separated the roles of designers and constructors, the LPDS sees the activities of these professionals as a continuum for project management to achieve three fundamental goals (Koskela 2000):

- Deliver the product,
- Maximize value, and
- Minimize waste.

Fundamental to the LPDS is the deployment of the "Five Big Ideas" as described in Chapter 2:

1. Collaborate, really collaborate,
2. Increase relatedness among all project participants,
3. Projects as networks of commitments,
4. Optimize the project, not the pieces, and
5. Tightly couple learning with action.

The first big idea requires assembling and empowering of all the people and resources necessary to develop appropriate design solutions and explore their impacts on construction delivery. Inherent in the use of the LPDS is also the use of The Last Planner® System (LPS) from the perspective of design. It is explained later in this chapter and in Chapter 4.

In brief, it comprises

1. The master pull schedule,
2. The lookahead schedule,
3. The weekly work plan (WWP),
4. The daily work plan where applicable, and
5. Performance measurement, learning, and improvement.

Structure of the Lean Project Delivery System (LPDS)

The LPDS comprises a number of phases that capture the intent of the traditional project phases, but juxtaposes them in such a manner as to apply production system design principles to enhance the delivery of the entire project from predesign to completion and use. The phases are:

1. Project definition
2. Lean design
3. Lean supply
4. Lean assembly
5. Use/completion

The LPDS model represents these phases as a series of overlapping triads. As described by Ballard and Ballard and Howell (2003a), these phases influence each other "so a conversation is necessary among the various stakeholders." In the diagram (Figure 3.1), work structuring provides a foundation for the process and sets the stage for production control, which is represented by a horizontal bar. Work structuring is a term developed by the Lean Construction Institute to indicate process design. It is a process of subdividing work such that pieces are different from one production unit to the next to promote flow and throughput, and to have work organized and executed to benefit the project as a whole. Production is redefined from "monitoring results" to "making work flow according to plan, re-planning when it cannot." Plans to complete are continually updated in a proactive rather than reactive mode, looking ahead instead of backward.

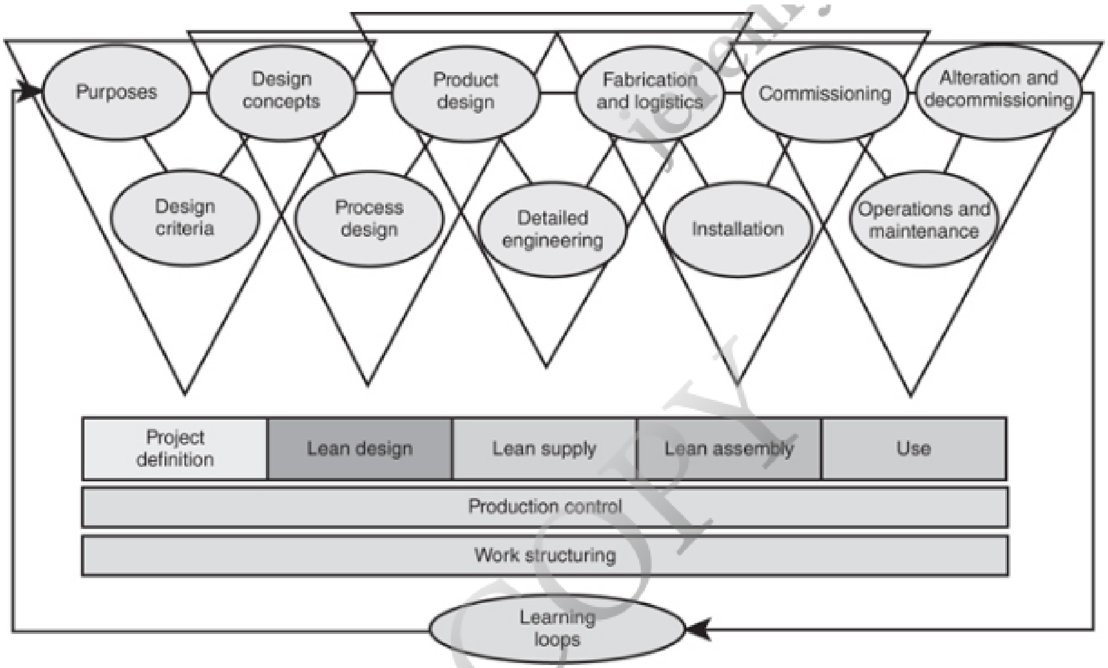

Figure 3.1 The Lean Project Delivery System™

Source: Adapted from Ballard, G., and G. Howell, *Building Research and Information*, 2003a

The LPDS was updated to include additional concepts and methods drawn from the Toyota product development system, especially target costing and set-based design. These have been adapted to the construction industry and integrated with computer modeling and relational forms of contract (Ballard 2008).

As described by Koskela *et al.* 2002 (page 214), the LPDS is structured to achieve the Transformation, Flow, and Value (TFV) goals The model improves project delivery through the following characteristics:

1 Downstream stakeholders are involved in upstream decisions – such as front-end planning and design through cross-functional teams.
2 Commitments are deferred to the last responsible moment.
3 Project control has the job of execution as opposed to reliance on after-the-fact variance detection.
4 Pull techniques are used to govern the flow of materials and information through networks of cooperating specialists.
5 Capacity and inventory buffers are used to absorb variability.
6 Feedback loops are incorporated at every level, dedicated to rapid system adjustment (i.e., learning).

Project definition

Project definition typically involves developing project alternatives at a conceptual level, analyzing project risks and the economic payoff, and developing a financial plan. A decision is made to proceed if the owner considers conditions to be favourable; a plan is developed for the organization and control of the project. Effective project scope definition enables all involved parties to understand the owner's needs, and to work toward meeting those needs. Traditionally, project definition has been established by the architect (or engineer for non-building projects) working alone with the owner. In lean project definition, representatives of every stage in the life cycle of a facility are involved, including members of the production team that will design and build it. (Koskela *et al.* 2002). The project definition phase comprises:

- Needs and values determination,
- Design criteria, and
- Conceptual design.

In the needs and values determination, design professionals assist the owner/client in clarifying a value proposition; that is, the purpose of the project and the needs to be served. A design criteria document describes specific needs to be met, such as size, space proximities/adjacencies, and energy efficiency requirements. The conceptual design uses the design criteria and value proposition to define an outline design that serves as a starting point for the design phase.

Establishing design criteria

The design criteria define the owner's basis of design (BOD). It reflects the owner's needs and wants that must be satisfied by the design of the project. This may include the use of spaces, their sizes, finishes, and activities to be performed within them. For example, a room that houses equipment with a high-sensible heat load will need power outlets/connections with adequate power capacity ratings. It will also need cooling designed to offset the respective heat loads. The aspect ratio – length versus width may influence the operations to be housed – a manufacturing assembly operation has different operational flow requirements than an office environment with a high-occupant load. Owners such as institutions – schools, universities, hospitals, and franchise retailers – may have formal design criteria developed through many years of experience. Other owners may require more intensive evaluation and analysis in order to develop project-specific design criteria.

Lean design phase

The lean design phase comprises: conceptual design, process design, and product design. It builds on the output from the project definition phase, but with a deviation from traditional design practice. Traditional design tends to follow a familiar pattern. In architectural projects (as opposed to EPC projects) an architectural firm serves as the principal designer, and is supported by design engineers such as civil/structural, mechanical, and electrical. The design team often starts by designing the design process; they may use Post-It notes on a wall and apply the activity definition model (ADM) to ensure that design assignments have necessary prerequisite work completed and that no constraints would delay the process.

In conventional projects, the architect provides preliminary drawings to the other disciplines at various stages in the design process and the engineers apply their respective design parameters to the architectural framework. Although this work may benefit from the cost efficiencies of 3-D CAD (or more advanced versions), the process is not generally interactive – it progresses forward and is additive as new information is included. It is often punctuated by design changes originating from scope changes or value engineering exercises necessitated when someone determines that the budget may not accommodate the design features that have been developed. There is very little involvement, if any, of contractors/builders in the design process in design-bid-build projects.

In design-build projects, a single entity contracts with the owner/client; there is an interplay between designers and builders, but the owner/client is not generally included in this process and does not have a fiduciary relationship with the designer of record. In CM@ Risk the builder is brought on board with the primary motive of becoming familiar with the project and its environment; the risk of unforeseen conditions is reduced.

The foregoing traditional methods separate design from construction – designers focus on product design and not process design in order not to assume the constructor's risk. This risk avoidance has other negative consequences. Research findings suggest that designers can in fact have a strong influence on construction safety. In 1985 the International Labor Office recommended that designers give consideration to the safety of workers who are involved in erecting buildings. In 1991, the European Foundation for the Improvement of Living and Working Conditions concluded that about 60% of fatal accidents in construction are the result of decisions made before the site work begins. A 1994 study of the United Kingdom's construction industry found a causal link between design decisions and construction safety.

With lean projects, as shown in the second triangle, lean design is a significant departure from the foregoing scenarios. Design is done with both the construction product and the process in mind. Constructability reviews and value engineering are not seen as tools to apply in a problem-solving mode, but rather, are continually integrated with decision-making in the design process. This is accomplished with cross-functional teams that include architects, engineers, contractors, subcontractors, and various specialists who collaborate with each other and interactively make decisions that are optimal for the product and the process. A cluster organization is one very effective way to bring knowledgeable team members together for joint activity.

Lean supply

The third triad, lean supply, comprises product design, detailed engineering, fabrication, (Ballard and Howell 2003a); it requires up-front product and process design to define what is needed and when it should be delivered. This is especially important with engineered to order components as utilized in EPC projects. Lean supply also includes reducing the lead time for project information requirements. It involves the use of supply chains to optimize the delivery of materials, components and major building sub-assemblies. It is described in greater detail in Chapter 4.

Lean assembly

Lean assembly is practiced in the actual construction of a project, putting materials, systems, and components in place to create a completed facility.

The lean assembly triad contains fabrication and logistics, installation, and commissioning. Prefabrication is a production technique that can enable a contractor to operate in a lean manner by reducing the many nonvalue-added steps that are required in field fabrication. Whereas field work contends with uncertain conditions such as weather, and limitations in the availability of skilled labor, material, and equipment, shop fabrication benefits from a predictable, controlled environment. Tweet/Garot, a specialty contractor in Wisconsin has improved efficiency by prefabricating many of its products for quick and efficient site installation. This includes plumbing work for bathrooms in a given building in congruence with the construction schedule. Over a period of time, Tweet/Garot has progressed to 70% installation in the field and 30% fabrication in the shop. With that new approach, workers spend a relatively short period of time doing installation work. Prefabricated piping is interconnected within minutes because of the precision of design.

The commissioning process overlaps in the last two triangles; it provides quality assurance before a facility is completed and accepted by the owner by ensuring that all systems have been installed as promised in keeping with the designer's plans and specifications. It improves the probability that the facility will meet the owner's project requirements (OPR) and performs as expected, to provide user satisfaction.

The fifth triad, "Use," refers to a completed facility. Following successful commissioning, the facility should undergo a protracted operations and maintenance phase as it is used. "Alteration and Decommissioning" refer to a future activity when the facility may be repaired, renovated, or taken out of service.

Learning loops

"Learning loops" span all the activities in the five triads, and refer to the application of root cause analysis to the Last Planner® System on a weekly basis to review PPC values and commitment reliability. Learning is also accomplished through ongoing retrospectives as well as the process of post occupancy evaluation (POE). In POE reviews a facility is surveyed after occupancy/acceptance to review the consequences of decisions made during the execution of the project. As mentioned by Koskela *et al.* (2002), it is important to know the extent to which design and construction were based on a correct determination of customer and stakeholder values. It examines both the product and the process used to create it. The POE enables project participants to learn from past decisions.

Production control

Production control is represented as a horizontal bar that extends from the very inception of the project to its conclusion (Figure 3.1). Koskela *et al.* (2002) refer to traditional project control as "trying to steer a car by looking in the rear view mirror". Instead, lean production control is achieved through a systematic process for making assignments ready to be performed, combined with explicit commitments by people at the production level to what work will be released to their customer processes in the next plan period. This is typically one week" It consists of work flow control and production unit control.

Work structuring

Work structuring and production control are used throughout a project to manage production. The term work structuring was developed by the Lean Construction Institute (Ballard 1999) to describe construction-related process design. It is a process of subdividing work so that pieces are different from one production unit to the next to promote flow and throughput, and to have work organized and executed to benefit the project as a whole. Work structuring is described in greater detail as a part of the LPS. Koskela *et al.* (2002).

Table 3.1 Comparison of the LPDS with traditional systems

	Lean project characteristics	*Traditional project characteristics*
1	The focus is on the production system	The focus is on transactions and contracts
2	The TFV goal	The T goal
3	Downstream players are involved in upstream decisions	Decisions are made sequentially by specialists,
4	Design coordinates both the product and the process	Process design is done separately after product design
5	Design considers product life-cycle stages	Design does not consider life-cycle stages
6	Actions are taken at the last responsible moment	Actions are taken as soon as possible
7	Supply chain lead times are reduced systematically	Organizations accept market conditions, availability
8	Learning is included in projects, firms and supply chain management	Learning occurs sporadically
9	Stakeholder interests are aligned	Stakeholder interests are not aligned
10	Buffers are sized and located to absorb system volatility	Participants protect their interests with large inventories.

Source: Adapted from Table 14.2 of Koskela *et al.* 2002

The LPDS and the Last Planner® System of production control

Several tools have been developed to manage the LPDS; some are conceptual, some are procedural, some are embedded in software. The Last Planner® System is a complex tool that includes multiple rules and techniques, namely the activity definition model (ADM), Constraints analysis, and Percent Plans Complete.

This varied tool set is very powerful and has yielded significant performance improvements in the design and construction processes for almost two decades. Bertelsen (2001) reported that Danish contractors had reduced project durations by 10%, increased productivity by 20%, and improved profitability 20–40% on projects where they applied lean principles.

The Last Planner® System of production control (LPS) is an important subset of the LPDS. It is a collaborative commitment-based planning system that integrates "should/can/will/did" planning with constraint analysis, and work planning based on reliable promising, and learning. It works in conjunction with it and facilitates continuous improvement of processes by keeping track of plan reliability as PPC values. It also tracks the reasons for non-completion (RNC), enabling project teams to adopt countermeasures and continuously improve performance during the course of a project.

One important simulation that is based on the LPS is the Parade of Trades. It demonstrates the importance of reducing variation to increase the speed of construction operations. Typically, seven players assemble around a table and roll a die in turn to move 35 chips around the table. In one iteration a standard die is used with face values from one to six. The average value per roll is 3.5. In another iteration other dies are used that have an average value of 3.5. One special die may have faces of 3 and 4. But its variability is much less than that of a standard die. It does not offer dramatic rolls of sixes. Nor the disappointment of aces. At the end of the game the "slow" die often clears all the chips faster than the other dies that have a higher variability. It provides a more reliable workflow, and faster work completion. In effect, it demonstrates the principle of "going slow to go fast".

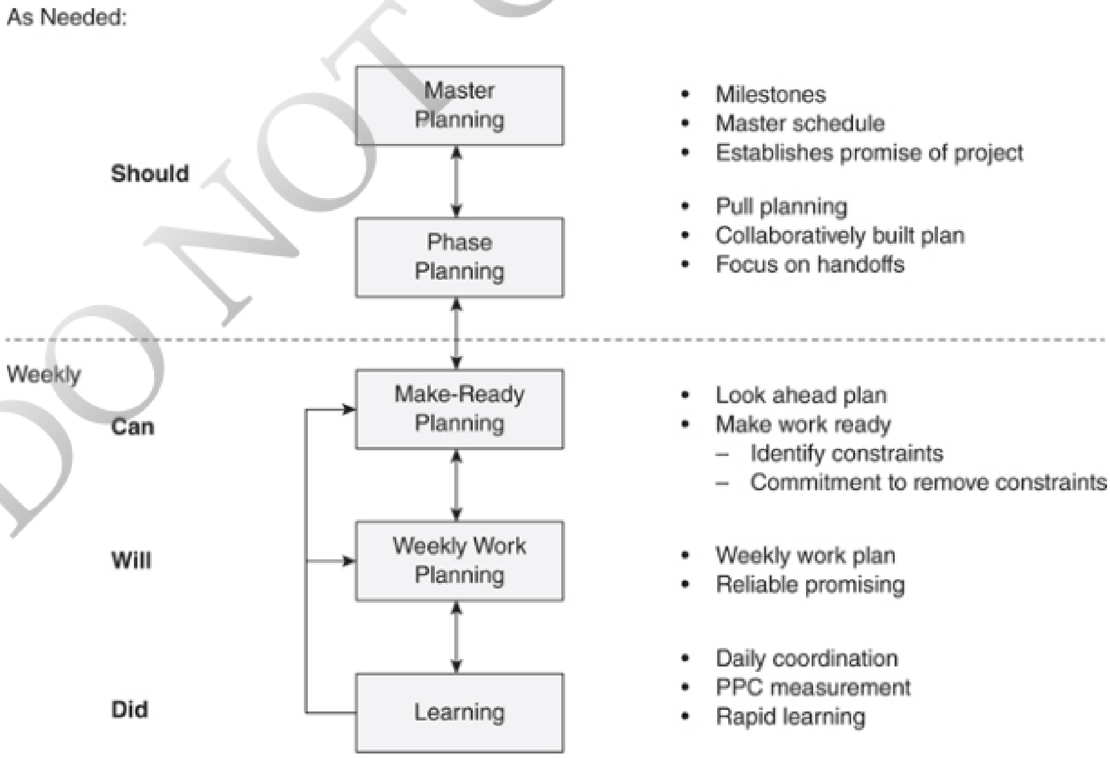

Figure 3.2 Schematic of the Last Planner® System

The LPDS and the Last Planner® System of production control

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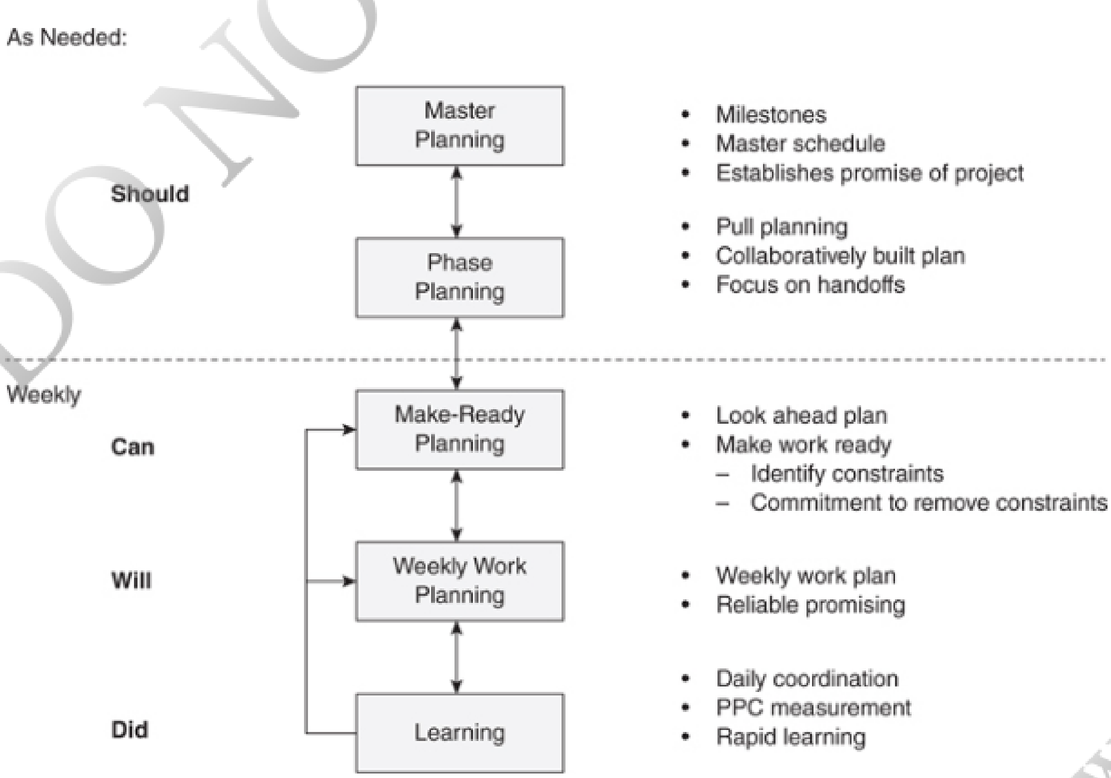

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