2.0 Literature Review

2.1 Introduction

What is “Lean”?

“Lean” is the core idea to maximize customer value while minimizing waste, simply “Lean” means creating more value for customer with fewer resources.

A lean organization understands customer value and focuses its key processes to continuously increase it. The ultimate goal is to provide perfect value to the customer through a perfect value creation process that has zero waste.

To accomplish this, lean thinking changes the focus of management from optimizing separate technologies, assets, and vertical departments to optimizing the flow of products and services through entire value streams that flow horizontally across technologies, assets, and departments to customers.

Eliminating waste along entire value streams, instead of at isolated points, creates processes that need less human effort, less space, less capital, and less time to make products and services at far less costs and with much fewer defects, compared with traditional business systems. Companies are able to respond to changing customer desires with high variety, high quality, low cost, and with very fast throughput times. Also, information management becomes much simpler and more accurate.

2.2 A Brief History of Waste Reduction Thinking

The avoidance and removal of waste has a long history, and as such this history forms much of the basis of the philosophy now known as "Lean". In fact many of the concepts now seen as key to Lean have been discovered and rediscovered over the years by others in their search to reduce waste.

2.2.1 Pre-20th century

The printer Benjamin Franklin contributed greatly to waste reduction thinking Most of the basic goals of lean manufacturing are common sense, and documented examples can be seen as early as Benjamin Franklin. Poor Richard's Almanac says of wasted time, "He that idly loses 5s worth of time, loses 5s, and might as prudently throw 5s into the river." He added that avoiding unnecessary costs could be more profitable than increasing sales: "A penny saved is two pence clear. A pin a-day is a groat a-year. Save and have."

Again Franklin's The Way to Wealth says the following about carrying unnecessary inventory. "You call them goods; but, if you do not take care, they will prove evils to some of you. You expect they will be sold cheap, and, perhaps, they may be bought for less than they cost; but, if you have no occasion for them, they must be dear to you. Remember what Poor Richard says, 'Buy what thou hast no need of, and ere long thou shalt sell thy necessaries.' In another place he says, 'Many have been ruined by buying good penny worths'." Henry Ford cited Franklin as a major influence on his own business practices, which included Just-in-time manufacturing.

The concept of waste being built into jobs and then taken for granted was noticed by motion efficiency expert Frank Gilbreth, who saw that masons bent over to pick up bricks from the ground. The bricklayer was therefore lowering and raising his entire upper body to pick up a 2.3 kg (5 lb.) brick, and this inefficiency had been built into the job through long practice. Introduction of a non-stooping scaffold, which delivered the bricks at waist level, allowed masons to work about three times as quickly, and with less effort.

2.2.2 20th century

Frederick Winslow Taylor, the father of scientific management, introduced what are now called standardization and best practice deployment. In his Principles of Scientific Management, (1911), Taylor said: "And whenever a workman proposes an improvement, it should be the policy of the management to make a careful analysis of the new method, and if necessary conduct a series of experiments to determine accurately the relative merit of the new suggestion and of the old standard. And whenever the new method is found to be markedly superior to the old, it should be adopted as the standard for the whole establishment."

Taylor also warned explicitly against cutting wages or discharging workers when efficiency improvements reduce the need for raw labor: "…after a workman has had the price per piece of the work he is doing lowered two or three times as a result of his having worked harder and increased his output, he is likely entirely to lose sight of his employer's side of the case and become imbued with a grim determination to have no more cuts by marking time and doing what he is told."

Shigeo Shingo, the best-known exponent of Single Minute Exchange of Die (SMED) and error-proofing or poka-yoke cites Principles of Scientific Management as his inspiration.

Single Minute Exchange of Die (SMED) is one of the many lean production methods for reducing waste in a manufacturing process. It provides a rapid and efficient way of converting a manufacturing process from running the current product to running the next product. This rapid changeover is the key to reducing production lot sizes and thereby improving flow.

Poka-yoke (ポカヨケ) is a Japanese term that means "mistake-proofing". A poka-yoke is any mechanism in a lean manufacturing process that helps an equipment operator avoid (yokeru) mistakes (poka). Its purpose is to eliminate product defects by preventing, correcting, or drawing attention to human errors as they occur. The concept was formalised, and the term adopted, by Shigeo Shingo as part of the Toyota Production System.

American industrialists recognized the threat of cheap offshore labor to American workers during the 1910s, and explicitly stated the goal of what is now called Lean manufacturing as a countermeasure. Henry Towne, past President of the American Society of Mechanical Engineers, wrote in the Foreword to Frederick Winslow Taylor's Shop Management (1911), "We are justly proud of the high wage rates which prevail throughout our country, and jealous of any interference with them by the products of the cheaper labor of other countries. To maintain this condition, to strengthen our control of home markets, and, above all, to broaden our opportunities in foreign markets where we must compete with the products of other industrial nations, we should welcome and encourage every influence tending to increase the efficiency of our productive processes."

2.2.3 Ford starts the ball rolling

Henry Ford continued this focus on waste while developing his mass assembly manufacturing system. Charles Buxton Going wrote in 1915:

> Ford's success has startled the country, almost the world, financially, industrially, mechanically. It exhibits in higher degree than most persons would have thought possible the seemingly contradictory requirements of

> true efficiency, which are: constant increase of quality, great increase of pay to the workers, repeated reduction in cost to the consumer. And with these appears, as at once cause and effect, an absolutely incredible enlargement of output reaching something like one hundredfold in less than ten years, and an enormous profit to the manufacturer.

Ford, in My Life and Work (1922), provided a single-paragraph description that encompasses the entire concept of waste:

> I believe that the average farmer puts to a really useful purpose only about 5% of the energy he expends.... Not only is everything done by hand, but seldom is a thought given to a logical arrangement. A farmer doing his chores will walk up and down a rickety ladder a dozen times. He will carry water for years instead of putting in a few lengths of pipe. His whole idea, when there is extra work to do, is to hire extra men. He thinks of putting money into improvements as an expense.... It is waste motion, waste effort, that makes farm prices high and profits low.

Poor arrangement of the workplace, a major focus of the modern Kaizen, and doing a job inefficiently out of habit, are major forms of waste even in modern workplaces.

Ford also pointed out how easy it was to overlook material waste. A former employee, Harry Bennett, wrote:

> One day when Mr. Ford and I were together he spotted some rust in the slag that ballasted the right of way of the D. T. & I [railroad]. This slag had been dumped there from our own furnaces. 'You know,' Mr. Ford said to me, 'there's iron in that slag. You make the crane crews who put it out there sort it over, and take it back to the plant.'

In other words, Ford saw the rust and realized that the steel plant was not recovering all of the iron.

Ford's early success, however, was not sustainable. As James Womack and Daniel Jones pointed out in "Lean Thinking", what Ford accomplished represented the "special case" rather than a robust Lean solution. The major challenge that Ford faced was that his methods were built for a steady-state environment, rather than for the dynamic conditions firms increasingly face today. Although his rigid, top-down controls made it possible to hold variation in work activities down to very low levels, his approach did not respond well to uncertain, dynamic business conditions; they responded particularly badly to the need for new product innovation. This was made clear by Ford's precipitous decline when the company was forced to finally introduce follow-on to the Model T.

Design for Manufacture (DFM) also is a Ford concept. Ford said in My Life and Work (the same reference describes just in time manufacturing very explicitly):

> ...entirely useless parts may be a shoe, a dress, a house, a piece of machinery, a railroad, a steamship, an airplane. As we cut out useless parts and simplify necessary ones, we also cut down the cost of making. ... But also it is to be remembered that all the parts are designed so that they can be most easily made.

This standardization of parts was central to Ford's concept of mass production, and the manufacturing "tolerances" or upper and lower dimensional limits that ensured interchange ability of parts became widely applied across manufacturing. Decades later, the renowned Japanese quality guru, Genichi Taguchi, demonstrated that this "goal post" method of measuring was inadequate. He showed that "loss" in capabilities did not begin only after exceeding these tolerances, but increased as described by the Taguchi Loss Function at any condition exceeding the nominal condition. This became an important part of W. Edwards Deming's quality movement of the 1980s, later helping to develop improved understanding of key areas of focus such as cycle time variation in improving manufacturing quality and efficiencies in aerospace and other industries.

While Ford is renowned for his production line it is often not recognized how much effort he put into removing the fitters' work to make the production line possible. Until Ford, a car's components always had to be fitted or reshaped by a skilled engineer at the point of use, so that they would connect properly. By enforcing very strict specification and quality criteria on component manufacture, he eliminated this work almost entirely, reducing manufacturing effort by between 60-90%. However, Ford's mass production system failed to incorporate the notion of "pull production" and thus often suffered from over-production.

2.2.4 Toyota develops TPS

Toyota's development of ideas that later became Lean may have started at the turn of the 20th century with Sakichi Toyoda, in a textile factory with looms that stopped themselves when a thread broke, this became the seed of autonomation or Jidoka. Toyota's journey with JIT may have started back in 1934 when it moved from textiles to produce its first car. Kiichiro Toyoda, founder of Toyota, directed the engine casting work and discovered many problems in their manufacture. He decided he must stop the repairing of poor quality by intense study of each stage of the process. In 1936, when Toyota won its first truck contract with the Japanese government, his processes hit new problems and he developed the "Kaizen" improvement teams.

Levels of demand in the Post War economy of Japan were low and the focus of mass production on lowest cost per item via economies of scale therefore had little application. Having visited and seen supermarkets in the USA, Taiichi Ohno recognized the scheduling of work should not be driven by sales or production targets but by actual sales. Given the financial situation during this period, over-production had to be avoided and thus the notion of Pull (build to order rather than target driven Push) came to underpin production scheduling.

It was with Taiichi Ohno at Toyota that these themes came together. He built on the already existing internal schools of thought and spread their breadth and use into what has now become the Toyota Production System (TPS). It is principally from the TPS, but now including many other sources, that Lean production is developing. Norman Bodek wrote the following in his foreword to a reprint of Ford's Today and Tomorrow:

> I was first introduced to the concepts of just-in-time (JIT) and the Toyota production system in 1980. Subsequently I had the opportunity to witness its actual application at Toyota on one of our numerous Japanese study missions. There I met Mr. Taiichi Ohno, the system's creator. When bombarded with questions from our group on what inspired his thinking, he just laughed and said he learned it all from Henry Ford's book." It is the scale, rigor and continuous learning aspects of the TPS which have made it a core of Lean.

2.3 Types of Wastes

While the elimination of waste may seem like a simple and clear subject it is noticeable that waste is often very conservatively identified. This then hugely reduces the potential of such an aim. The elimination of waste is the goal of Lean, and Toyota defined three broad types of waste: muda, muri and mura; it should be noted that for many Lean implementations this list shrinks to the last waste type only with corresponding benefits decrease. To illustrate the state of this thinking Shigeo Shingo observed that only the last turn of a bolt tightens it—the rest is just movement. This ever finer clarification of waste is the key to establishing distinctions between value-adding activity, waste and non-value-adding work. Non-value adding work is waste that must be done under the present work conditions. One key is to measure, or estimate, the size of these wastes, to demonstrate the effect of the changes achieved and therefore the movement toward the goal.

The "flow" (or smoothness) based approach aims to achieve JIT, by removing the variation caused by work scheduling and thereby provide a driver, rationale or target and priorities for implementation, using a variety of techniques. The effort to achieve JIT exposes many quality problems that are hidden by buffer stocks; by forcing smooth flow of only value-adding steps, these problems become visible and must be dealt with explicitly.

Muri is all the unreasonable work that management imposes on workers and machines because of poor organization, such as carrying heavy weights, moving things around, dangerous tasks, even working significantly faster than usual. It is pushing a person or a machine beyond its natural limits. This may simply be asking a greater level of performance from a process than it can handle without taking shortcuts and informally modifying decision criteria. Unreasonable work is almost always a cause of multiple variations.

To link these three concepts is simple in TPS and thus Lean. Firstly, muri focuses on the preparation and planning of the process, or what work can be avoided proactively by design. Next, mura then focuses on how the work design is implemented and the elimination of fluctuation at the scheduling or operations level, such as quality and volume. Muda is then discovered after the process is in place and is dealt with reactively. It is seen through variation in output. It is the role of management to examine the muda, in the processes and eliminate the deeper causes by considering the connections to the muri and mura of the system. The muda and mura inconsistencies must be fed back to the muri, or planning, stage for the next project.

A typical example of the interplay of these wastes is the corporate behaviour of "making the numbers" as the end of a reporting period approaches. Demand is raised to 'make plan', increasing (mura), when the "numbers" are low which causes production to try to squeeze extra capacity from the process which causes routines and standards to be modified or stretched. This stretch and improvisation leads to muri-style waste which leads to downtime, mistakes and backflows and waiting, thus the muda of waiting, correction and movement.

The original seven muda are:

- Transportation (moving products that are not actually required to perform the processing)
- Inventory (all components, work in process and finished product not being processed)
- Motion (people or equipment moving or walking more than is required to perform the processing)
- Waiting (waiting for the next production step)
- Overproduction (production ahead of demand)
- Over Processing (resulting from poor tool or product design creating activity)
- Defects (the effort involved in inspecting for and fixing defects)

Later an eighth waste was defined by Womack et al. (2003); it was described as manufacturing goods or services that do not meet customer demand or specifications. Many others have added the "waste of unused human talent" to the original seven wastes. These wastes were not originally a part of the seven deadly wastes defined by Taiichi Ohno in TPS, but were found to be useful additions in practice.

Some of these definitions may seem rather idealistic, but this tough definition is seen as important and they drove the success of TPS. The clear identification of non-value-adding work, as distinct from wasted work, is critical to identifying the assumptions behind the current work process and to challenging them in due course.

2.4 Lean Construction

Lean construction is a translation and adaption of lean manufacturing principles and practices to the end-to-end design and construction process. Unlike manufacturing, construction is a project based-production process. Lean construction is concerned with the holistic pursuit of concurrent and continuous improvements in all dimensions of the built and natural environment: design, construction, maintenance & recycling. This approach tries to manage and improve construction processes with minimum cost and maximum value by considering customer needs.

Lean construction accepts the production system design criteria as a standard of perfection. But how does the Toyota system, lean production, apply in construction? Manufacturers make parts that go into projects in controlled environments but the design and construction of unique and complex projects in highly uncertain environments under great time and schedule pressure is fundamentally different.

Certainly the goal of delivering a project meeting specific customer requirements in zero time sounds like the objective for every project, and the evidence of waste is overwhelming. Waste in construction and manufacturing arises from the same activity-centered thinking, “Keep intense pressure for production on every activity because reducing the cost and duration of each step is the key to improvement.”

Managing construction under Lean is different from typical contemporary practice because it;

- has a clear set of objectives for the delivery process,
- is aimed at maximizing performance for the customer at the project level,
- designs concurrently product and process, and
- applies production control throughout the life of the project.

By contrast, the current form of production management in construction is derived from the same activity centered approach found in mass production and project management. It aims to optimize the project activity by activity; assuming customer value has been identified in design. Production is managed throughout a project by first breaking the project into pieces, i.e. design and construction, then putting those pieces in a logical sequence, estimating the time and resources required to complete each activity and therefore the project. Each piece or activity is further decomposed until it is contracted out or assigned to a task leader, foreman or squad boss. Control is conceived as monitoring each contract or activity against its schedule and budget projections. These projections are rolled up to project level reports. If activities or chains along the critical path fall behind, efforts are made to reduce cost and duration of the offending activity or changing the sequence of work. If these steps do not solve the problem, it is often necessary to trade cost for schedule by working out of the best sequence to make progress. The focus on activities conceals the waste generated between continuing activities by the unpredictable release of work and the arrival of needed resources. Simply put, current forms of production and project management focus on activities and ignore flow and value considerations.

Managing the combined effect of dependence and variation is a first concern in Lean production. The problem of dependence and variation can be illustrated by what happens in heavy traffic on a freeway. If every car drove at exactly the same speed then spacing between cars could be very small and the capacity of the freeway would be limited by whatever speed was set. Each car would be dependent on the one ahead to release pavement and variation would be zero. In effect, there would be no inventory of unused pavement. In reality of course, each car does use the pavement released to it from the car ahead but speeds vary.

Under the pressure to get to work or home, gaps between cars close and any variation in speed demands immediate response from following cars. As the gaps close, small variations in speed propagate along and across lanes. One small hesitation can lead to a huge standing wave as traffic slows to a crawl. Recovery is difficult because it is impossible to get everyone to accelerate smoothly back up to the standard speed and interval. High speed at any one moment does not assure minimum travel time in conditions of dependence and variation. The idea that you do not get home any faster by driving as fast and as close to the car ahead is counter intuitive. Certainly the system itself does not function as well when dependence is tighter and variation greater.

Managing the interaction between activities, the combined effects of dependence and variation, is essential if we are to deliver projects in the shortest time. Minimizing the combined effects of dependence and variation becomes a central issue for the planning and control system as project duration is reduced and the complexity increases. The need to improve reliability in complex and quick circumstances is obvious. New forms of planning and control are required.

The first goal of lean construction must be to fully understand the underlying “physics” of production, the effects of dependence and variation along supply and assembly chains. These physical issues are ignored in current practice which tends to focus on teamwork, communication and commercial contracts. These more human issues are at the top of practitioner’s lists of concerns because they do not, indeed cannot see the source of their problems. It is not that these people are stupid, but that they lack the language and conceptual foundation to understand the problem in physical production terms. The development of partnering illustrates this point.

Partnering makes great sense from an activity perspective. But few realize Partnering is a solution to the failure of central control to manage production in conditions of high uncertainty and complexity. In these circumstances, representatives of each activity must be able to communicate directly without relying on the central authority to control message flow, and so Partnering works. From the lean understanding of the physics of production, Partnering is evidence of a failure in production management but it provides the opportunity for collaborative redesign of the planning system to support close coordination and reliable work flow.

Lean supports the development of team work and a willingness to shift burdens along supply chains. Partnering relationships coupled with lean thinking make rapid implementation possible. Where Partnering is about building trust, lean is about building reliability. Trust is the human attitude that arises in conditions of reliability. We are not likely to trust one another very long if we do not demonstrate reliability. Reliability is the result of the way systems are designed. Of course people manage systems and in current terms they do a fine job. The problem is that production systems just do not work well when every person tries to optimize their performance without understanding how their actions affect the larger web.

The problem of matching labor to available work offers a good example of the difference between the contemporary view of the workplace and lean. “Matching labor to work” means having the resources on hand for a crew to work steadily and without interruption. Current practice views the assignment to the crew as a sort of “mini contract” which is more or less independent of other assignments, and sets the person in charge responsible for the organization of resources and direction of the crew. To be fair, companies have logistics systems that try to get the resources close to the crew and a few actually try to assemble and assign packages of work. But the majority of foremen are responsible for the final collection of resources and assuring that their crews can work continuously. When this approach fails to produce acceptable results, when the numbers are bad, management assumes the foreman or crew is not performing.

Companies typically maintain elaborate cost control systems to measure this performance. These systems are the manifestations of the cause and effect theories operating in the company. At the heart of this model is the belief that the crew is essentially independent and that all costs charged to an account arise within from the effort necessary to complete the assignment by the crew.

The lean construction view is different as it views the problem in physical production terms. The crew works at variable rates using resources supplied at varying rates. Matching labor to available work is a difficult systems design problem with a limited number of “solutions.” Lean works to isolate the crew from variation in supply by providing an adequate backlog or tries to maintain excess capacity in the crew so they can speed up or slow as conditions dictate. On occasion, people acting on intuition apply these techniques. Unfortunately neither resource nor capacity buffers reduce the variation in supply and use rates of downstream crews.

These problems are solved by long and predictable runs in the factories. In these stable circumstances managers can predict the work content at each station and shift labor along the line to minimize imbalance. Such factories are mostly dreams that have little to do with construction where we only have some idea of the labor content of activities from previous projects.

People holding current practice dear sometimes say they are helpless victims of fate when faced with managing uncertainty on projects. Their view is that uncertainty arises in other activities beyond their control. The lean approach is to assure we do not contribute to variation in work flow and to decouple when we cannot get it under control. In lean construction as in much of manufacturing, planning and control are two sides of a coin that keeps revolving throughout a project.

- **Planning:** defining criteria for success and producing strategies for achieving objectives.
- **Control:** causing events to conform to plan and triggering learning and re-planning.

Lean construction rests on a production management mind. We ask about the way work itself is planned and managed. We want to know the whether the planning system itself is under control, the location of inventories and excess capacity, and the extent to which the design and construction process itself supports customer value.

Lean construction embraces uncertainty in supply and use rates as the first great opportunity and employs production planning to make the release of work to the next crew more predictable, and then we work within the crews to understand the causes of variation.

Where current practice attacks point speed, lean construction attacks variation system wide.

Under lean, labor and work flow are closely matched when variation is under control and activities de-coupled through capacity or resource buffers when variation is not under control and work content unbalanced. These solutions are directed by the physics of the situation. Where current practice assesses and attempts to control individual performance, we see the planning system as the key to reliable work flow. Construction is different from manufacturing in the way work is released to the crew. Manufacturing work is released, moves down the line, in manufacturing based on the design of the factory; construction work is released by an administrative act, planning. In this sense, construction is directives driven and so measuring and improving planning system performance is the key to improving work flow reliability. Measuring planning system performance reflects our understanding of cause and effect. Once we understand physics problems at the crew level, we see all sorts of new issues and opportunities.

2.5 Lean Construction Systems and Tools

The first objective is to bring the flow of work and production itself under control. This effort shows immediate results and demands the project delivery system be changed to better support reliable work flow. These include changing how work is structured early in design and the organization and function of both the master project plan and look ahead process.

We start with working to understand the physics of production at the task level, and then to design the underlying systems to support high performance. The planning system is the logical first target, but other design, procurement and logistic systems must also be considered. We understand that it will be necessary to change the organization to support these redesigned systems. Here we expect to see distributed control replace current reliance on central control. Research efforts now underway explore the application of pull techniques both on site and in design. Finally, we expect new forms of commercial contract to emerge that give incentives for reliable work flow and optimization at the deliverable-to-the-client level. In this way we move from task to system to organization to contract.

Human issues come into play on implementation. Systems, teams, organizations, communication and contracts do not change the physics. Their design does limit what can happen just as physical rules place other limits. For example, the need for upstream investment to reduce downstream variation is in conflict with current practices of buying each piece for the lowest cost, or of pushing each crew to work quickly as opposed to reliably. Uncertainty in work flow places great demand on communication channels as people attempt to find some way to keep the project or their crew moving in the face of uncertainty. But flexibility defined in this way requires slack resources and injects more uncertainty into the flow of work. Where we see uncertainty as the consequence of the way we manage work, they see uncertainty as environmental and beyond their control. We operate on different theories, we tell different stories.

Managers in most companies and on most projects have an inflated view of the reliability of their planning system. This attitude changes once the decision is taken to make assignments to criteria and the results come in. New opportunities are revealed and new demands arise in all directions. Upstream changes typically include changes in the timing and size of deliveries from fabricators. Horizontally, coordination with other specialty contractors shifts from a central controlled push functions to decentralized pull. Downstream, the effect of reliable work flow may be to change the way labor is managed. One contractor now shifts labor between nearby projects because it is possible to predict the actual demand for labor in coming weeks. Hoarding labor is reduced and fewer workers can service more jobs resulting in higher productivity at lower cost hence an optimized operation at project level rather than individual company level.

2.5.1 Planning System (Last Planner System®)

Ballard (2000) indicates that *Last Planner System®* (LPS) is a technique that shapes workflow and addresses project variability in construction. The Last Planner is the person or group accountable for operational planning, that is, the structuring of product design to facilitate improved work flow, and production unit control, that is, the completion of individual assignments at the operational level. In the last planner system, the sequences of implementation master schedule, reverse phase schedules (RPS), six-week look ahead, weekly work plan (WWP), percent plan complete (PPC), Constraint analysis and Variances analysis sets up an efficient schedule planning framework through a pull technique, which shapes work flow, sequence, and rate; matches work flow and capacity; develops methods for executing work; and improves communication between trades. It will achieve *Should-Can-Will* which is the key term in WWP.

- "Should" indicates the work that is required to be done according to schedule requirements.
- "Can" indicates the work which can actually be accomplished on account of various constraints on the field.
- "Will" reflects the work commitment which will be made after all the constraints are taken into account.

Various key contributions to improve the work flow are included: two-way communication, the constraints analysis process in six- week look ahead before assignments are executed, the analysis of reasons for variance after assignments are completed, the efforts of each planner, and the training of the project team. Traditional practices do not consider a difference between what *should, can*, *and will* be done, the assumption being that pushing more tasks will result in better results.

The important role of the Last Planner tool is to replace optimistic planning with realistic planning by evaluating the performance of workers based on their ability to reliably achieve their commitments. The goals of Last Planner are to pull activities by reverse phase scheduling through team planning and optimize resources in the long-term. This tool is similar to the *Kanban system* and production leveling tools in Lean manufacturing.

2.5.1.1 Master Schedule

The master schedule is an overall project schedule, with milestones, that is usually generated for use in the bid package. Reverse Phase Scheduling (RPS) is produced based on this master schedule.

2.5.1.2 Reverse Phase Scheduling (RPS)

Ballard and Howell (2003) indicated that a pull technique is used to develop a schedule that works backwards from the completion date by team planning; it is also called Reverse Phase Scheduling (RPS). They also state that phase scheduling is the link between work structuring and production control, and the purpose of the phase schedule is to produce a plan for the integration and coordination of various specialists' operations.

The reverse phase schedule is developed by a team consisting of all the last planners. It is closer to reality than the preliminary optimal schedule which is the master schedule. However, without considering actual field factors in the RPS, the RPS is less accurate than the WWP.

2.5.1.3 Six-Week Lookahead (SWLA)

Ballard (2000) indicated that the tool for work flow control is lookahead schedules. SWLA shows what kinds of work supposed to be done in the future. In the lookahead window, week 1 is next week, the week after the WWP meeting. The number of weeks of lookahead varies. For the design process, the lookahead window could be 3 to 12 weeks. All six-week-lookahead durations and schedules were estimated based on the results of the RPS, and constraints are indicated in order to solve the problems before the actual production takes place. SWLA is distributed to all last planners at WWP meetings. Lean lookahead planning is the process to reduce uncertainty to achieve possible constraint free assignments (Koskela et al. 2000).

2.5.1.4 Weekly Work Plan (WWP)

Should, Can, and Will are the key terms in WWP (Ballard 2000). Weekly Work Plan (WWP) is produced based on SWLA, the actual schedule, and the field condition before the weekly meeting. Along with this plan, manpower from each trade will be adjusted to the need. The WWP meeting covers the weekly schedule, safety issues, quality issues, material needs, manpower, construction methods, backlog of ready work, and any problems that can occur in the field. It promotes two-way communication and team planning to share information on a project in an efficient and accurate way. It can improve safety, quality, the work flow, material flow, productivity, and the relationship among team members. Ballard and Howell (2003) indicates that WWP should emphasize the learning process more by investigating the causes of delays on the WWP instead of assigning blames and only focusing on PPC values. Variance analysis is conducted based on the work performance plan from the previous week. The causes of variance should be documented within the WWP schedule.

2.5.1.5 Percent Plan Complete (PPC)

The measurement metric of Last Planner is the percent plan complete (PPC) values. It is calculated as the number of activities that are completed as planned divided by the total number of planned activities (Ballard 2000). The positive (upward) slope between two PPC values means that production planning was reliable and vise versa. According to Ballard (1999), PPC values are highly variable and usually range from

30% to 70% without lean implementation. To achieve higher values (i.e., 70% and above), additional lean construction tools such as first run studies have to be implemented.

2.5.2 Increased Visualization

The increased visualization lean tool is about communicating key information effectively to the workforce through posting various signs and labels around the construction site. Workers can remember elements such as workflow, performance targets, and specific required actions if they visualize them (Moser and Dos Santos 2003). This includes signs related to safety, schedule, and quality. This tool is similar to the lean manufacturing tool, Visual Controls, which is a continuous improvement activity that relates to the process control.

2.5.3 Daily Huddle Meetings (Tool-box Meetings)

Two-way communication is the key of the daily huddle meeting process in order to achieve employee involvement. With awareness of the project and problem solving involvement along with some training that is provided by other tools, employee satisfaction (job meaningfulness, self-esteem, sense of growth) will increase. As part of the improvement cycle, a brief daily start-up meeting was conducted where team members quickly give the status of what they had been working on since the previous day's meeting, especially if an issue might prevent the completion of an assignment (Schwaber 1995). This tool is similar to the lean manufacturing concept of employee involvement, which ensures rapid response to problems through empowerment of workers, and continuous open communication through the tool box meetings.

2.5.4 First Run Studies

First Run Studies are used to redesign critical assignments (Ballard and Howell 1977), part of continuous improvement effort; and include productivity studies and review work methods by redesigning and streamlining the different functions involved. The studies commonly use video files, photos, or graphics to show the process or illustrate the work instruction. The first run of a selected craft operation should be examined in detail, bringing ideas and suggestions to explore alternative ways of doing the work. A PDCA cycle (plan, do, check, act) is suggested to develop the study: Plan refers to select work process to study, assemble people, analyze process steps, brainstorm how to eliminate steps, check for safety, quality and productivity. Do means to try out ideas on the first run. Check is to describe and measure what actually happens. Act refers to reconvene the team, and communicate the improved method and performance as the standard to meet.

This tool is similar to the combination of the lean production tool, graphic work instructions, and the traditional manufacturing technique, time and motion study.

2.5.5 The 5s Process (Visual Work Place)

Lean construction visualizes the project as a flow of activities that must generate value to the customer (Dos Santos et al. 1998). The 5s process (sometimes referred to as the Visual Work Place) is about "a place for everything and everything in its place". It has five levels of housekeeping that can help in eliminating wasteful resources (Kobayashi 1995; Hirano 1996):

- Seiri (Sort) refers to separate needed tools / parts and remove unneeded materials (trash).
- Seiton (Straighten or set in order) is to neatly arrange tools and materials for ease of use (stacks/bundles).
- Seiso (shine) means to clean up.
- Seiketsu (standardize) is to maintain the first 3Ss. Develop a standard 5S's work process with expectation for the system improvement.
- Shitsuke (sustain) refers to create the habit of conforming to the rules.

This tool is similar to the 5S housekeeping system from lean manufacturing. The material layout is commonly used for acceleration of 5S implementation on the construction site. Spoore (2003) indicates that 5S is an area-based system of control and improvement. The benefits from implementation of 5S include improved safety, productivity, quality, and set-up-times improvement, creation of space, reduced lead times, cycle times, increased machine uptime, improved morale, teamwork, and continuous improvement (Kaizen activities).

2.5.6 Fail Safe for Quality and Safety

Shingo (1986) introduced Poka-yoke devices as new elements that prevent defective parts from flowing through the process. Fail safe for quality relies on the generation of ideas that alert for potential defects. This approach is opposed to the traditional concept of quality control, in which only a sample size is inspected and decisions are taken after defective parts have already been processed. This is similar to Visual inspection (Poka-Yoke devices) from lean manufacturing. Fail safe can be extended to safety but there are potential hazards instead of potential defects, and it is related to the safety risk assessment tool from traditional manufacturing practice. Both elements require action plans that prevent bad outcomes.

2.5.7 Design System (Design for Build-ability / Detailed Engineering)

Design for Manufacture is the general engineering art of designing product in such a way that they are easy to manufacture; migrating the above methodology into construction hence we have Design for Build-ability. Improving Design for Build-ability has seen better project performance in term of quality, time and cost (Wong, Lam, Chan & Shen, 2007). The virtues of this approach have also been recognised by researchers such as Hassan (1997) and Zin, Nesan and Mohammed (2004), whilst the Singapore Government has taken a step further by enforcing law to require attainment of minimum build-ability score before its statutory authority give approval.

Good Build-ability Design and Precise Detailed Engineering reduce ambiguity that bridge the information flow between consultants to site personnel hence skill labour. This process is crucial in ensuring smooth work flow downstream and positive result has been seen with Design-Build Project.

2.5.8 Procurement & Logistic System (Just-In-Time, JIT)

Procurement can reduce the time required for acquisition of resources by eliminating wasted time in information flow, reducing transport distance by selection of local suppliers and by the use of blanket purchase order, logging total project quantity required, allowing multiple release against it at different time as and when needed by Last Planner on site. In addition, procurement team must work with construction team on timing of delivery in order to release resources for delivery just when needed. This reduce on-hand inventory, space requirement, and double handling when equipment and material can be placed directly into final position off delivery vehicle.

As delivery variation decline, Construction can reduce the size of backlog require to initiate work, thus advancing construction mobilization. In addition, there will remain opportunity for squeezing time from construction process primarily from better coordination of interdependent craft.

2.5.9 Enterprise Resource Planning System (ERP)

The material management process combine and integrate the individual function of material requirement planning, material takeoff, vendor evaluation and selection, purchasing, expedition, shipping, material receiving and inventory, material distribution, and even accounting function (Bell and Stukhart, 1987). These processes are timely and those who involve have to coordinate and communicate effectively especially with Last Planner on site, this makes material management system suitable to be benefited from information technology implementation.

The evolution of Wireless Data Telecommunication enable construction firm to integrate Head Office computer base material management system (MMS), which store, sort, combine and print data file pertaining to material requisition, purchasing, vendor evaluation and warehouse inventory (Bell and Stukhart, 1987) with Off Site computer system to perform function related to design, project scheduling and accounting, improving cost and document processing cycle time by the used of information technology system.