LEAN SUPPLY SYSTEMS IN CONSTRUCTION

Roberto Arbulu[1] and Glenn Ballard[2]

ABSTRACT

This paper proposes a strategy to improve the management of supply systems in construction using lean principles and techniques. The objective is to assure on-time delivery of information and materials to project sites at least cost and maximum value for the final customer. The primary mean for achieving this objective is to accomplish supply management functions with least waste; e.g., low supply and demand reliability, large inventories not needed to absorb variability, and physical waste. The paper explores supply complexity in construction in order to better understand where certain types of waste are originated. The strategy proposes the use of a web-based tool based on the Last Planner System to improve planning reliability so demand variability is minimized, the use of regional logistics centers for distribution of materials to sites, the use of kanban techniques to pull selected materials on a just-in-time basis, and a link between production control and material management processes on site. It also highlights the importance of minimizing material lead times with emphasis on standardization and pre-assembly practices so supply systems are more effective. It concludes highlighting the most important challenges for the implementation of this strategy.

KEY WORDS

Assembly package, inventory, just-in-time, kanban, logistic centers, pre-assembly, supply chain management, value stream.

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INTRODUCTION

In recent years, there have been several efforts to better understand how to manage construction supply chains efficiently and effectively (e.g., Wegelius-Lehtonen 1995, O'Brien 1995, Wegelius-Lehtonen and Pahkala 1998, Naim et. al. 1999, Vrijhoef and Koskela 2000, Arbulu et. al. 2003). Achieving excellence in the management of construction supply chains represents a way of increasing competitive advantage in the market. The reality is that supply chain participants (i.e., owners, contractors, suppliers, etc.) are still in exploration towards a better understanding of what supply chain management is, how they can increase their competitive advantage by applying it, and the dynamics it involves.

Construction practitioners have been witnesses of how the construction industry has been bombarded with so many 'solutions' to the supply chain (this is the way they are being offered) creating confusion amongst supply chain participants regarding if these solutions should be adopted or not and how. A typical example of this is the introduction of standard solutions in the area of information technology. In most cases, solutions are not necessarily tailored to deal with the real problems of our industry leaving important gaps after their implementation (which indeed create opportunities for others to come to the party, and therefore the cycle never ends).

Instead of trying to identify which supply chain solutions should be adopted, practitioners in the construction industry should first get a basic understanding of how supply chains are configured first so a holistic view can be obtained. This is certainly not a task typically performed as part of standard procedures in construction. The use of value stream mapping represents an example of a tool to achieve this (e.g., Arbulu 2002, Arbulu et. al. 2003).

Construction is known as being ruled by schedules. It is not difficult to find management personnel arguing about working under so many pressures to achieve project milestones and not having the luxury of time to see the whole picture! This is, in part, a symptom from a construction industry dominated by extreme specialization within functionally stove-piped organizations. Everything is optimized to meet individual participant's performance objectives but far from optimal and from a systems perspective (e.g., Tommelein et al. 1999, Bashford et al. 2002). The question is: who is looking at the whole?

The management of supply chains is indeed a relatively new topic in the construction industry. Construction supply chains should be well thought-out networks of interrelated processes designed to satisfy end-customer needs (Arbulu et al. 2003). To achieve this, a holistic view needs to be adopted so opportunities for performance improvement at the systems level can be identified. Determining these opportunities will be difficult without understanding the dynamics of the network of interacting activities in the supply chain (system behavior). This paper explores some of these dynamics.

Along with supply chain complexity and dynamics, today's construction projects are known as 'complex, uncertain, and quick' (Shenhar and Laufer 1995). They require the definition, design, and implementation of temporary production systems that incorporate temporary flows of physical resources (e.g., labour, materials, equipment, etc) and information for the on-time completion of project milestones. These flows create what the authors name here as 'supply systems'. A supply chain may contain one or more supply systems.

This paper proposes a strategy to improve the management of supply systems in construction using lean principles and techniques. The objective is to assure on-time delivery of information and materials to project sites at least cost and maximum value for the final customer. The primary mean for achieving this objective is to accomplish supply management functions with least waste. The strategy proposes the use of web-based tool created using principles from the Last Planner System to improve planning reliability and to increase visibility across supply systems so demand variability is minimized. The use of regional logistics centers is considered for consolidation and distribution of materials to sites. The use of logistics centers is certainly not new. Other industries like retailing have incorporated logistic centers as part of their logistic strategies.

This strategy incorporates the use of lean techniques like kanban to pull selected materials on a just-in-time basis from suppliers or logistics centers to site. Linking production control and material management processes on site then become a must to achieve just-in-time deliveries. Finally, this paper highlights the importance of minimizing material lead times with emphasis on standardization and pre-assembly practices so supply systems are more effective. It concludes highlighting the most important challenges for the implementation of the strategy.

DEFINITION OF TERMS

This section is devoted to provide basic definitions for the following terms: supply chain management, supply chain, supply systems, and value stream. Definitions from recognized sources have been adopted. The intention is to bring some clarity to how these concepts differentiate and relate between each other.

SUPPLY CHAIN MANAGEMENT AND SUPPLY CHAIN

Tommelein et. al. (2003) performed an extensive study about supply chain practices in the U.S. construction industry. This study defines Supply Chain Management (SCM) as "the practice of a group of companies and individuals working collaboratively in a network of interrelated processes structured to best satisfy end customer needs while rewarding all members of the chain". This definition implicitly defines Supply Chain (SC) as a group of companies and individuals working collaborately in a network of interrelated processes.

SUPPLY SYSTEMS

The authors realize that the term supply system has not been extensively used in the construction industry. It may be confused with supply chain but it actually means something different. The authors propose that supply systems are systems that need to be defined, designed, and implemented to deliver effective flows of materials, information, and capital across the supply chain. Supply systems are therefore part of a supply chain, and as such, must be considered as an important part of any supply chain management initiatives.

VALUE STREAM

This paper adopts the definition of value stream provided by Rother and Shook (1998), which states that a value stream is "all the actions (both value added and non-value added) currently required to bring a product through the main flows essential to every product: (1) the production flow from raw material into the arms of the customer, and (2) the design flow from concept to launch". While supply chain relates to a network of companies working collaboratively, value stream relates to the process across this network.

Other terms that will be used in this paper are: assemble, fabricate, pre-assemble, prefabricate, prefabrication, lead time, and fabricator lead time. These have been defined in depth in Ballard and Arbulu (2004).

TRADITIONAL SUPPLY SYSTEMS IN CONSTRUCTION

The construction industry is dominated by specialization within functions in organizations and great fragmentation (Tommelein et. al 2003). One of these functions is procurement (sometimes known as purchasing). Traditionally, procurement practices in construction focus on obtaining the lowest price possible for each product and associated services (e.g., transportation). Previous studies (e.g., O'Brien 1999, Naim et. al 1999) have highlighted barriers to adopt supply chain management practices in construction. Certainly, one of these barriers is the way commercial deals are managed which determines (almost by default) how supply systems are finally configured. It is not difficult to hear that 'what happens after the procurement phase is a logistics problem' due to the lack of focus on achieving continuous flow to deliver the maximum value to the final customer. The conclusion here is that supply systems are not defined and therefore not even designed, they just happen!

Rethinking the role of procurement should be one of the first actions towards a change on how to better deal with supply systems. Procurement teams should take a more proactive role towards a better understanding of supply dynamics and complexity which will make explicit that supply can and should be controlled (people in construction operate as if they cannot control supply). One of the targets should be to control deliveries like site activities. The next section illustrates some basic areas of supply dynamics and complexity.

UNDERSTANDING SUPPLY COMPLEXITY

The application of supply-chain management techniques in manufacturing environments has been widely recognized as a source of important cost savings (e.g., Hopp and Spearman 2000, Arntzen et. al. 1995). The understanding of supply complexity has been a key area for this success.

This section is devoted to illustrate how supply complexity impacts temporary production systems in construction creating waste and potentially affecting on-time project completion. Challenges across the construction industry may vary accordingly with the complexity of each project. However, a challenge shared by all projects is the match between site demand and supply. Any type of variability in both demand and supply will be critical to effective project management and will impact the total production system performance increasing cost and time and reducing quality and safety. Following are three scenarios that demonstrate the interaction between supply and demand and how the influence of variability in both will degrade project performance.

SCENARIO 1: UTOPIA

Variability is omnipresent in any production and supply system. "Variability is closely associated with randomness. Therefore, to understand the causes and effects of variability, one must understand the concept of randomness and the related subject of probability" (Hopp and Spearman 2000). Womack and Jones (1996) define 'pursue perfection' as one of the five lean principles. Variability will then block the road towards perfection unless it is minimized. A production system with few signals of variability is closer to perfection. A supply system that includes production systems with minimum variability will therefore be more effective and efficient.

Variability can be understood as the opposite to reliability. The greater the system reliability, the lower the variability present in the system. Scenario 1 assumes that both the reliabilities[3] of supply and demand are 100%. It assumes a perfect and unreachable deterministic world (without variability). The end result is that materials and information - important components on any supply system - flow continuously. Figure 1 illustrates this scenario that represents utopia.

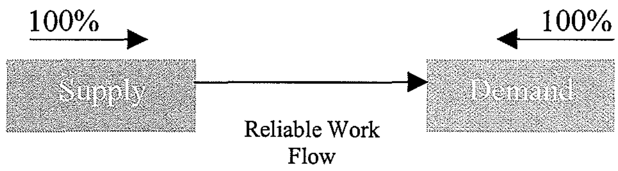

Figure 1: Matching Demand and Supply – Scenario 1

SCENARIO 2: RELIABLE SUPPLY – VARIABLE DEMAND

Independently of the complexity of the supply chain, scenario 2 assumes that suppliers are 100% reliable. Here variability comes in many forms and types, of which demand variability is one, and can be understood for our purpose as changes in requests after commitments have been made (Ballard and Arbulu 2004). One way to express the effect of demand variability is through the Percentage Plan Complete (PPC) that measures workflow reliability. In this scenario, PPC_{daily} = 90% (variability=10%). This means that 10% of the activities were not completed as planned. This implies that, if 100% of the activities were planned, the resources to complete those activities were available and ready to use on site. Therefore, 10% of the resources are not used when requested representing waste. The best-case scenario is when these materials can be installed the next day, but experience tells us that this is not always the case. The consequence is clear: materials accumulate on site (sometimes without control). Figure 2 illustrates this scenario with a triangle representing material inventories.

[3] Reliability is the measurement of work committed versus work completed for a given period of time.

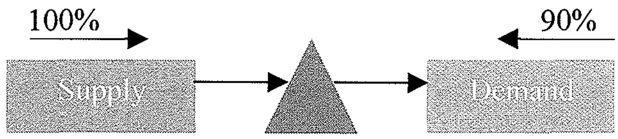

Figure 2: Matching Demand and Supply – Scenario 2

SCENARIO 3: VARIABLE DEMAND AND SUPPLY

In any production system, demand and supply vary. Figure 3 illustrates the details for this scenario with both the reliability of demand and supply less than 100%. The combined effect in this case is that work-in-process (WIP=materials inventories) increases as well as potential delays occur due to an unreliable supply. This increases cost and time (i.e., labour looking for materials not working, cost of managing material inventories) and also reduces quality and safety (i.e., space on site is used to storage materials potentially blocking workflow and risking product quality and safety).

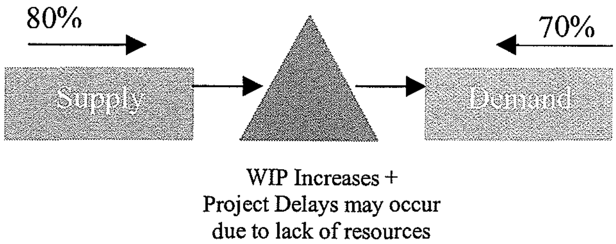

Figure 3: Matching Demand and Supply – Scenario 3

Scenario 3 is closer to reality in construction. However, scenario 3 is oversimplified and it does not take into account, for example, different sources of demand variability and how the complexity of the supply chain (e.g., number of supply systems) will impact cost, time, quality, and safety. Refer to Ballard and Arbulu (2003) for a more comprehensive description of different sources of demand variability.

The next section explore the supply part of scenario 3 in more depth by analyzing the effect of having a complex supply chain (made of several supply systems) in a temporary production system.

THE MATCHING PROBLEM

In *Factory Physics,* Hopp and Spearman (2000) describe the Assembly Operations Law as: "The performance of an assembly operation is degraded by increasing any of the following: (1) number of components being assembled, (2) variability of components arrivals, and (3) lack of coordination between component arrivals".

In construction, site installation can be seen as series of site assembly operations. Several and simultaneous site assembly operation complicate physical flows in a production system because they involve matching. Processes can't start until all necessary materials are present. The matching problem (Hopp and Spearman 2000) is augmented due to variability on each supply system. The more complex the supply chain (directly proportional to the number of supply systems), the smaller the probability that all materials required to complete a task will arrive to site on a just-in-time basis.

To illustrate this effect, the concept of Merge Bias is used. Merge Bias is a system characteristic that applies when several flows join, and completion of all activities along these flows (e.g., deliveries) is prerequisite to starting the activity that follows (e.g., site installation). The presence of several flows creates a 'matching problem' that constrains the start of the activity that follows. From a supply system perspective, the matching problem then can be understood as the probability of on-time delivery from 'N' supply systems to site and it can be calculated as the product of the probability of on-time delivery for each of the supply systems.

Figure 4 presents a simplified representation of 'N' different supply systems targeting on-time delivery to site. The assumption here is that each supply system includes only one material.

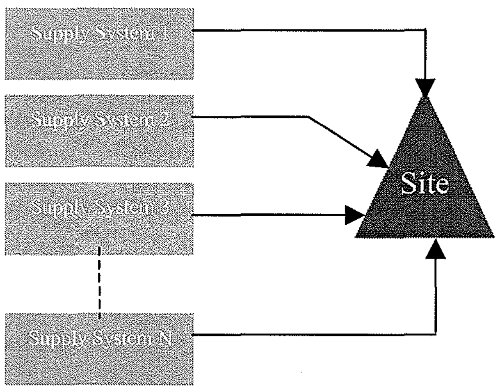

Figure 4: The Matching Problem

For example, if N=10 and the probability of on-time delivery for each of the 10 supply systems is 99%, then the probability of on-time delivery for all the 10 components or materials can be calculated as $P_{success} = 0.99^{10} = 90\%$. This indicates that independently on having a reliable supply (99%!/supply system), our chances to succeed decreased to 90% due to the complexity of the supply chain. If the number of supply systems is doubled (20), the $P_{success} = 0.99^{20} = 82\%$. The bigger the number of supply systems, the lower the probability of success to achieve on-time site deliveries. Table 1 analyzes different scenarios up to 20 supply systems assuming equal probabilities of on-time delivery for each system as 99%, 95%, 90%, and 75%. Figure 5 then presents the results graphically.

From Figure 5, it can be concluded that a combination of low reliability of supply and a complex supply chain (e.g., high number of supply systems) work together as a constraint to achieve on-time deliveries. If the reliability of supply is 75% and the supply chain has more than 10 different supply systems, the probability of success is close to zero.

The reader may be thinking that if this is really true, how is supply being done so projects can be completed on time? Firstly, the matching problem is a real problem. Secondly, the authors believe that few people in the construction industry are aware of the matching problem. However, intuitively, decisions are made to solve it by accumulating large buffers of finished products (sometimes more than 2 weeks of work) close to the matching point on site to reduce the probability of supply failure. Ironically, the industry then has been solving the matching problem by creating considerable amounts of waste. This has important consequences in project performance because (1) time and cost will increase due to labour looking for materials not working, and management creating teams to manage the logistics of the inventories, and (2) quality and safety will be reduced due to damage of stored materials, and stored materials being at risk of design revisions and programme changes especially if design decisions are made at the Last Responsible Moment.

	Psuccess			
# of SS*	**99%**	**95%**	**90%**	**75%**
1	99%	95%	90%	75%
2	98%	90%	81%	56%
3	97%	86%	73%	42%
4	96%	81%	66%	32%
5	95%	77%	59%	24%
6	94%	74%	53%	18%
7	93%	70%	48%	13%
8	92%	66%	43%	10%
9	91%	63%	39%	8%
10	90%	60%	35%	6%
11	90%	57%	31%	4%
12	89%	54%	28%	3%
13	88%	51%	25%	2%
14	87%	49%	23%	2%
15	86%	46%	21%	1%
16	85%	44%	19%	1%
17	84%	42%	17%	1%
18	83%	40%	15%	1%
19	83%	38%	14%	0%
20	82%	36%	12%	0%

(*) SS= Supply Systems

Table 1: Probabilities of On-time Deliveries

Certainly, one of the solutions to the matching problem is to have a buffer of materials (or finished products) on site that absorbs the effect of supply variability and supply chain complexity, but the real question is: how big should this buffer be? Minimizing the size of this buffer is part of the discussion presented in the following section.

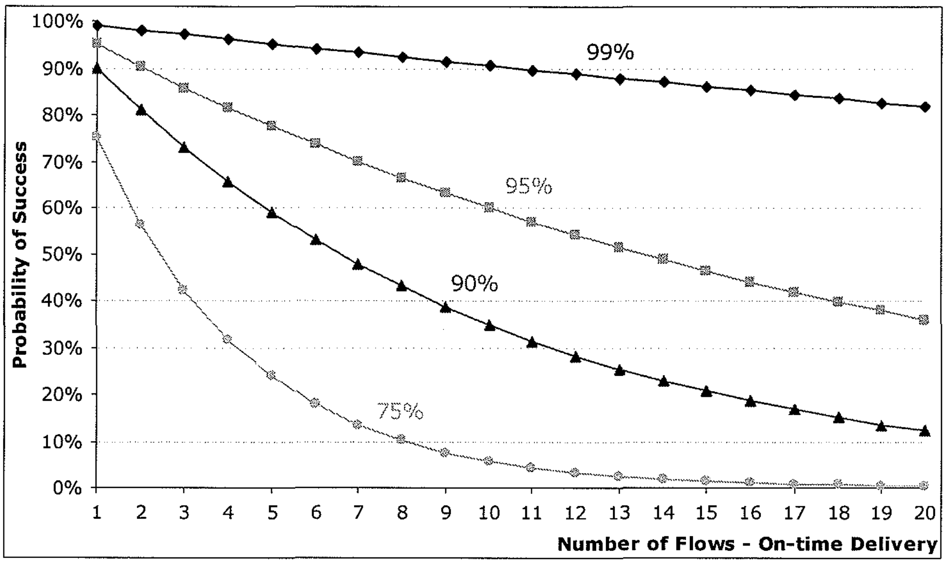

Figure 5: Graphical Representation - Probabilities of On-time Deliveries

THE STRATEGY: LEAN SUPPLY SYSTEMS

DEFINITION AND SCOPE

So far, the paper has illustrated some of the problem dynamics involved in supply systems and how the construction industry has been providing a solution far from optimal (an intuitive solution). The proposed strategy takes into account these dynamics focusing on achieving on-time delivery of information and materials to project sites at least cost and maximum value for the customer. The primary goals are to (1) simplify the configuration of construction supply systems, (2) to reduce variability embedded on those systems (including variability coming from site), and (3) to improve visibility across supply systems.

DESCRIPTION

This strategy proposes the implementation of the following:

1. Use of a web-based tool designed based on the Last Planner System (LPS) to control production on site on a daily basis increasing workflow reliability, therefore reducing demand variability. This tool should not replace planning, forecasting, and scheduling, but rather works in conjunction with them. Working with weekly production plans will not necessarily deliver the value expected to achieve just-in-time deliveries. Planning tools such as process mapping and scheduling are still required to properly manage workflow.

2. Link the web-based production control tool with the material management process. This way, engineered-to-order[4] and made-to-order products can be pulled from suppliers. This will also trigger the delivery of materials to Logistic Centres. This is better explained as follows.

3. Use Logistics Centers (LCs) as part of the definition and design of supply systems. A LC is defined here as a permanent consolidation point, where materials from different supply systems are assembled in packages before they are delivered to project sites. LCs can be seen as decoupling points in supply systems. Naim et. al. 1999 further discusses the use of decoupling points through an application to the UK housebuilding industry. It is suggested that LCs are located within a radius defined by 1/2 day's delivery duration. If this cannot be accomplished, special considerations need to be taken when designing the supply systems to avoid delays in transportation to site.

4. Kit today (at LCs) all information and materials in assembly packages for site installation tomorrow. The information required for kitting is sent via the web-based tool to LCs. The size of the buffer required to absorb variability is proposed as 1 day. This means that assembly packages should contain the materials required to complete 1 day of work for a specific task on site. The concept of single-piece-flow is applied here considering 1 day as the single piece.

5. Deliver assembly packages based on pull from site. The use of a web-based production control tool will provide the mechanisms and signals to trigger deliveries from LCs to site. This way the assembly packages will not be pushed to site without explicit request from site based on daily production plans. Waste in the system will be reduced and the use of space can be better controlled.

6. Define, design, and implement supply systems focused on replenishing selected made-to-stock materials using milk runs and kanban techniques. Arbulu et. al. 2003 proposes a strategy to implement this type of supply system. Wegelius-Lehtonen and Pahkala (1998) introduces standard materials (or made-to-stock) as a type of logistics chains in construction.

7. Define, design, and implement standardization and pre-assembly strategies. Pre-assembly can be performed at LCs or at suppliers' facilities as appropriate. Pre-assembly reduces the number of flows going directly to site therefore reducing the effect of the matching problem. Sometimes the matching problem can be moved upstream in the supply chain, but in that case, the scope is reduced (e.g., only materials required to assemble a package) and the environment can be more controlled than on site.

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[4] Construction deals with three general types of products: (a) Made-to-stock (e.g., consumables), (b) Made-to-order (e.g., standard materials from catalogs that require an order to be fabricated), and (c) Engineered-to-order (e.g., reinforcement – design information is required to start fabrication). Made-to-order and engineered-to-order products usually have long lead times.

8. Minimize material lead times and inventories not needed to absorb variability. Zabelle and Ballard (1999) highlight the importance of achieving a window of reliability greater than fabricator lead times by improving plan reliability and reducing lead time for supply. Lead times that exceed a site's window of reliability increase the probability of untimely delivery. A long lead time is determined relative to the ability of the customer (the construction site) to accurately forecast future states of the building process on site, and thus the ability to determine when a component will be required for installation. Ballard and Arbulu (2004) also discuss the drivers of prefabrication lead times.

   From a supply chain perspective, a short lead time has the following advantages over a long lead time (after Koskela 2000 p. 60): (1) faster delivery of the product or service to the customer, (2) reduced need to accurately forecast future demand, (3) less opportunity for disruption in the supply chain due to (design) changes, (4) greater possibility that participants will interact in a timely fashion with other supply chain participants, (5) easier synchronization of one supply chain with others (e.g., merging supply chains at the site), and (6) less opportunity for products to become obsolete.

This strategy is probably better suited for adoption by general contractors. This will require that contractors move from a single-project to a multi-project view as shown in Figure 6. Owners may also adopt the proposed strategy for a single project according with its magnitude. In this case, the boxes depicting projects in Figure 6 would represent sub-projects.

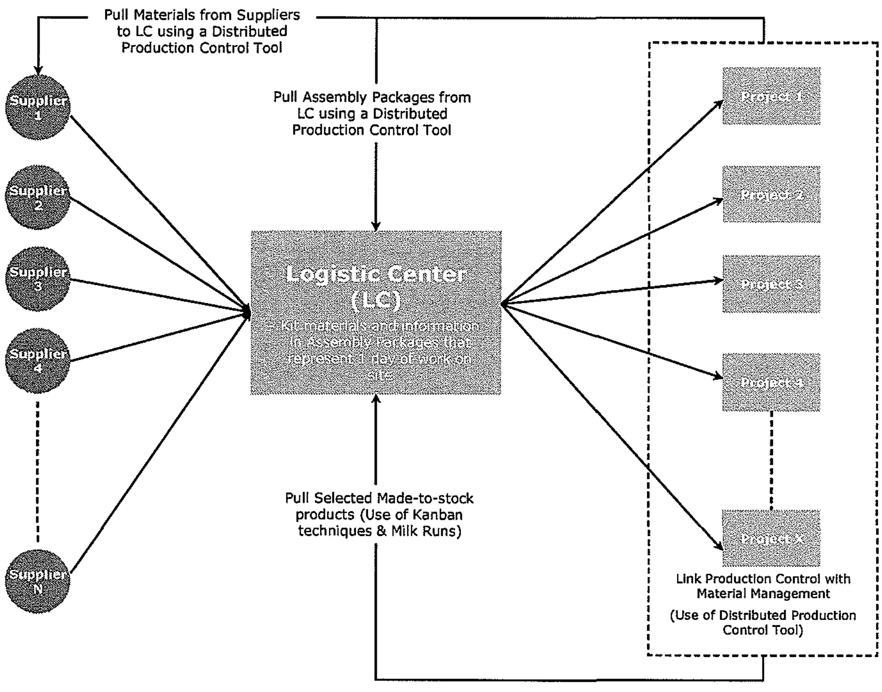

Figure 6: Lean Supply Systems Strategy

CONCLUSIONS

This paper has illustrated that the combination of variability in demand and supply will directly impact project performance increasing cost and time and reducing quality and safety. The proposed strategy targets the reduction of demand variability by stabilizing workflow on site. It also presented a way of reducing materials inventories on site by implementing pull techniques (i.e., use of kanban, pull assembly packages). It proposes the combination of the use of Logistics Centres and a distributed (web-based) production control tool that increases visibility across supply chains as well as provides better forecast information (live).

Successful implementation of this strategy will require a holistic view that includes not only a supply chain view but also a multi-project view. It is important to keep in mind that because of competitors' pressures, it is no longer sufficient to be the best. Companies must look for different and new ways to manage projects and for new techniques and tools to improve the reliability of supply and demand. The lean philosophy must be applied consistently to maximise the elimination of waste and increase workflow across the value stream. The conditions to achieve workflow should be set early in the process. Procurement should focus on sole sourcing and the creation of different supplier selection criteria including capabilities and culture (go beyond just lowest cost possible). A shift is required from purchasing thinking to system thinking. The lowest cost for each step in the value stream will not guarantee the lowest cost for the whole value stream! To adopt this view, this strategy requires the creation of a different environment where owners, construction companies, and material suppliers do business based on mutual trust and respect. Strategic relationships are therefore pre-requisites to extending lean concepts to supply systems and supply chains.

This strategy is being implemented in the construction of a major international transportation hub in the U.K. The authors will publish complementary papers to further detail the results of this implementation as well as different material management strategies within supply systems.

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