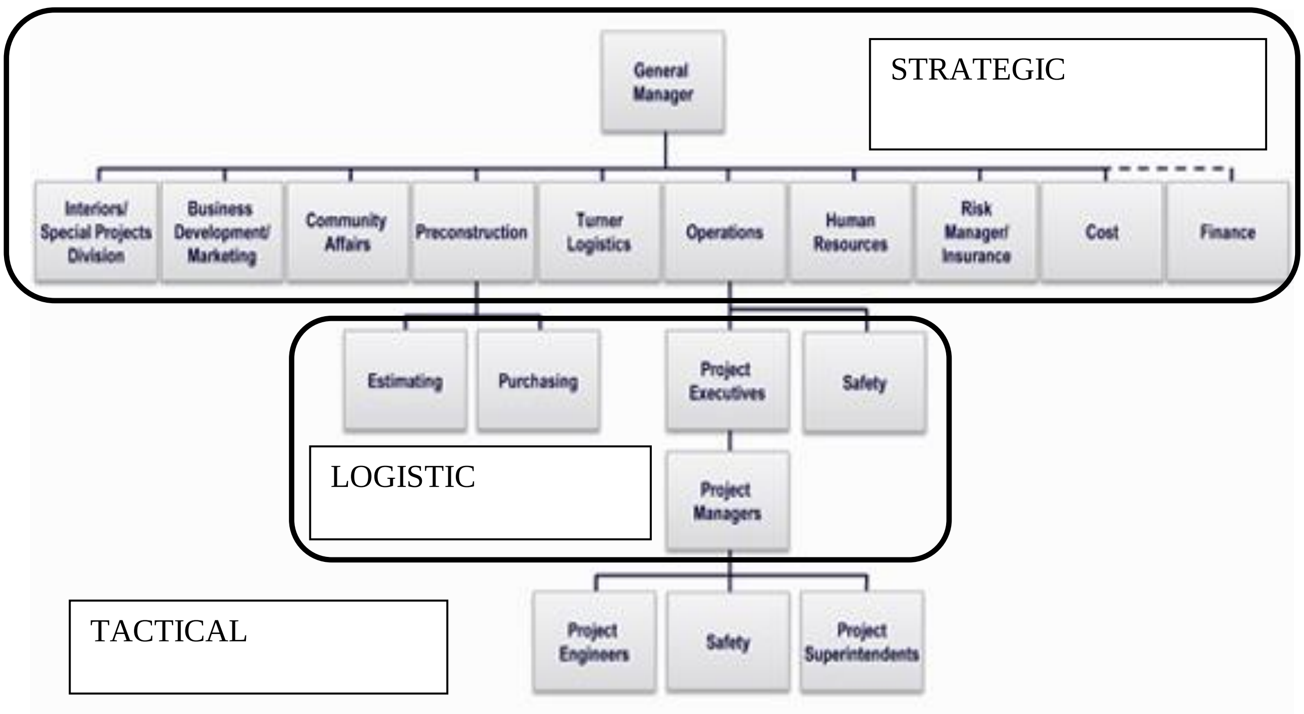

Figure 3. Typical company organization chart, the basic structure of a business unit

Fernández-Solís (2008) and Fernández-Solís and Rybkowski (2015) have shown that all building construction stakeholders follow an organization template with the strategic, logistic and tactical levels, see Figs. 4 and 5.

Owner

- Private
- Public

Designers

- Architects
- Engineers
- Consultants

Builder

Trade Partners

- Suppliers
- Manufacturers

Stakeholder Type	Owner	Designers	Contractor	Trade Partners
Strategic				
Logistic				
Tactical				

Figure 4. Typical basic structure of a stakeholder organization unit, cloud = actual construction

Organization Structure

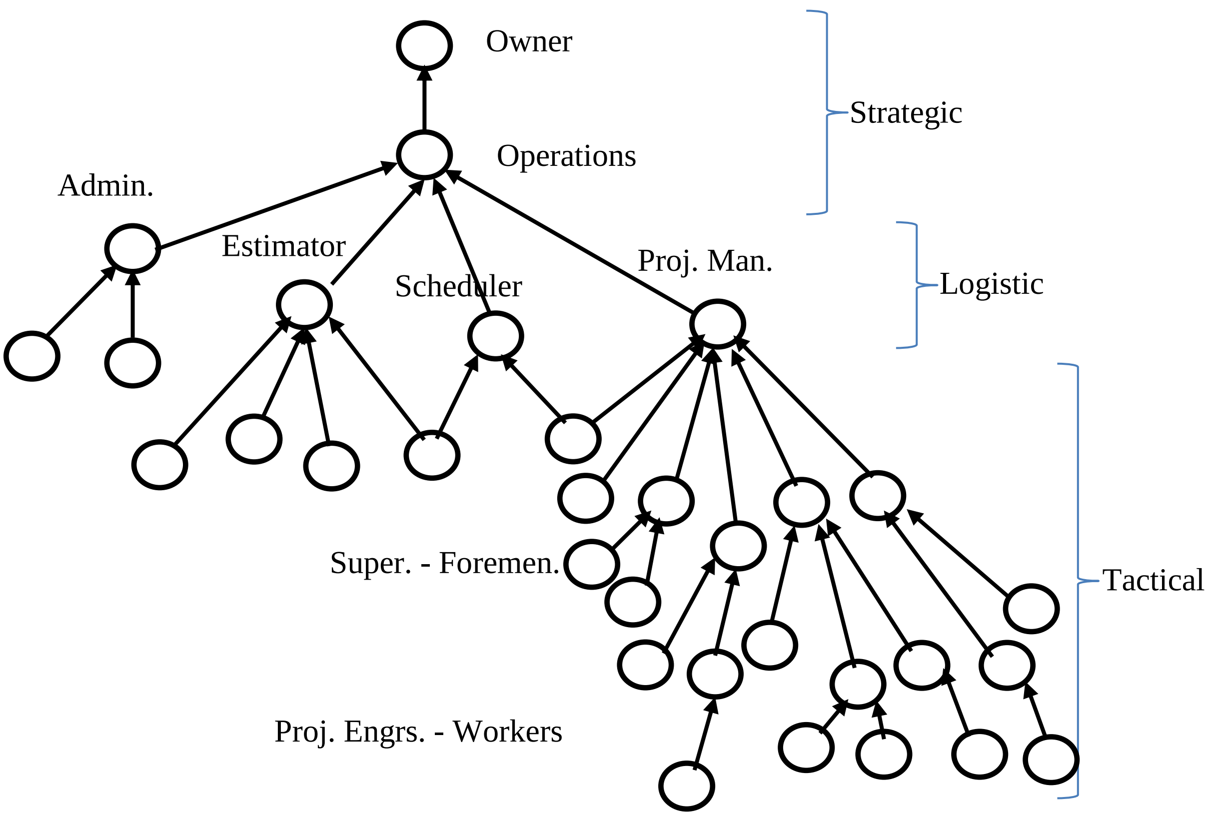

Figure 5. Organization model overview

At the strategic level, an organization's mission, vision and objective setting levels, we are going to analyze the advent of project delivery systems. At the logistic level, where organizations generate project planning, we are going to analyze the evolution of scheduling theories and lean practices, Fernández-Solís (2013). At the tactical level, where an organization executes the plan, also known as boots on the ground, we are going to review the advent and evolution of work task/time studies, Arbulu and Tommelein (2002).

STRATEGIC

Strategic origin is from the early 19th century: from French stratégique, from Greek stratēgikos, from stratēgos (see stratagem). It relates to the identification of long-term or overall aims and interests and the means of achieving them.

In construction, strategic planning, by the company leadership (owners, presidents, board of directors, vice presidents, principals), is defined as an organization process of defining its direction and allocating resources to pursue its strategy. In Construction, as in most other organizations, strategic leadership focus in establishing, growing, promoting, and passing-on (transmit, transfer) a company name, culture, brand, leadership development, ethics, mission, vision and objectives among others.

An organization strategic mission is to promote growth and plan for survival in adverse times and make the organizational decisions such as hiring, firing and promotion of personnel. In general, this level answers the questions of how we came into being, what is our mission and vision, where are we going and how are we going to get there and stay out of trouble (i.e. court). Strategic level adds value by the organization's services.

Once goals are set, the strategic mission, vision and objectives requires determining a plan of actions, and what resources need to be mobilized. Further plan details the cost and schedule within the overall company direction. Organizations need to know if they have achieved their goals through measurable means. In addition, the organization must capture lessons learned, to avoid costly repetitions, and provide for a continuous improvement of the strategic plan.

Construction is based on a need, a promise to deliver (a project) in exchange of an agreed compensation. The contract provides for the delivery of the solution to the owner's expressed needs (project intent) and the acceptance of the solution (project) and executing the compensation[8]. In the early times, this was an informal agreement sealed by a handshake (Lai and Kao 2009). The loop between a customer and a performer is typical of any transaction, such as between owner and designer, designer and engineer or design consultant, owner and GC, GC and each sub-contractor, and between each subcontractor and its vendors, see Fig. 6.

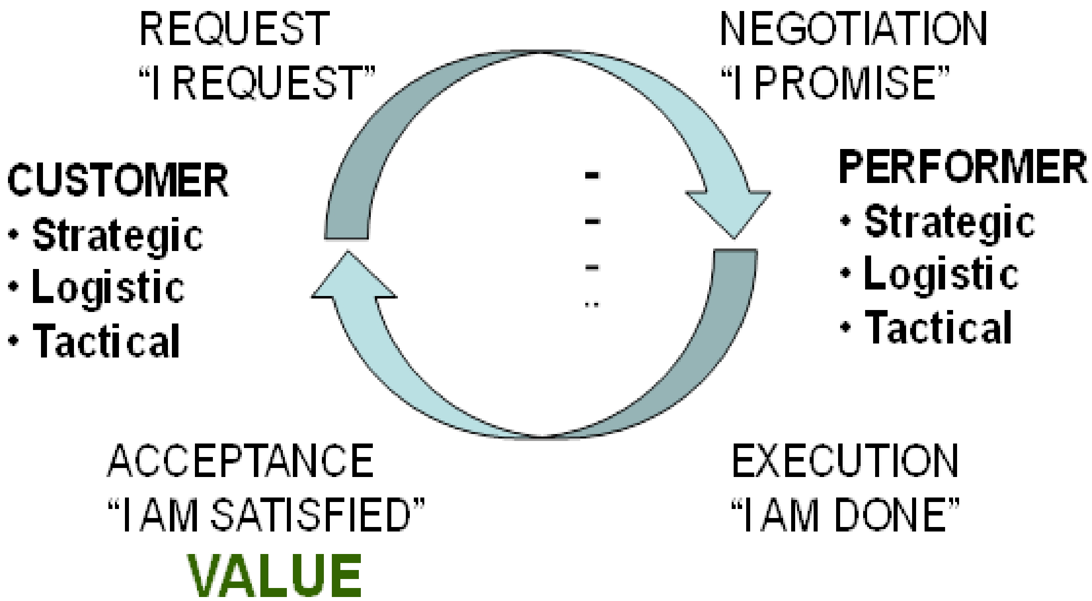

Figure 6. Request – promise – execute – acceptance loop between customer and performer.

Project delivery systems

Initial Problem (**P_1**): The informal agreement lends to misinterpretations, graft, nepotism, etc. and therefore (**S_1**) a more formal contractual agreement that could be enforced in court became the norm. In order to avoid the problems of graft, nepotism etc. the industry implemented a design, bid build process.

However, this created (**P_2**) when the economy downturns forced bidders to undercut the numerous and hungry competition in order to survive. They did this by taking advantage of the legal provisions created by the Spearin Doctrine, Golden and Thomas (1885). This doctrine (implied warranty) established a precedent understood that the general contractor is not held responsible for the consequences of defects in the plans and specifications prepared by the owner (or for the owner).

In short, an open invitation to submit change orders for any defect, error or omission in the plans. The game evolved in a design adversarial attitude of getting the work at any cost and then finding defects, errors and omissions on the documents (E&O). Furthermore, E&O let to retching up the cost through change orders, Obrien (1998), see Fig.7.

Figure 7. Drive to be a low bidder… what a general bought with the original contract versus with change orders.

The industry at large responded with (**S_2**) by creating a plethora of project delivery systems (PDS). Konchar and Sanvido (1998) listed, compared and contrasted these PDS that are not based on lowest bid but on value. Some examples are: Construction Sealed Proposal (CSP), Design Build (DB where the builder and designer are under one contract and therefore theoretically eliminating the owner from the loop of providing defect free construction documents), Construction Manager at Risk (CM@R) and others.

However the compensation package on all these project delivery systems is typically based on a percentage of the work or General Condition Fee, Halpin (2010). Therefore the incentive to the designer and even more to the builder is for the cost to escalate so their share also increases proportionally, the new manifestation of the solutions to the problem innate in the system all along, call it (**P_3**), see Fig. 8.

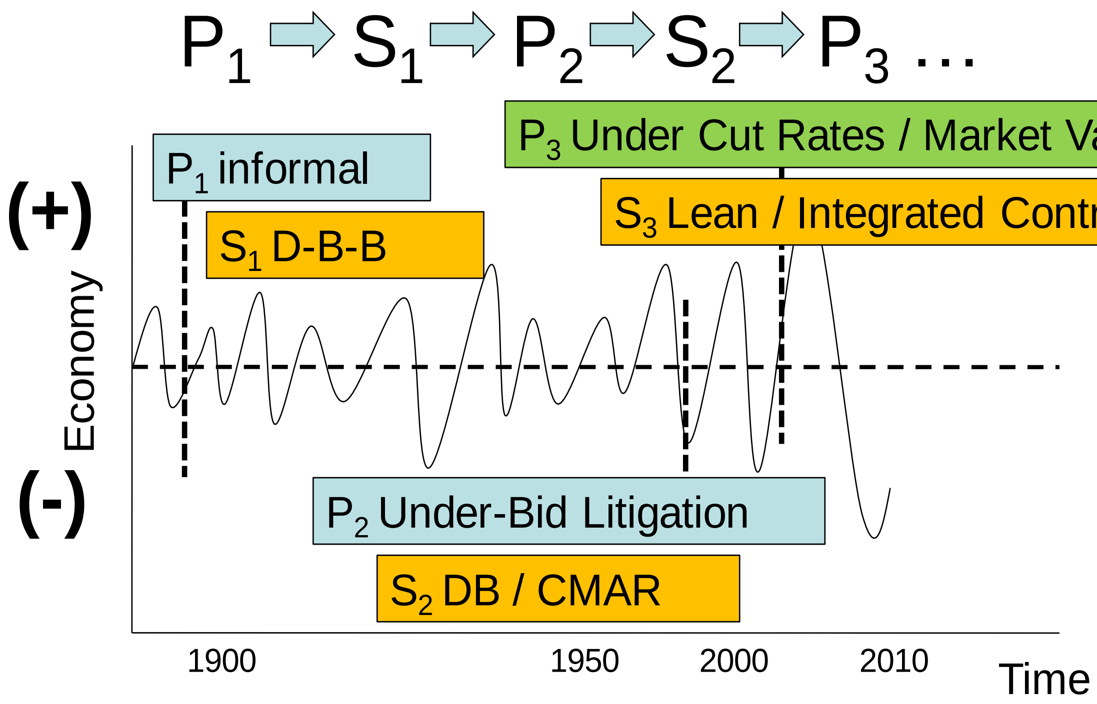

Figure 8. Schematic history of project delivery system over economic cycles.

The most advanced solution (**S3**) to the problem is the creation of what is labeled Integrated Project Delivery (IPD). Kent and Becerik-Gerber (2010) analyze IPD in which an owner contracts with the designer, builder and major contractors, place the owner contingency on an escrow account adding the contingencies and profits of all the named stakeholders. IPD challenges the stakeholders to deliver the project below cost and time. Any change orders come out of the escrow. In practice, when this works well and all stakeholders share the escrow at the percentage of their contribution. The net effect is a win-win for all with increased profit margins for the stakeholders.

At the strategic level, there is a considerable opportunity for exacting better performance in the form of more predictable outcomes (efficiency), higher stakeholder buy-in the project, incentivizing teamwork through higher profit margins, minimizing mediation, arbitration and litigation disputes and creating a two prong focus: maximizing value for the owner and minimizing wasteful processes and practices. The downside, according to Matthews and Howell (2005) is that IPD (**P4**) is not well-known, has not been extensively proven, and has serious potential downside when the parties do not buy-in all the way.

Internal and external project planning

Most stakeholders planning efforts and published research focuses on project planning. This is project planning is external to a stakeholder organization. A project is the object of organization efforts. Stakeholders pursue projects that lines up with their strategic vision, mission and objectives. Stakeholders are aware of their scarce (limited) resources of capital and talent (human resources, personnel, staff, bench strength) and the projects they pursue. For example, problem (**P1**), internal project planning at the strategic level must answer questions such as: How many foremen crews do the subcontractor has? How many are in current projects? When are the projects going to finish and the crews become available? What is the quality and experience of the crew talent? How many senior project manager, project managers, junior project managers, project managers in training, senior superintendents, superintendents A, superintendent B, superintendents in training, project engineers, Schedulers, Estimators, field personnel? What projects are coming up and the crews that are already committed? Which owners are repeat owners and which are one time owners? What is the profit margin on each ongoing and upcoming project?

Solution (**S_1**): Strategic organization plans attempts to match the best crew experience with the appropriate client that has the adequate profit margin and risk due to project type. For example, owners that have repeat business are typically treated different than those that have one and only one project. Projects that have higher profit margins are likewise treated different when it comes to assigning limited resources with different expertise.

Problem (**P_2**): Service companies have multiple projects at different stages and hopefully an equal number on the to-do list – backlog. Each project has its own issues at different level of criticality. Any project of the service provider can cause the organization to react and move assets to respond to the dynamics of a project in crisis. If this happens with a number of stakeholders of one project, even if at different times, a project may experience chaotic flow. Project risk of going into crisis by contagion is higher in in small towns where most general contractors use the same set of subcontractors. Logistics is the planning of a project that unfortunately <u>never takes into consideration what is happening to all other projects of all stakeholders</u> as this is not in the contract, and therefore not controllable.

The internal company logistic planning of operations is information held confidential. What is happening on an organization multiple projects is a closely guarded strategic asset and not transparent to the outside of the organization.

Not all project managers have the same experience, skillsets, lessons learned, background, just like no superintendent, project manager, or foreman does. Not all clients are the alike. Some clients are repeat business others are one time. Not all the projects are alike in terms of the profit margins agreed or the risks or the type. Even projects of the same type by the same client present different site challenges.

Academia and research has not fully embraced or understood the following issues: How stakeholders internally manage the match of scarce company personnel resources with projects? What happens to other projects in crisis? Does a sub working on your project has the manpower and experience needed to put out fires in other projects? For example a sub on another project that has nothing to do with yours is in trouble affecting a subcontractor commitment to that project that however is also committed to your project. Even more, the crew on the other project at risk is the same crew slotted to come to your project but is now delayed through no fault of your own. This type of event is the real cause that all our efforts at managing time through schedule technologies and techniques have failed to produce substantial efficiency and reliable improvements. SLR provides no paper on this topic, therefore a fertile area of research. See Fig. 9.

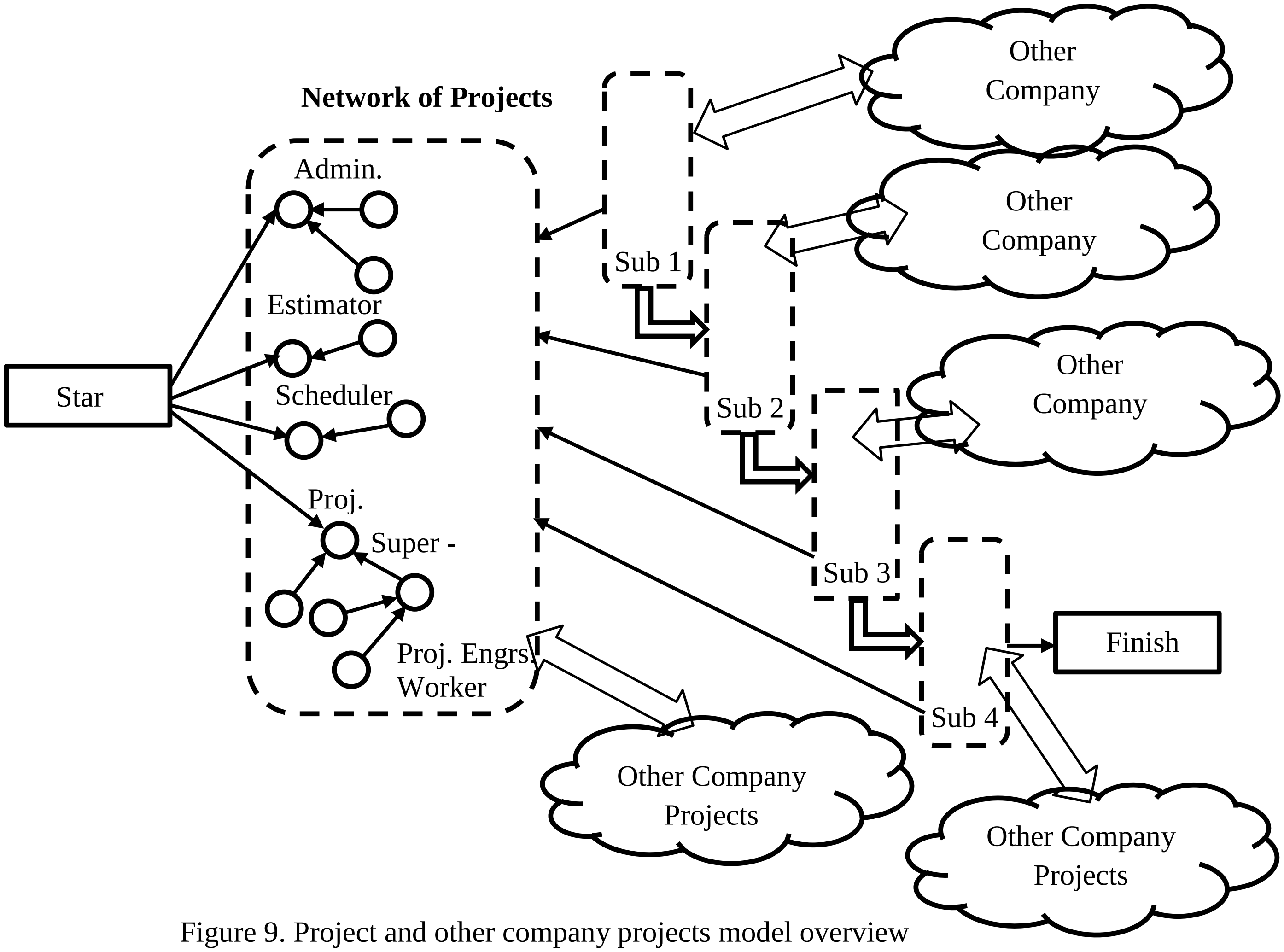

Figure 9. Project and other company projects model overview

LOGISTIC

The word logistics is derived from the Greek adjective logistickos meaning "skilled in calculating", Rutner and Langley (2000). In construction as in most organizations, logistic planning is required to achieve the company strategic mission, vision and objectives. This plan encompasses labor, material, information flow, risk, security, contracts and agreements among many other items.

The personnel at the logistic level of each stakeholder organization includes planners, architects, engineers, project managers, office personnel, human resources, accountants, estimators, schedulers, and IT personnel.

The role at the logistic level relates to planning, organizing, documenting, creating, coordinating and disseminating information to stakeholders and keeping financial records of all transactions. In general, the logistic level of any organization is charged with carrying out the objectives of the organization. Logistics adds value through service, (it almost exclusively done by changing, manipulating and transmitting information). Information has value if it is correct, complete, timely and unambiguous, Fernandez-Solis (2015).

Planning the project execution starts once an organization (Architect or Engineer in design and General Contractor in building) decides to pursue a project and secures in a contract the promise to deliver. Planning, for the designers, is creating the design intent. Planning, for the builder, is adding logistics to the design intent for its execution by the subcontractors. Plan execution has to consider the owner critical needs and compensate the logistics so that it can be implemented.

Texas A&M University in College Station, the demolition and building of Kyle Stadium, FAQ 2015, is an extreme example of the implementation tradeoffs. It took nine months and a total cost in place of $450 MN which translates to one million dollars of construction in place per calendar day working 24/7 with a 20% contingency embedded in the cost as there was no time for change order paperwork. Kyle Field renovation came on time and with no change orders. This was accomplished by the terms of the contract and the extensive use of last planner system techniques, see Fig. 10.

Figure 10. Kyle field renovation project 2014-2015

Kyle Field critical schedule and the contract imposed extreme penalties for schedule non-performance did not allow internal or external delays, including adverse weather, to interfere. All the stakeholders involved considered Kyle Field their top priority project, trumping all others. Any issues that arouse in the process which required shifting manpower, material, and labor affected other company projects but not vice versa. Kyle field is a unique and extreme case study in productivity (Just in Time delivery), efficiency (very high PPC), high percentage of readily available contingency (with after the fact accountability and transparency), and cost controls (zero change orders).

The problem (**P_1**) with schedule planning is that the variables and constraints that are taken into the schedule never match the site condition once the project receives the notice to proceed, Fernandez-Solis (2008). The first solution (**S_1**) is to create a planning system that takes into consideration the buffers necessary in order to account for the unknown. The solution came in the form of Critical Path Method (CPM). CPM generates (**P_2**) because a critical path is dynamic and in constant flux due to externalities. The buffers change according to the circumstances (Kerzner 2013). To accommodate for all eventualities the buffers had to be excessive. Today the owner carries a financial buffer in the form of contingency. The GC carries a financial buffer as contingency and another as float time (Ibbs and Kwak 2000). Each subcontractors carry financial buffers and another as float time. The same is for suppliers and vendors. The waste in construction when compared to manufacturing accounts for all these buffers in cost and float time. Contingencies and float time are accumulated and embedded in the project by the way the industry operates. The underlying cause is the unpredictable, unreliable planning that manifests as the difference between the planning exercise and the field reality. Can this paradigm change or is it embedded in the systemic nature of the industry and thus innate, unchangeable?

Lean construction academicians studied lean manufacturing and came up with transferable theories, techniques and methods to the practice. For example, to address the waste in construction reliability, Lean experts then came up with solution (**S_2**) as the Last Planner® System (LPS), Ballard (2000).

Space limitations prohibit an extensive elaboration of Lean Construction theories such as LPS. The following is an LPS summary: the foremen and team leaders (those that have direct oversight with the boots on the ground) gather and plan the work from the end to the beginning including risk and float time. This major upfront effort should result in a buy-in on the project schedule as planned by those that will actuate and execute the schedule, Formoso and Moura (2009).

The problem remains (**P_3**) that although there are claims of substantial improvements, of approximately 30% waste removal, Porwal, et al. (2010) and Fernandez-Solis et al. (2012), through reliable performance through phase or pull planning, look ahead, constraints removals, make work ready planning, weekly work planning and tracking through plan percent complete tracking, the achievements are project by project as the systemic nature or industry paradigm has not changed.

Phase plan or pull planning, Tommelein (1998), is defined as a work plan using what in manufacturing is called pull technique. Pull technique requires a conversation between upstream and downstream customers, the next trade that will follow the work, see Fig. 11.

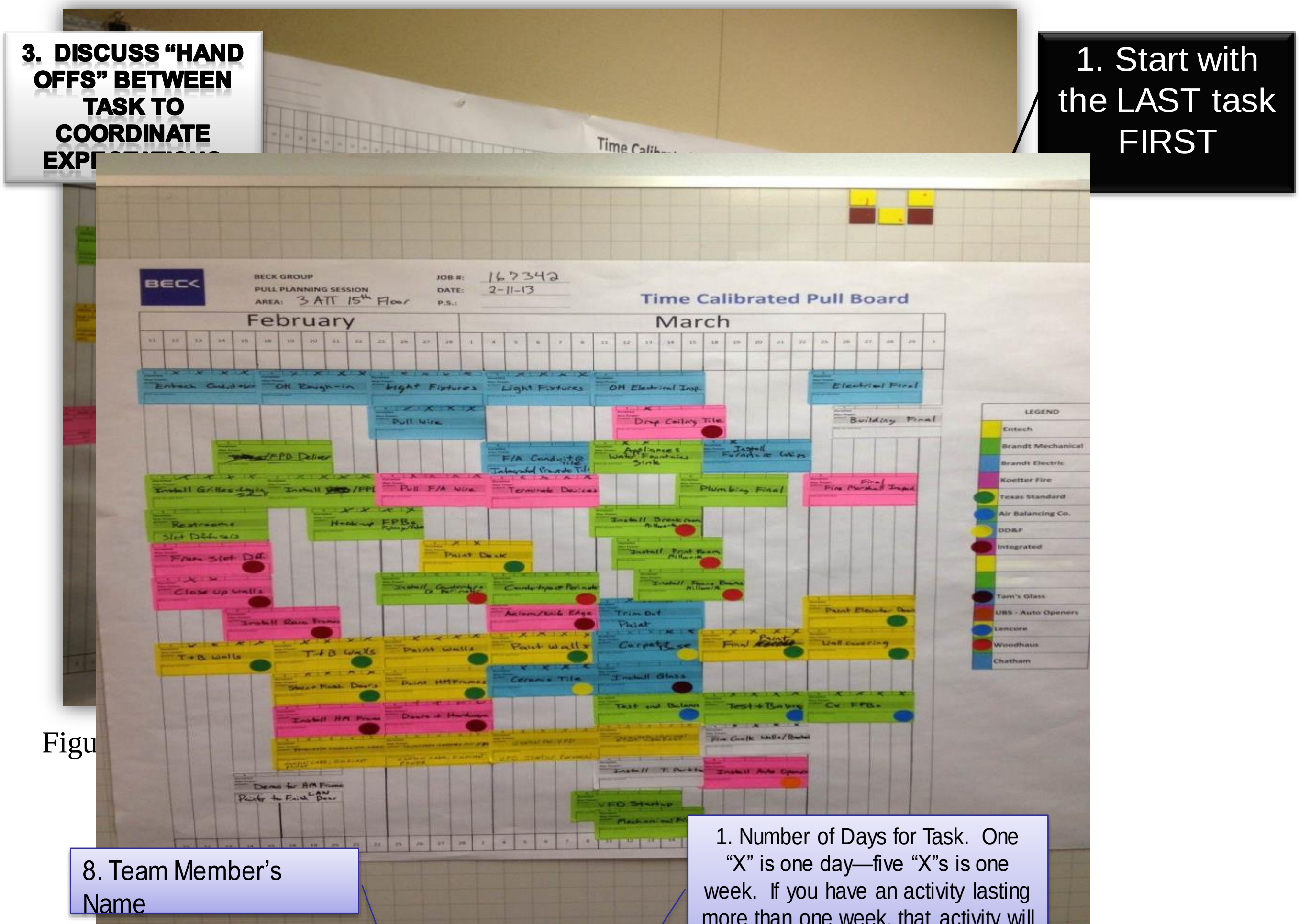

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Figure 12. Look ahead planning at a constructio

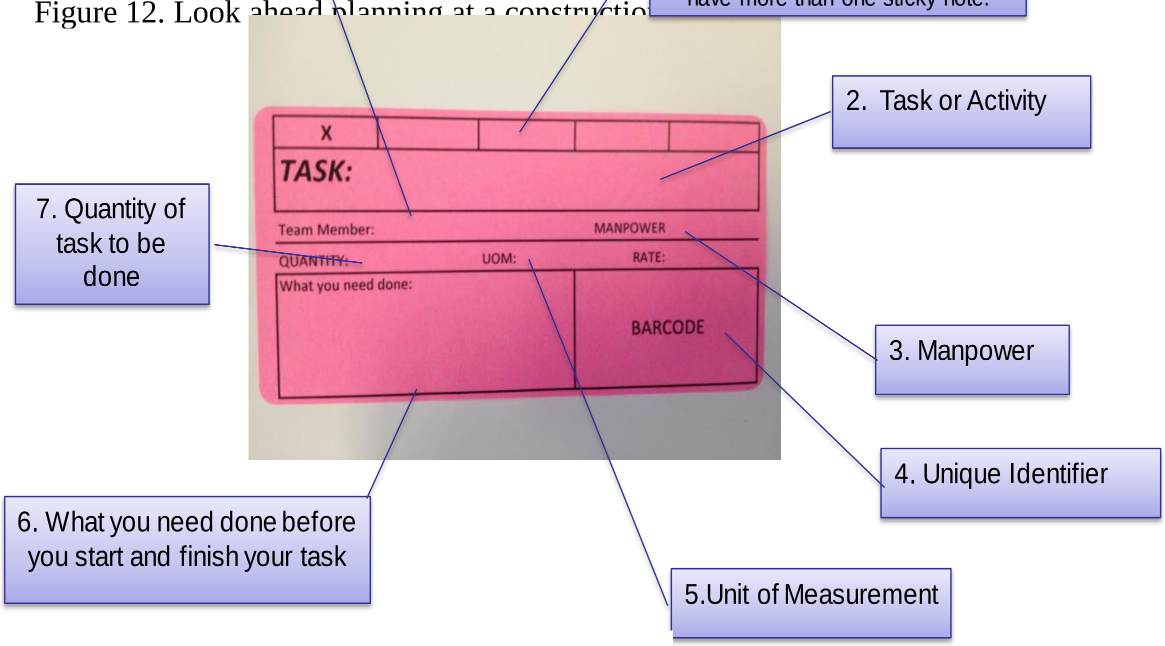

Figure 13. Pull Planning

Look ahead, Hamzeh et al. (2008 and 2012) is part of the LPS that focuses on making the work ready by identifying and removing constraints, obstacles, impediments in advance of the work. This look ahead may be from six weeks out to one week out and in some cases the day before the work needs to be done, see Figs. 12 and 13.

A constraint Feng and Burns (1997 and 2000) is anything that prevents an activity from starting, advancing or completing. Typically is something not foreseen in the phase or pull planning but discovered through the process of look ahead plan, see Fig. 14.

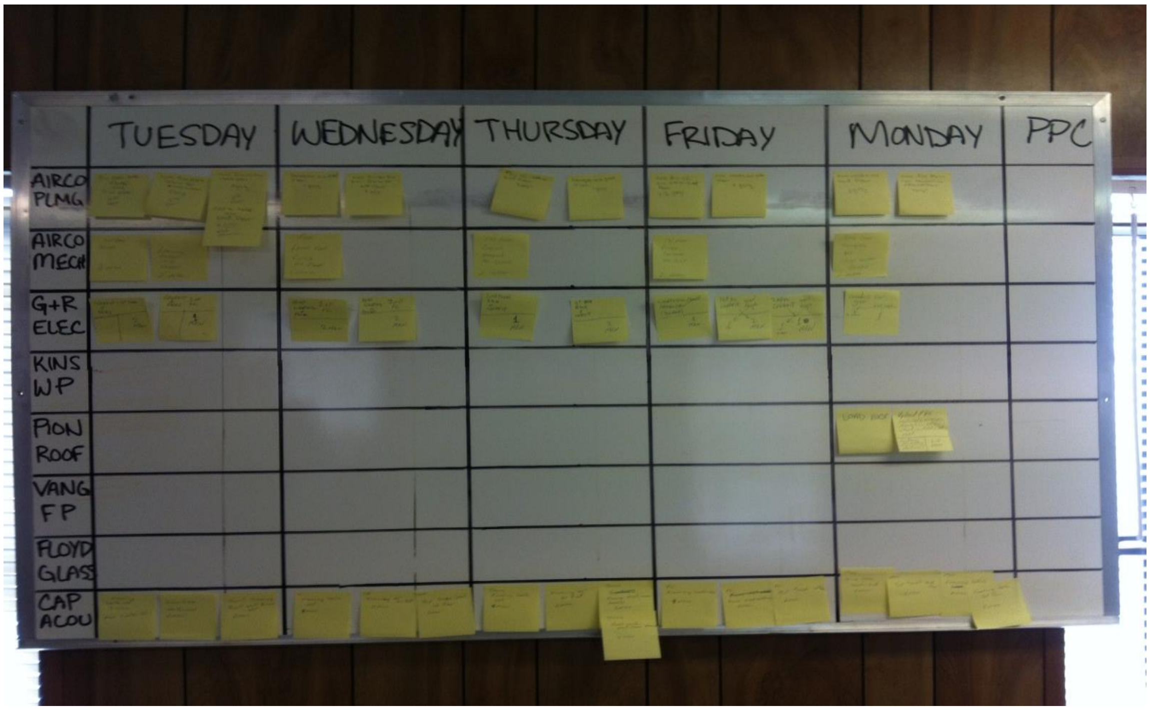

Figure 14. Weekly work plan

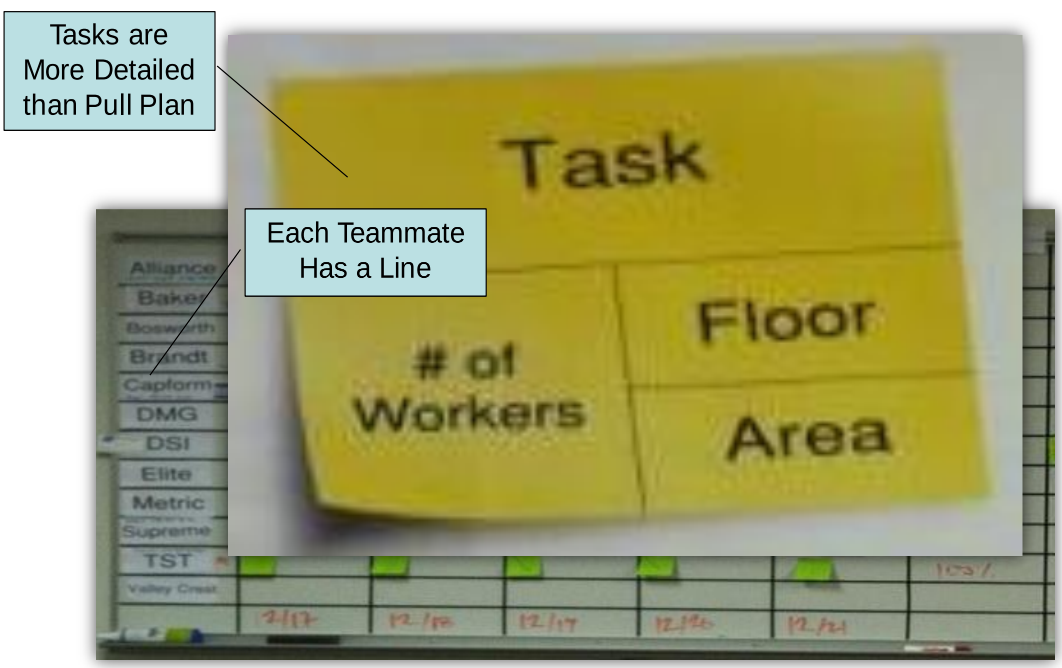

Figure 15. Weekly work plan task per pull plan

Make work ready Ballard et al. 2003) is then the process of removing constraints, impediments, obstacles so that the task can be executed correctly, completely, timely and the information on how to do it is unambiguously understood by those performing the work.

Weekly work plan, Ballard and Howell (1994) and Choo et al. 1999), is a commitment to act on the task because there are no constraints and can be executed as planned. The weekly work plan also considers what is understood as a correct, complete and timely task so that after it is done a check can be made that verifies its performance and captured in the Plan Percent Complete (PC) documents, Sacks et al. (2010), see Figs. 15 and 16.

Figure 16. Constraints, inspections and deliveries

A PPC is a time-line measure of how well the plan is being performed by others. For example: A check of the work done against the weekly work plan is entered in the PPC. If the work is complete and correct and timely it receives a 1 if not it receives a 0. The number of tasks for the week becomes the denominator and the sum of tasks that received a 1 becomes the numerator creating a fraction that can be translated into a percentage and tracked over time, see Fig. 17.

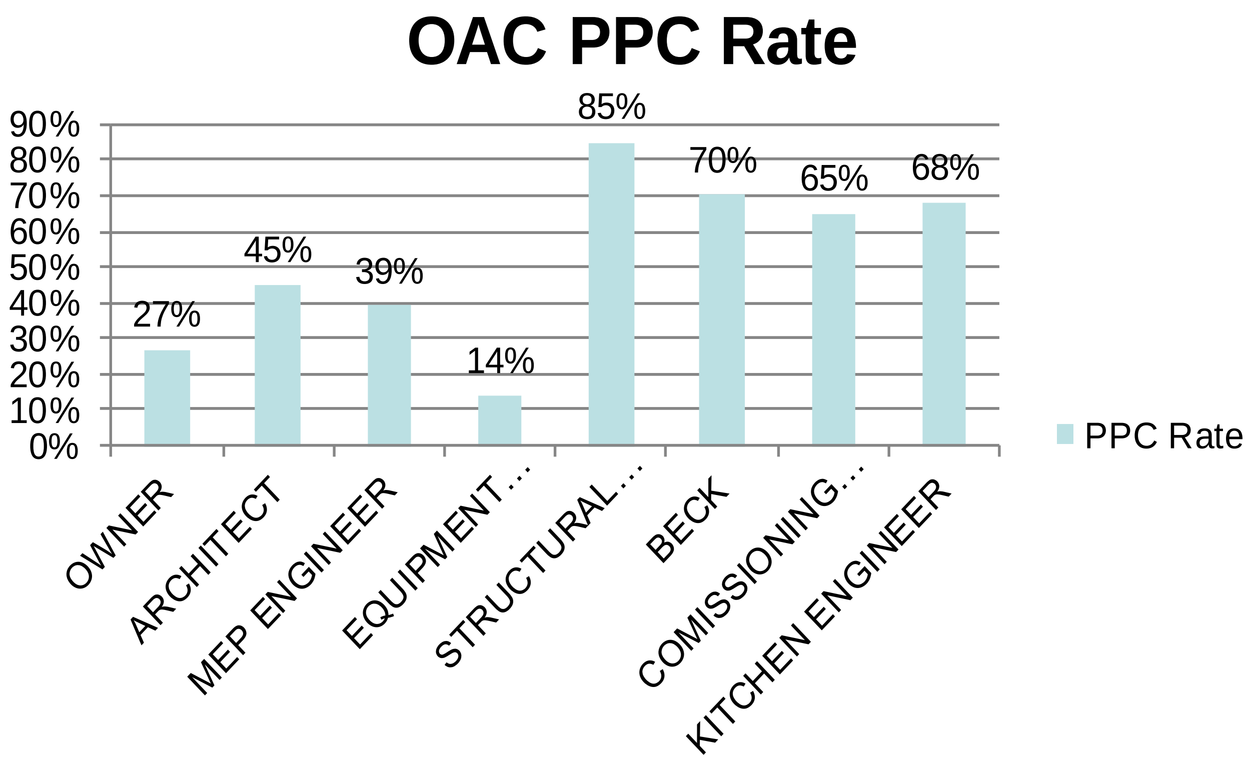

Figure 17. Final project PPC by stakeholder

In spite of all lean and other productivity and efficiency initiatives, the project reliability in the industry remains low. Why is that possible? Because work is performed at the subcontractor level who is autonomous agents with two game positions, Fernández-Solís et al. (2015).

The game is played to fulfill the strategic plan: grow to survive (offensive) and survive to grow (defensive). In good times, grow to survive: Sub-contractors and also general contractors, when awarded more projects than it has crews to manpower for a job, the unofficial practice is to scuttle crews from projects to man new projects.

Companies, no matter what, do not say: 'sorry but we just got awarded five projects and have crews for three so please go to my bond agent and collect on my performance bond'. In bad times, survive to grow: Subcontractors and general contractors let the middle management go; keeping upper management that is then tasked to do both jobs and the tactical boots on the ground is the last to go in real bad times. Upper/middle management now has to do more jobs than before and the net result is the same as in good times, moving from one to the other as fast as possible to maximize manpower productivity.

This type of action is not only at the subcontractor level but also upstream. Construction gaming is directed by economic cycles. Therefore it is endemic in the industry at all levels. For example, gaming happens at the owner, general contractor level, designer, consultant engineers and any service provider, subcontractor, supplier and vendor during good times when there is more work than can be done, in time, with scarce resources.

The systemic nature of the industry, Fernández-Solís (2008) responds to the cycles of the general economy with detrimental effect to reliable and consistent productivity. According to Dubois and Gadde (2002), a loosely coupled system is the main characteristic of construction.

A loosely coupled system in construction, along with the strategic gaming mentioned, conspire against a predictable and reliable planning efficiency. Loosely coupled system has been characterized by having the following attributes and examples in construction at the appropriate level:

- *Enormous number of permutations and possible combinations*. I.e. there is one owner but large number of stakeholders. Some typical stakeholders are: designers, consultants, GC, subcontractors, supplier and vendors. A different stakeholder may be used on every project, György and Fath (2007). Stakeholders will use a very large number of products and labor personnel called to execute the project, see Fig. 18.

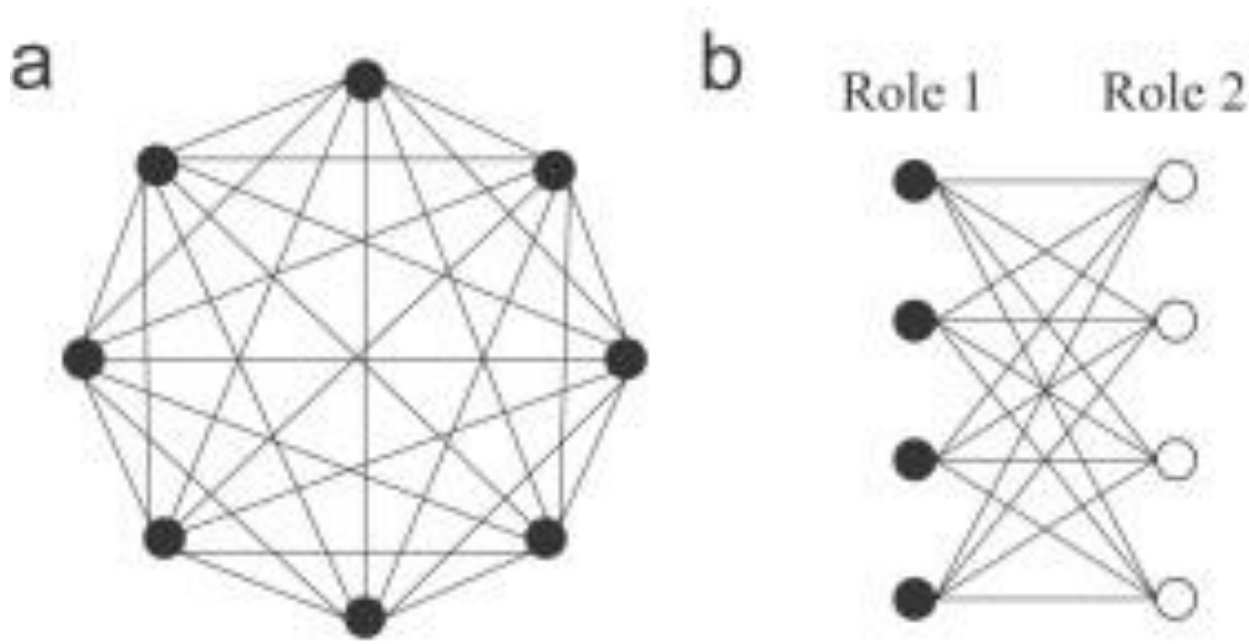

Figure 18. Schematic connectivity structure for (a) population (symmetric) and (b) two population (asymmetric) games. Black and white dots represent players in different roles. Adapted from:
http://www.sciencedirect.com/science/article/pii/S0370157307001810

- *Complex operations*. I.e. It is argued that building construction is complicated but not complex. However research indicates that due to the above large number of permutations and possible combinations, the lack of repeatability, the on-site, open to the weather, varying team, etc. have all the ingredients of a complex problem, see Fig. 19.

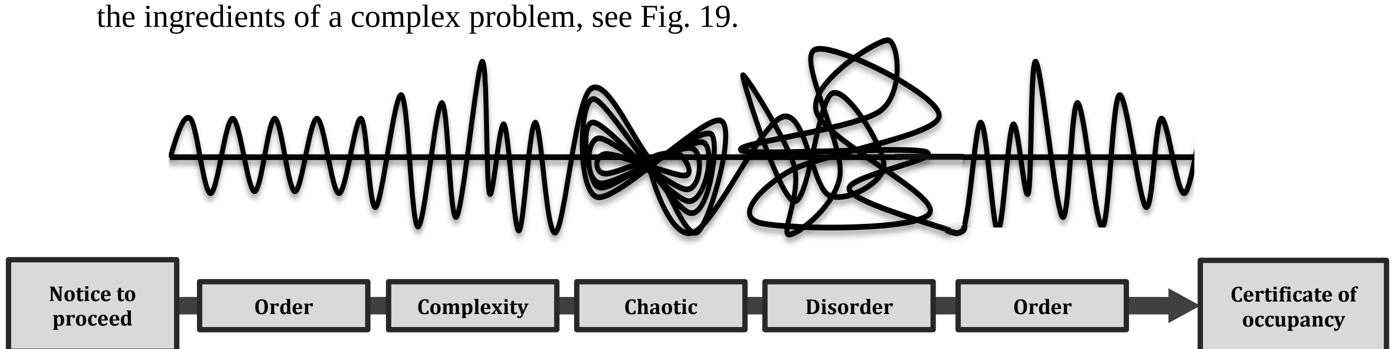

Figure 19. Graphic metaphor of order, complexity, chaos and disorder back to order

- *Inefficient operations*. I.e. this is apparent when studies and governmental reports compare service industries such as manufacturing and construction. Construction is estimated to operate at an average efficiency and effectiveness process and product rate of 50% when manufacturing operates at above 98%, Fernández-Solís et al. (2012).

- *Sub-optimization*. I.e. the systemic nature of construction indicates that most projects are a prototype, one-of-a-kind, and therefore hard to capture and enforce lessons learned. Every project, by virtue of site, location and team composition will be different in many ways with different challenges and variables. Optimization at the work make ready is somewhat possible. However, making a project optimization the standard of performance for all future projects in a company remains elusive. To standardize optimization in the industry requires a paradigm shift, and the transformation of an entire economic sector, a monumental challenge.

- *Some tightly coupled, others time-sensitive specialized activities with sequentially interdependent activities*. I.e. General Contractor self-performing work is an example of tightly-coupled, time-sensitive specialized activity that is followed with sequentially interdependent activities. A GC that self-performs site and foundation concrete work claims that it provides greater project schedule and budget control at a time when getting the project off-the-ground has major repercussions for the remaining work in the project, see Fig. 20.

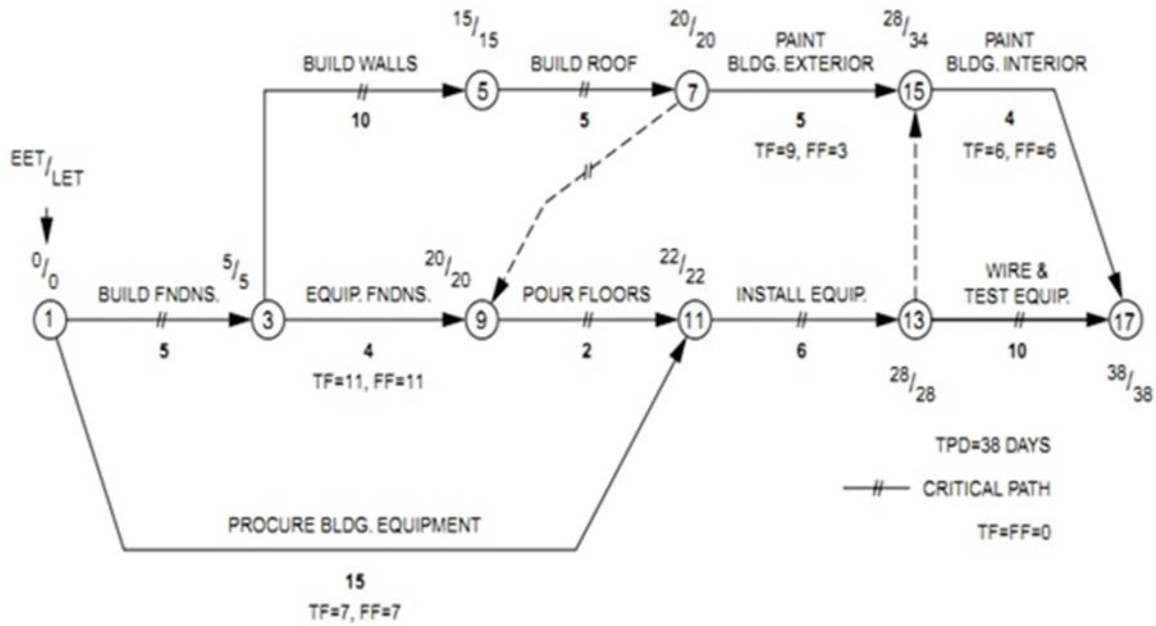

Figure 20. Graphic of planning through critical path method.

- *Overlapping activities*; long lead time and slack built in adaptive on-site changes and consequential changes, such as fast tracking in Design-Build projects in comparison with linear Design-Bid-Build projects, see Fig. 21. I.e. typical projects have overlapping activities by the same or different subcontractors that take place on the same or different areas of the project.

  Long lead items are critical to a project. Vertical circulation (elevators), Mechanical systems, and glazing are some of the long lead items identified in a project schedule and specifications. Float time is built into the schedule to account for on-site changes and consequential changes. In the case of long lead items and other imponderables that are unanticipated. Critical path scheduling methods and project budget controls from the owner, GC, sub-contractors, suppliers and vendors have these buffers included in the plans (Elazouni 2009 and Steyn 2001). These buffers are needed for the current systemic nature of the industry (Herroelen et al. 2002 and Zika-Viktorsson et al. 2006)).

  However, as the industry becomes more automated, the buffers and contingencies will shrink as production becomes more predictable and reliable. In other words, buffers and contingencies are a form of waste that has to be carried in the project at the current state of the art production practices.

- *Generation of variations*. I.e. a superintendent has total control and responsibility for everything that

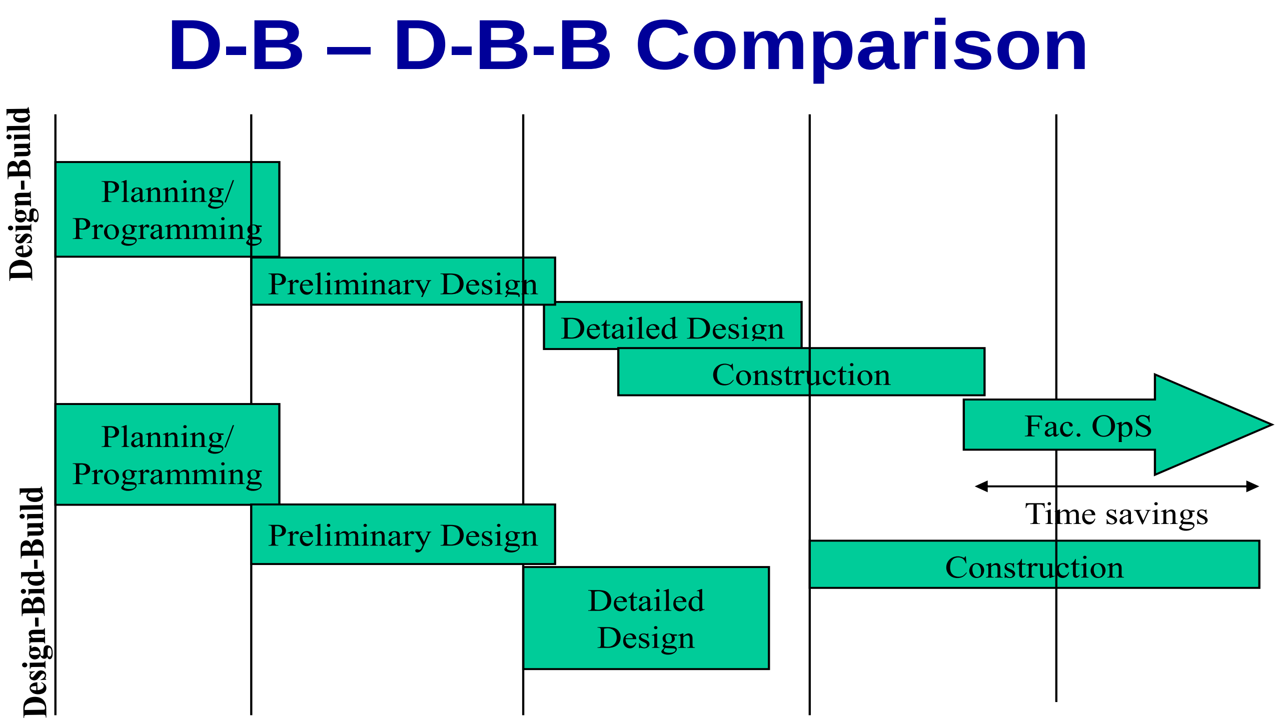

Figure 21. Graphic metaphor of Design-Build (D-B) fast track, concurrent and Design-Bid-Build (D-B-B) liner processes.

takes place on the site. A superintendent will attest that no two hours, days, weeks, months or projects are the same. The number of variations that has to be dealt on an hourly basis is the dynamics of building construction. Projects only stabilize after the Certificate of Occupancy (C.O.)

is issued, the project is past the warranty period and operations and maintenance take over the facility.

- *Self-determination; coordination with different firms, each adding a measure of slack*. I.e. A project list of service providers is extensive. There is a hierarchy of risk, responsibility and authority captured by a project organization chart. The complexity of the communication web is exponentially increased with the addition of a stakeholder (Brown and Eisenhardt 1997). The fact that stakeholders enter and exit the project at an appointed time and the project lead shifts creates another level of information transfer complication. The most critical aspect is the self-determination of stakeholders. This topic is treated below as the stakeholder autonomous agent.

- *Work is redone when non-conforming rather than product discarded as in manufacturing*. I.e. In the rush to get the project completed, anticipated and unanticipated events exhaust the time buffers, quality suffers in the push to finish and non-conforming work generates a punch list, see Fig. 22.

Project Name & Contract No.

Project Close-Out Time-Line

Turner Construction Co. Date

Task	Responsibility						Construction				Follow-up	Caution!	Refererence
	Exec. or Mgr	Engineer	Superintendent	Accountant	Cost Engineer	Purchasing	Project Start-up	25% complete	50% complete	75% complete	Within 60 days after work is complete	Before final payment to subcontractor	
Start-up													
1 Obtain a no lien agreement from the subcontractor						•	•						
2 Include subcontractors' close-out instructions in the buy-out		•	•			•	•						Section 4
3 Develop a list of close-out submittals and review it with the architect and owner		•					•						Section 4
4 Have subcontractors identify close-out costs in their Schedule of Values			•				•						Section 4
5 Set-up a Project Close-Out Matrix		•						•					Sections 4 and 5
6 Develop a master Project Close-Out Schedule			•							•			
Punch List													
7 Obtain the subcontractor's Incomplete Items List			•							•			Section 3
8 Develop an above-ceiling Incomplete Items List			•							•			Section 3
9 Produce the master Incomplete Items List			•							•			Section 3
10 Obtain the punch list from the architect and/or owner			•							•			Section 3
11 Obtain the Certificate of Substantial Completion from the architect		•								•			Section 3
12 Complete the punch list work and get final acceptance of all work			•							•			Section 3
Occupancy													
13 Develop a life safety check list			•							•			
14 Arrange for inspections by all governing entities			•							•			Section 3
15 Obtain sign-offs for all applicable tests			•							•			Section 3
16 Obtain the Certificate of Occupancy and transmit to the owner via the Project Engineer		•	•							•			Section 3
Documentation													
17 Obtain the Operations & Maintenance Manuals from the subcontractors		•								•			Section 4
18 Perform all required owner training			•							•			Section 3
19 Obtain warranties and guarantees from manufacturers, vendors and subcontractors		•								•			Section 4
20 Obtain attic stock and special tools from manufacturers, vendors and subcontractors		•	•							•			Section 3
21 Check subcontractors' progress in completing as-builts on a monthly basis		•	•										Section 4
22 Submit final as-builts to the architect		•									•		Section 4
23 Hold final general Job Minutes Meeting		•								•			Section 4
24 Send Subcontractor Close-Out Letters to all subcontractors		•								•			Section 4

ATTACHMENT 2-1 *Time_Line* SECTION 2 - PROJECT CLOSE-OUT OVERVIEW

Figure 22 Punch list template

Most punch lists have to do with commissioning of mechanical systems or finishes. However the list encompasses all the work of a project that is found, upon inspection or performance, to be deficient or defective.

In addition it is proven that the systemic nature of building construction is a complex system, Fernández-Solís (2013), Bertelsen (2005), adding the following elements:

- *Autonomous agents*: Stakeholders are varied, not identical, with different perspectives and interests, which change over time, Bertelsen (2005). Project stakeholders form a self-organization control structure, Kaufman, (1993), Edmondson and Moingeon (1998). I.e. All stakeholders, from the owner to the suppliers and vendors have the temporary project as the only unifying event. All autonomous agents function in the general economy and primarily work for their best interest and secondarily work for the best interest of the project. Ultimately the best interest of both organization and project should coincide but oftentimes it does not, hence the crux of the problem. The stakeholder's best interest within the general economy during upward trend (bull market or expansion) has an offensive position of grow to survive. However in a downward general economic trend (bear market or depression) stakeholders take a defensive position of survive to grow, see Fig. 23.

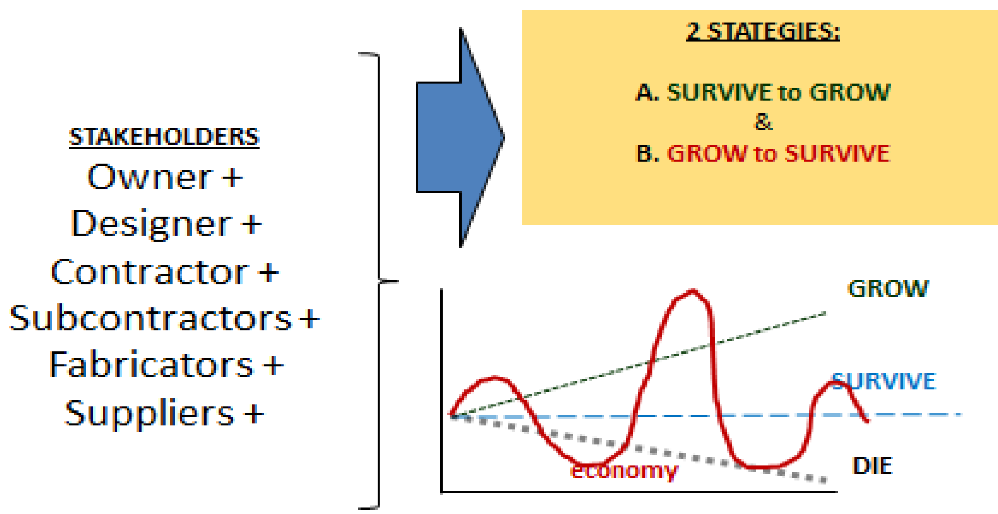

Figure 23. Stakeholder strategies in response to the general economy

Each stakeholder also has limited resources that have to be allocated among all the ongoing and upcoming projects. It is this feature along the defensive or offensive position that throws a kink into any project schedule. In a growing economy, an adverse event on ongoing projects may require a company re-allocation of resources from the other projects. A positive event, such as acquiring more projects those available resources may also require a reallocation of resources from an existing project. The same on a downward economy, the stakeholder may have to reduce manpower and reshuffle resources on existing projects. Depletion of projects from a company back-log in a depression may create problems with worker attitude and performance as the expectation of lay-off remains a possible option to the company.

- *Non-Standard*: The system allows varying associations over time. I.e. An owner may do from time to time another project with one of many more service providers that were used in the past. However, a greater probability is that the majority of the service providers for the same owner's new project will have different people involved. This oftentimes happens, even if the same stakeholders are contracted.

- *Co-evolution (self-organization)*: The parts may evolve in conjunction with each other in order to fit into a wider system. I.e. No construction project is prescriptive to the level of detail that is found in manufacturing. Construction organizations, and especially boots on the ground, evolve and adapt, during project duration, to each other's activities. Project planning implicitly assumes that the stakeholders and workers will bring to the project this co-evolution knowledge from past projects. No specification can prescribe the how to which is integral part of the stakeholder contribution to the project ability to self-organize the work on a day to day basis.

- *Self-modification*: Parts can change their associations or connectivity freely. I.e. Project stakeholders have to adapt to the project dynamics in which players are constantly entering and exiting the project. The transferring of project's history and lessons learned among those exiting and entering is not a structured process. This deficient historical project transference requires an additional level of self-adaptation and modification that is not found in manufacturing. Manufacturing requires a clear communication and continuity such as when a crew shift takes place. Construction has a degree of communication and continuity but not to the level found in manufacturing.

- *Downward causation*: A system is made up of its parts, and the parts are affected by the emergent properties of the whole system. I.e. As mentioned, a project stakeholder is the active, autonomous, self-modifying part of a project that affects and is affected by all other players (parts) active at any point in time during the project execution. A project whole is greater than the sum of its parts but only when the C.O. is issued, and the owner takes position of the project for its intended use. There are a number of transferences that take place at this point where the principal value creation from downward causations takes place. Some of the transferences are: utilities, building for its intended use, insurance, start of warranties and guarantee period, and construction to permanent financing.

- *Self-reproduction*: The system can replicate, albeit with variations. I.e. Self-reproduction is dominant at the worker and foremen crew level were work is repeatable. Worker repeatable actions are prominent to less variability in relation to the rest of the processes.

- *Mutability*: Random interval changes may occur on the system. I.e. Predictable changes should be anticipated and taken account on the schedule and planning. Unpredictable and thus unanticipated changes have to rely on the buffers and contingencies embedded on a project. Because they are unpredictable from project to project random but calculated changes need to occur in order for the system to return to the schedule and cost boundaries.

- *Undetermined values*: the meaning of the system's interface with its environment is not specified at the outset, Bertelsen (2005). I.e. although this is a difficult concept to understand, it is an extension of the unpredictable elements afore mentioned that may surface in construction. Undetermined values are generated by autonomous agents react to the state of the general economy to advance the strategy of their game plan.

- *Fitness*: The distribution of choices can be modeled using the concept of fitness landscapes, with local optima and global optimum that are relative and dynamic. I.e. Scheduling attempts and plans could not be done if construction did not have a local optima and a global optimum. However making the schedule exercise adapt to the dynamic condition in the field with above mentioned undetermined values remains elusive, even with lean practices such as LPS.

- *Non-uniform*: The system is different and evolves in time in response to internal and external demands. I.e. Non-uniformity captures the internal and external dynamics of a project. It is the major contributor to project risk.

- *Non-linearity (non-equilibrium)*: The system operates far from equilibrium since it takes energy from its environment Black et al. 2000 and Cooke-Davies 2002. I.e. it is safe to state that without major effort at planning and maintain execution boundaries, a project will gravitate towards chaos Araujo et al. (2003). Therefore a project consumes an inordinate amount of energy by all stakeholders to keep in the equilibrium. The boundaries a cost and schedule plan guide the project equilibrium. These boundaries protect the project from the non-uniform forces that internal and external forces may exert to take it out of equilibrium, Araujo et al. (1999).

- *Emergence*: A number of simple entities (agents) operate in an environment, forming more complex behaviors as a collective. I.e. The design intent is captured by a set of contract documents that include drawings, specifications and a contract. The contract documents are used to create the project flow form the simple to an environment forming ever increasing complex entities. Collaborative behaviors emerge in patterns and systems as a collective towards an orderly finale resulting in the C.O.

- *Attractors*: The system has multiple dynamic attractors; it can be stable for a while, but not permanently. I.e. A project, as defined above, is a dynamic endeavor of multiple stakeholders that are autonomous agents acting as attractors of order (Pennypacker and Dye 2002). However from time to time the project external (such as autonomous agents) internal and external forces, (such as all of the other above mentioned), temporarily force it towards non-linearity, deviation from plans and expectations.

- *Phase changes*: The feedback may lead to sudden jumps to other (relatively stable) phase. I.e. A project builds from phase to phase. Past phases tend to be more stable that current or future phases.

- *Unpredictability*: The system is chaotically sensitive to its internal conditions. I.e. The owner interest is at two critical points of a project: Notice to Proceed and certificate of occupancy (C.O.). In this sense an owner sees a project as a linear entity. The GC sees the cumulative variability of the subcontractors but as one high is offset by another low the variability is smoothed out. The subcontractor's foreman is the one that sees the greatest amount of repeated motions but greatest performance variability. An analysis of projects PPC show the chaotic tendencies, when they occur at the foremen group level, see Fig. 24.

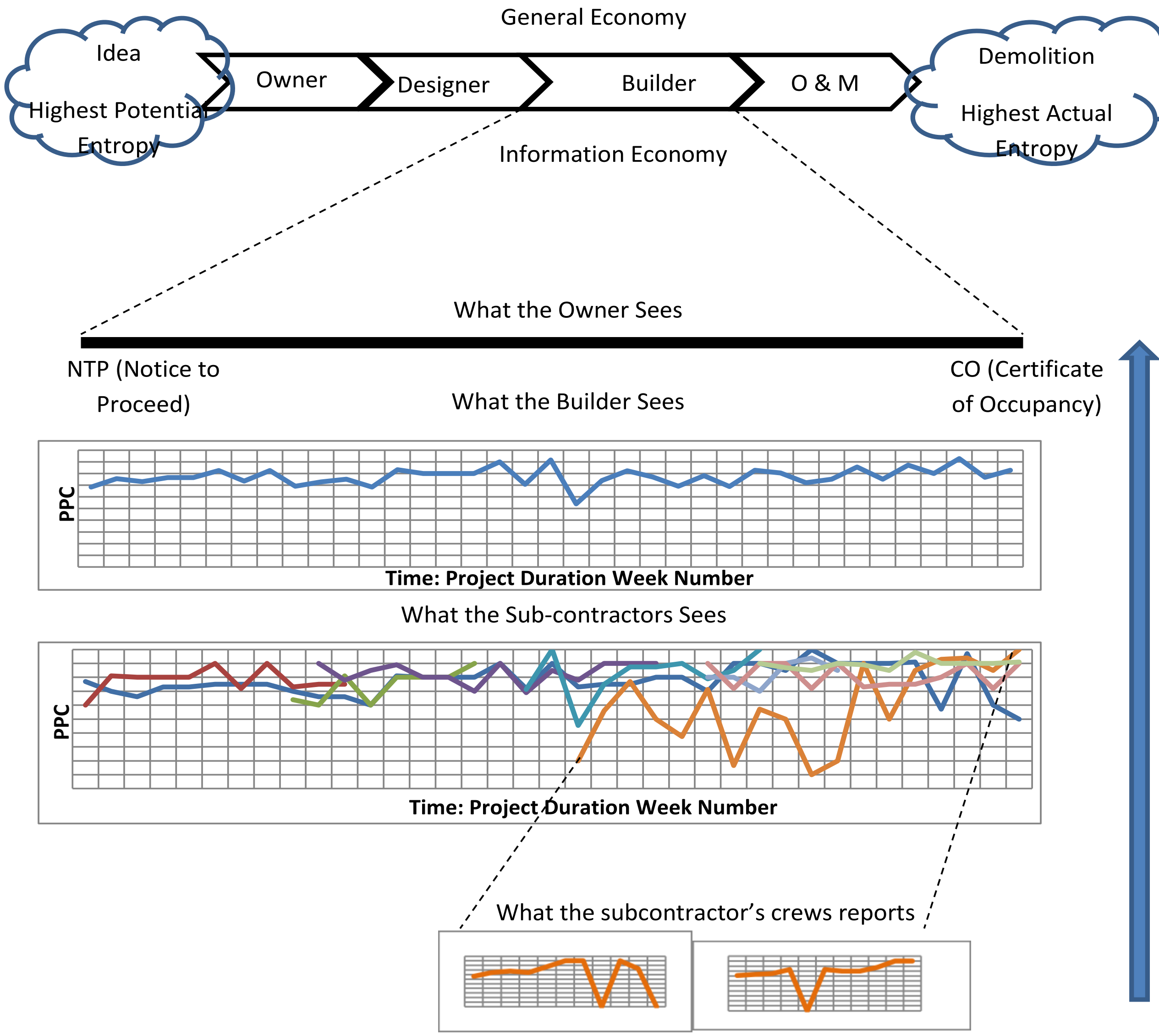

Figure 24. Graphic metaphor of how owner, builder, subcontractor and crews view a project in terms of PPC reports.

- *Instability*: Over the long-term step changes or catastrophes occur. I.e. the term catastrophe may be too severe for a typical project. The instability in production has the potential to introduce chaos in a relative smooth process. The probability of instability, chaos and catastrophe occurring in any one project is high due to the systemic nature of the industry. This is why construction finance is a risky business and demands a premium. This is also why bonding and insurance provide some protection and performance assurances. However this is also why there is a profitable field of construction arbitration, mediation and litigation.

- *Learning organization*: The organization evolves by learning from experience and errors. I.e. learning from errors occurs at all levels of the construction organization. Safety is critical at the boots on the ground. Lack of safety adversely affects productivity and by extension, the application for payment. Payment is based on percent complete that when compared to the established project schedule of values. At the subcontractor level the learning organization is manifested in order to provide an advantage over the competition and minimize safety and productivity waste.

Of all these, the greatest variable in construction productivity is the way the game is played by *autonomous players* (good times grow to survive and in lean times survive to grow) and how *reactive decisions* adversely affect ongoing projects. In other words, a company strategy for survival and growth requires that consideration of the state of all ongoing and future projects take precedent over the state of any single project.

Unfortunately instability, chaos or catastrophe on project A may require re-allocation of limited and scarce resources from other projects B, C, D. Other projects B, C, D may have to work with reduced resources while the problem in A is resolved. In time the projects B, C, D will get back the resources to complete but that has created an inefficient, unpredictable and unstable condition on the schedule and budget. Is this an exception or a common occurrence? All company strategic and logistic executions build on grow to survive or survive to grow game plan forming the fundamental, foundational, mission critical paradigm.

The most popular alternate to sub-contracting the work to autonomous agents is for a subcontractor to self-perform the work. An indication of the contrast between sub and self-perform work takes place during RFQ and RFP Company written and oral presentations. Companies claim that, in self-perform work, they have more control on the material, labor, schedule and cost than if done by others. For example, it is common for a company to self-perform foundation concrete work as it sets the stage for all other work. If this work is delayed in any way the project starts with a crashed schedule and may have used all the buffers that will be needed when other imponderables occur.

PROJECT DESCRIPTION	**DATA PROCESSING**	**RESULTING INFORMATION**	**MODEL INPUT**
PRODUCT DATA FUNCTIONAL REQUIREMENTS	QUALITY FUNCTION DEPLOYMENT	NUMBER OF PROJECTS AFFECTED	RELATIONAL COMPLEXITY
PROCESS DATA PROJECT PRESEDENCE AND DEPENDENCIES	DECISION SUPPORT STRUCTRE MATRIX	GAMING AND ASSYMETRIC INFORMATION	RELATIONAL UNCERTAINTY
ORGANIZATION DATA DECISION INPUT DATA AND GAME PLAN	ASSIGN PROJECT PRIORITY	MAPPING BETWEEN PROJECT PRIORITIES	DYNAMIC RESPONSIBILITIES AND INTERDEPENDENCIES

Figure 25. Processes of transforming organizational projects objectives into model inputs

Fig. 25 captures the proposed process for transforming organizational project objectives (product, process and organization data) into model inputs. This research paper identified dependent, independent and interdependent variables and the source of their metrics. The metrics will come from real projects.

TACTICAL

Tactical comes from the Greek taktike techne meaning "art of arrangement." When something is tactical, it is artfully arranged, or planned. In construction, the personnel at the tactical level of each stakeholder organization are the boots on the ground.   Boots in the ground are those close to the physical execution of the logistic plans, of interpreting the information provided. In general, the tactical level of any organization is charged with execution: creating a final product that is accepted by the owner (public or private) for its intended use.

The Contract Administrator (C.A.) in an architectural firm, a service organization, is the equivalent boots on the ground.   The C.A. interfaces between the owner's representative in the field and the builder to execute the design intent and make the project a reality. The owner's organization, through the owner representative, is the equivalent of boots in the ground. The tactical level personnel captures lessons learned--actual cost, schedules, obstacles, project flow, and performance. This performance information is passed to the logistics level for assimilation into future best practices. Best practices are filtered up to the strategic level, affecting the direction of the organization and its directive of growth and survival.

Work task/time studies attempt to optimize performance at the tactical level. The problem as initially observed (P_1) is that there is waste material and labor motion, Wilkinson (2013). The tentative solutions (S_1) rely on work task breakdown, (Lindhard and Wandahl (2012), time studies, and value stream analysis, Rosenbaum et al. (2013), Tommelein and Weissenberger (1999), Sacks et al. (2010), Ballard et al. (2003) and Frödell and Josephson (2008). Industry practice indicates that one of these research findings contributed any significant waste reduction on a consistent, predictable and permanent basis.

Value stream mapping as defined by six sigma, VSM (2015) "is a lean manufacturing or lean enterprise technique.   VSM is used to document, analyze and improve the flow of information or materials required to produce a product or service for a customer." A comprehensive set of VSM of discrete construction activities have not yielded significant productivity improvements, Dubois and Gadde (2000). The entrenched way of doing the work has not substantially changed, see Fig. 26.

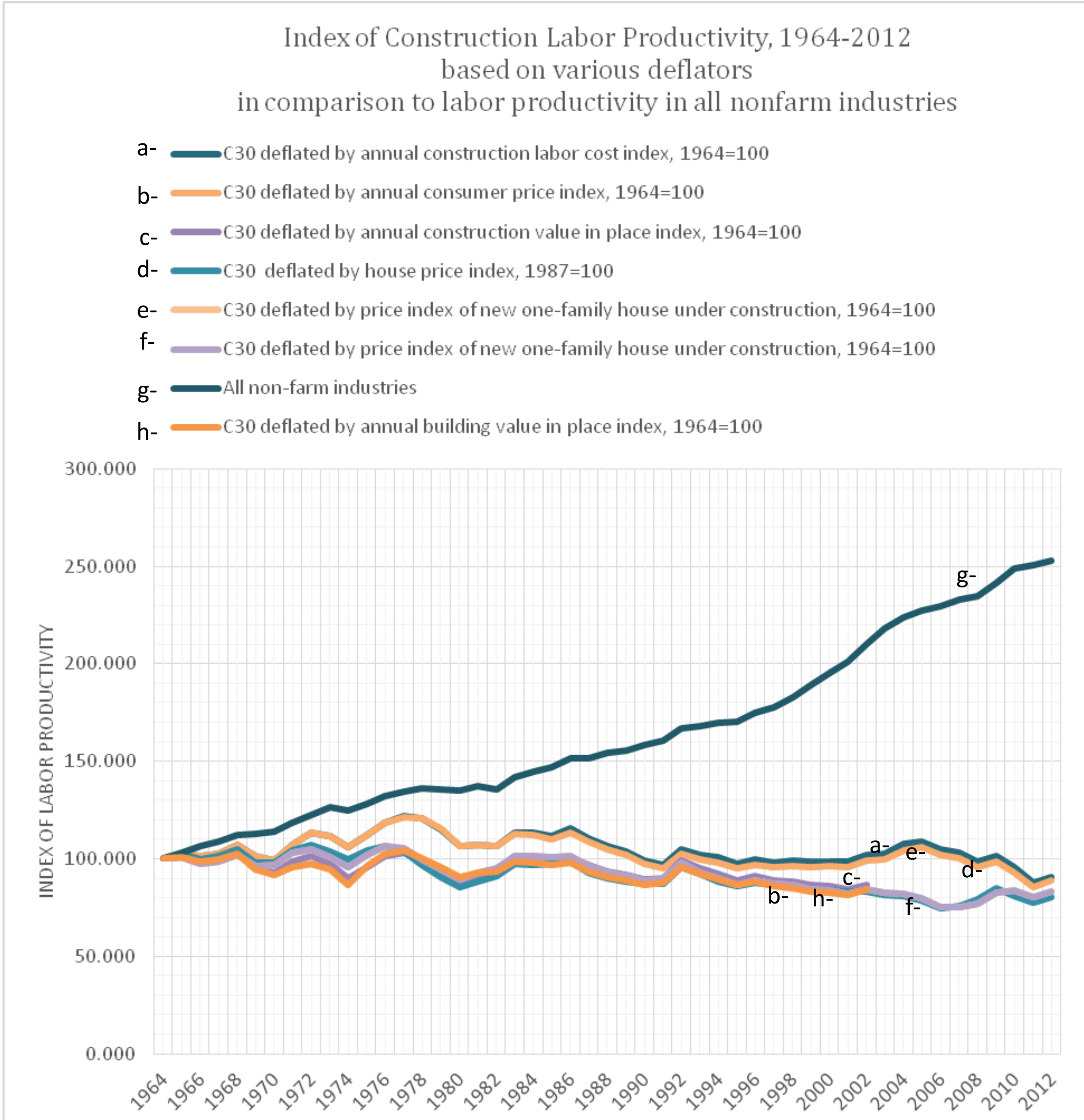

Figure. 26. Labor productivity in the construction industry. Reprinted from Teicholz (2013), with permission

Conclusion

There is a significant difference between a builder and a manager. Most general contractors are managers of projects and thus managers of information that others need in order to build, such as the specialty builders or subcontractors. The owner and designer teams likewise generate information and pass it to the general contractor. The GC adds value to the information package through its services and passes it to the specialty builder (subcontractors). The subcontractors add more value to the information package in the form of detailed buildable instructions. The foremen and its group of laborers take the information from their subcontractors and build.

A builder is a company that directly employs labor and has a significant labor risk on the work that they self-perform. This potential risk is the main reason why contractors do not self-perform work as much as they used to. Contractors have found that it is cheaper and less of a risk if they subcontract the work to specialty builders. Once the project structure places a general contractor in charge of specialty builders we have in essence a meta-project, a project of projects (Cusumano and Nobeoka 1998). The specialty builders, along with the general contractor, designer and its team and the owner are all working within the general economy as autonomous agents with a game plan: grow to survive a downturn and survive to grow in an upturn economy.

Company organization, structure, game plan and the fluidity they bring into execution is the cause of variability in production. All the efforts to improve productivity have failed and will fail unless they take into consideration the realities that occur beyond a contract boundary. The productivity war is not fought inside the walls of a project but inside the walls of a company with a survival and growth strategic game plan that oftentimes sacrifices the short term project plan.

Structured literature review was used to identify and analyze published research regarding construction productivity at the above-mentioned three levels. Sketches of organization and project models were created. These models are based on independent, dependent and interdependent variables uncovered in the literature review. The models use organization and process description language (Jin and Levitt 1996) to feed a project simulation that in turn will feed a meta-project Monte-Carlo simulation expected to generate massive quantity of data, see Fig. 27.

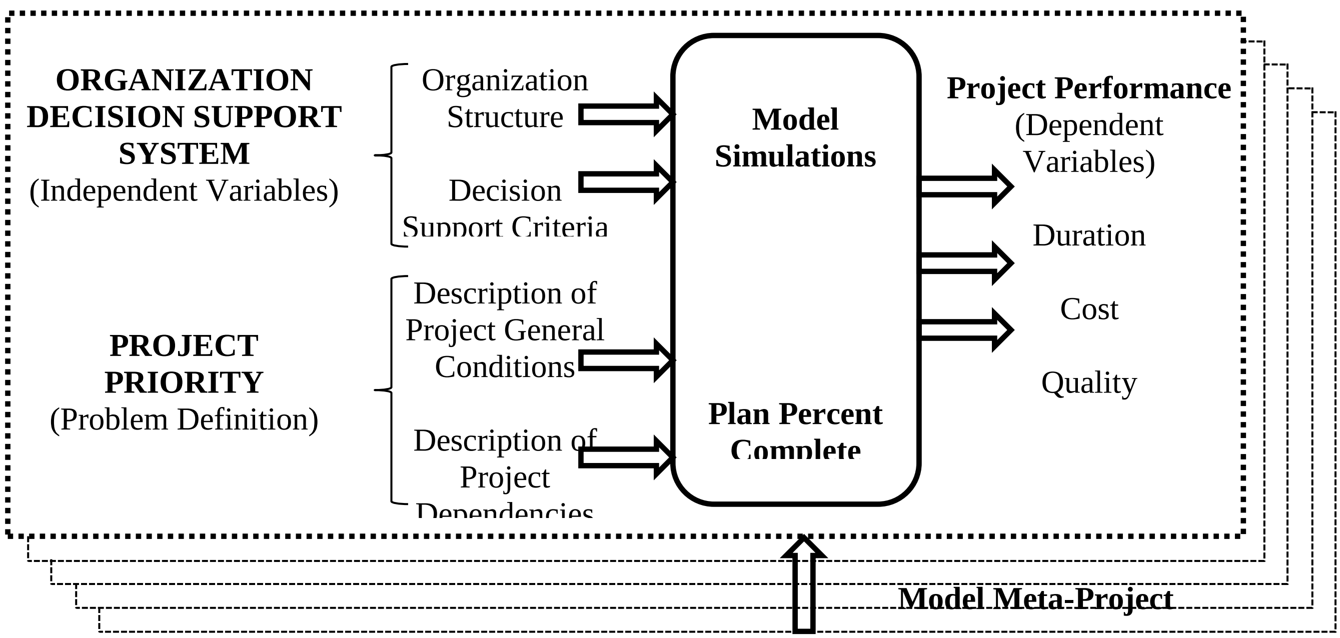

Figure 27. Inputs and outputs of model and meta-project model

The data will be tested internally and externally through case studies and verified against actual projects, organization and productivity theories and the experience of project personnel, see Fig. 28 for the proposed model architecture.

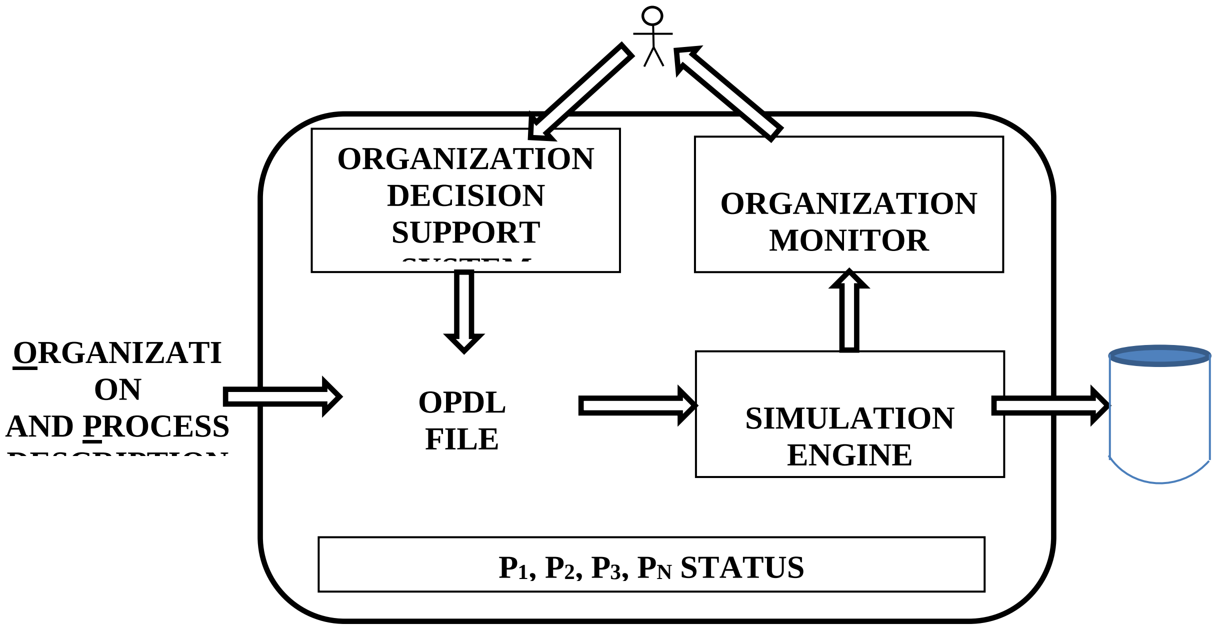

Figure 27. Model system architecture

Extensive and validating research is needed on the general contractors and subcontractors strategic game plans and their meta-project logistics: how they internally schedule projects, on hand and upcoming as well as how critical issues are handled when they impact other company projects (Choo and Tommelein 2003).

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