Applying Lessons from Lean Production Theory to Transit Planning

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Abstract

Lean production theory provides a basis for understanding how Personal Rapid Transit (PRT) improves upon traditional mass transit. Lean production refers to manufacturing processes that improve upon mass production techniques to reduce cost, reduce time to produce, improve quality, and better respond to market demands. The benefits of lean production techniques have been documented in several studies, including an intensive worldwide study of the automotive industry. Those same benefits as applied to transit planning have important implications for the economic development of our communities.

Introduction

Lean production theory focuses on managing the flow of production through all the steps that add value to the final product. In contrast, mass production focuses on maximizing the return from the initial investment in machinery and the initial overhead of setup. As a result, mass production is characterized by the processing of products in large batches. In practice, mass production produces mass waste, including over-production of unneeded or defective parts, excessive inventories at each stage of production, and excessive movement of parts between production facilities and/or storage facilities at each stage of production.

Mass transit shares many characteristics with mass production. Patrons are gathered into large lot sizes. Massive investments are made in machinery/vehicles and warehouses/stations. This results in mass waste: time wasted waiting for scheduled service, trips and time wasted in traveling to a transit corridor, time wasted transferring between lines and modes, station and vehicle capacity wasted during non-peak travel periods, and energy wasted by accelerating and braking heavy vehicles over short distances.

Critics of PRT say that no model of production economics demonstrates the superiority of PRT to mass transit service in either the return on investment or the overall quality of service. The authors contend that there is such a model in the lean production systems implemented by manufacturers in many different industries throughout the world. This paper maps the key principles of lean production to the key principles of PRT. We will trace the flow of patronage through the PRT production system, noting how it relates to lean production theory and citing similar examples in other industries.

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The growing world economy imposes new pressures upon communities to improve their transit infrastructure in order to remain economically competitive and protect their business tax bases from migration to other, more favorable, business environments. A "lean" transit technology will provide a key competitive advantage for some communities as an important piece of the total production system. We are projecting major economic benefits in a widespread adoption of "lean" transit systems (PRT), based on the demonstrated benefits of lean production over mass production.

The City Viewed as a Production Center

More than ever, economic competition between communities is a reality. It is no longer a question of getting the edge on an adjacent community. Businesses and individuals regularly evaluate their prospects in communities across the nation, and even internationally. The cost of doing business in a particular community drives the choices that businesses make about upgrading existing production facilities or relocating those facilities to other communities.

Even where businesses are deeply rooted in a single community, it is to the advantage of that community to improve the economic infrastructure in order to increase the competitive advantage and prosperity of local businesses. The overall competitive edge and the resulting growth of local businesses must benefit the total community.

It follows that a city is a center of production with a more or less deliberately organized production infrastructure in the same way that factories, stores, and offices are deliberately organized production centers. Since cities are production centers, the structuring of utilities (including transit utilities) which support the production capabilities of cities will benefit from the same disciplines that have revolutionized production facilities elsewhere.

The production disciplines referred to as "Lean" production theory were first used in Japanese factories. The Toyota production system is especially admired as a highly successful use of 'lean" techniques. The use of "lean" techniques has shown documented increases in productivity of up to 991% (Womack, Jones, p.90, 1996). Automotive companies around the world have found it necessary to adopt "lean" principles to remain competitive with Toyota and other Japanese automobile manufacturers. In the same way, cities can apply “lean” principles to transit to make their communities more competitive.

Lean Production Theory & Practice

Lean production theory encompasses several disciplines that are beginning to permeate business practices in a variety of production facilities.

Focus on Continuous Flow

At the most fundamental level lean production theory is process-oriented, by which it is meant that the flow of the entire production process is documented and studied as a whole. It is impossible to centrally plan and manage such a massive re-engineering of production processes. There is simply too much detail at every level. For this reason, the workforce is educated to understand Continuous Flow issues and empowered to make improvements to the production process. The entire workforce, the suppliers, and the customers are recruited to participate in improving production flow, in order to leverage the insights that are gained by looking at the problem of production from every angle.

The objective in creating Continuous Flow is to keep parts and components moving through the production process, without pause. The benefits of this to a production system is that materials are not purchased before they are required, that defects are detected early in the production process, and that resources are not expended storing and moving unneeded materials and components. Table 1 illustrates the dramatic performance improvements experienced by a manufacturer after restructuring their manufacturing process to allow Continuous Flow. (Womack, Jones, p.121, 1996)

Table 1: Continuous Flow Impact

	Batch & Queue / 1991	Flow / 1995
Development time for a new product family	3-4 years	1 year
Employee hours per machine	160	80
Manufacturing space per machine	100 square feet	55 square feet
Delivered defects per machine	8.0	0.8
Production throughput time	16 weeks	14 hours to 5 days
Product delivery lead time	4-20 weeks	1-4 weeks

Correct Measures

In order to show that improvements are in fact taking place, meaningful measurements are established that show when progress is made. The selection and establishment of relevant measures for the production process will drive all subsequent improvements. Measuring the wrong thing, in effect, establishes incorrect goals for the production process. Less effective measurements focus on specific activities such as the efficiencies of machinery, numbers of parts per hour, numbers of workers, or numbers of hours worked.

Better measurements focus on measurements that apply across the entire system of production. Reduction of the elapsed time between order and delivery (cycle time) is one of the primary measures of efficiency in lean production systems. Defect rates, parts delivered on time, inventory levels (less is better), and inventory turns (more is better) are also used to measure the progress of the production system.

Pull Production Systems

Planning and development of the ”lean” production process is distributed across the entire production system, based on measurements that are generally understood and easy to gather across the entire production system. Concurrently, the driving impetus of lean production is designed as a downstream “pull” from within the production units that are upstream in the production system, and ultimately as a “pull” from the customer. Pull production systems allow resources to respond to demand. In contrast, ‘push’ systems focus on maximizing resource use with little regard for actual demand.

There are various mechanisms used to implement “pull” in production systems. The kanban system invented by Taiichi Ohno of Toyota is one of the simplest and easiest to understand. The use of a part in production is accompanied by the movement of a card (kanban) upstream in production to trigger the replacement of the used part. In the Toyota system, nothing is produced until it is needed to replace an item that has been used downstream in the production process. There is a direct relationship between numbers of products being built and numbers of parts being built. It is difficult to appreciate the significance of this until an attempt is made to balance production without the benefit of a demand-based process control mechanism.

Eliminating Waste

In “lean” production systems great emphasis is placed upon the elimination of waste. Some of the measures of waste, however, would not be seen as such in traditional “mass” production systems. One such measure would be excessive inventory. In “lean” production systems “inventory is evil”. Let us suppose that in order to assure a constantly moving production line, the Toyota Company needed to maintain an inventory of one month’s supply of engines. Since Toyota produces 10,000 cars a month such an inventory represents an incredible investment in warehousing and extra transportation of parts, not to mention the capital that is tied up uselessly in 10,000 inventoried engines. Therefore the movement toward “just in time" inventories and “lean” production techniques that minimize waste caused by inventory.

The need for inventory is an indication that problems lie elsewhere in the production process. In “mass” production systems the usual answer to a production problem is to stock additional inventory before or after that point in production. In “lean” systems the answer is to fix the problem that is causing the need for excess inventory. In general, any aspect of production that does not add value to the final product is to be viewed as waste.

Sources of waste in the production process include over-production, waiting, transportation, excess processing, defective parts, and accidents. “Pull” combats over-production. Load balancing and reducing batch size combat waiting. Inventory reduction and work cell organization reduces wasted transportation. Continuous Quality Improvement addresses excess processing, defective parts, and safety.

As an example, setup time is that time spent preparing machinery for actual production. Since it is not an activity that directly adds value to the final product, reduction in setup time is a key technique to reduce the total waste in **Table 2: Sources of Production Waste** production and improve cycle time. As addressed earlier, reducing setup time improves the production process in other ways by allowing smaller batch sizes and therefore further inventory reductions. There are additional tools and techniques that are also used to combat the various forms of waste in the production process. See Table 2 for other recognized causes of waste in production (Jones, Richert, 2000).

Disregard of Variability
Central Control Fantasy
Contract Mentality
Fragmentation
Repetitive Failures
Lack of Production Knowledge

Balancing the Flow of Production

In “pull” systems, resources such as time, labor, materials, and machinery are balanced in relation to each other and in relation to the requirements of the total production process. The flow of production is leveled across the available resources and balanced against the demand for those resources. A balanced production process has fewer bottlenecks and fewer emergent contingencies, allowing tighter scheduling. Table 3 illustrates the concept of balancing production. System A represents an unbalanced system where Process 2 is a bottleneck. System B represents a balanced system where resources have been shifted and the flow rates of all processes are equal. With the same resources, System B is fifty percent more effective than System A.

Table 3: Balancing Production Flow

	System A		System B	
	Resources	Flow Rate	Resources	Flow Rate
Process 1: 2 Resources / Widget	6	3	6	3
Process 2: 3 Resources / Widget	6	2	9	3
Process 3: 1 Resource / Widget	6	6	3	3
System Flow Rate		2		3

In mass production, large batch sizes leveraged the capital investment in expensive machinery that had long setup times. Newer machine technologies and lean production processes emphasize flexibility in the production process. The setup time is shortened or eliminated, thereby allowing smaller batch sizes. While smaller batch sizes allow a reduced cycle time they also, in combination with pull production lines, ease the problems of leveling and balancing demand, load, time, labor, machinery, and materials. Balanced production processes and smaller batch sizes have the benefit of reducing inventory requirements, with the total effect resulting in a massive improvement in the production process.

Benefits of Lean Production

Since measures are collected as an intrinsic part of the lean production process there is no shortage of documentation of the results of using "lean" production systems. Typical documented benefits of using "lean" production techniques have been (Greenwood, 1994):

- human effort in production and design reduced by 50 percent
- manufacturing space reduced by 50 percent
- manufacturing throughput improvements of 20 to 100 percent
- time-to-market for new product reduced 50 to 75 percent
- investment tooling costs reduced by 50 percent
- tremendous improvement in major quality indices
- improvements in total inventory turns of 400 to 1000 percent.

Forty-eight U.S. companies using Just-In-Time work teams report (Waldo, 1991):

- 35% reduction in cycle time
- 24% reduction in late deliveries
- 30% reduction in hours/unit,
- 33% reduction in work-in-progress inventories
- 58% reduction in scrap rates
- 71% reduction in customer complaints
- 39% reduction in floor space required
- 33% reduction in raw material inventories
- 300% increase in inventory turns

If a city is viewed as a production system, civic leaders can expect related benefits by adapting lean principles to the provision of public services.

Characteristics of Lean Transit versus Traditional Mass Transit

There are a number of similarities between transit and production systems. The movement of passengers down an apparent assembly line to a final destination is a reasonable metaphor of production, particularly with a view toward the city as a production center. It is not passengers, however, that are being produced on the transit assembly line, but trips. So there are two perspectives from which to view transit flow: the quality of the passenger experience as a continuous motion through the system and the continuous production of trips by the transit system. They are not precisely the same things.

Focus on Continuous Transit Flow

A passenger must flow from origin to destination, uninterrupted by delays. Automobiles are successful because for many trips they provide that type of flow experience. The automobile fails in situations where traffic congestion slows the flow of vehicles.

It would be a mistake to substitute an emphasis on the flow of transit vehicles or passengers instead of focusing on the flow of trips. Unfortunately, most comparisons of transit modes take the same approach as taken by a 1992 assessment of LRT, APM and Guided Bus systems for Copenhagen, Denmark. (Kragerup, Sondergaard, 1993) In this analysis, an emphasis was placed on maximizing system capacity by shortening headways. Gross system capacity appears to be one of the more important criteria sought after in comparative analyses of transit modes. A manufacturing analogy would be to place the principal focus on the capacity of individual machines. Manufacturing experience demonstrates that an emphasis on improving production flow is more important than maximizing the capacity of even key machine resources.

The main impediment to continuous flow is the tendency to batch operations. Most current transit technologies move passengers in batches, due in part to an intuited but incorrect sense of efficiency. Passengers are gathered in groups and temporarily stored at stations. Trips occur according to a preset schedule that is optimized to make the most efficient use of the equipment. Lean planners understand that this emphasis on the use of equipment rather than production flow (passenger flow in the case of transit) creates waste in the value stream as the final product (a trip) is created. In the case of transit this waste (usually wasted time) impacts the passenger immediately.

PRT, as a planning strategy, addresses the issue of flow directly, and the flow characteristics of PRT are clear. After less than a three minute wait a vehicle arrives and the passenger boards. The vehicle is then instructed to bring the passenger to their destination, and it does so without any intermediate stops. The passenger flows uninterrupted through their transit experience. This focus on continuous passenger flow is far more efficient than a focus on system capacity when it comes to meeting criteria important to the passengers themselves. It also explains why an analysis of PRT networks can determine that PRT can attract and manage more trips than traditional mass transit rail systems (Anderson, 1998).

Correct Transit Measures

Passengers or vehicles moving through a transit system are not assemblies moving through a production line. The product of a transit system is a trip, not a passenger or a vehicle. Furthermore travel, in general, is not a value-added activity. Therefore, counting numbers of passengers, numbers of vehicles, or numbers of passenger miles is not a good measurement of transit value. Without quality measures there is little to distinguish one trip from another. Without quality measures it is impossible to understand why public transit systems do not meet public expectations.

The quality of a transit trip is measured by:

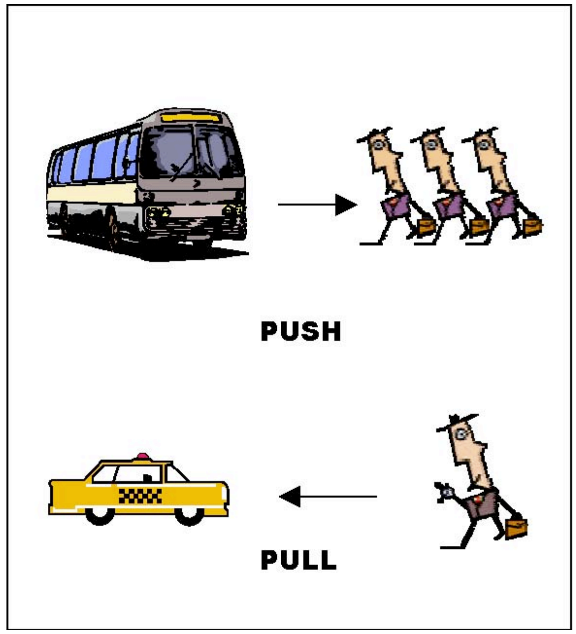
- The **convenience** of the trip origin and the trip final destination to the transit system, recorded as the total distance that passengers must walk during the trip.
- The relative **duration** of the trip, from first origin to final destination, recorded as a proportion of the traveler's day.
- The number of transfers.

. • The **timeliness** of the trip in delivering the passenger to the next appointment. This is measured as total wait time, including the time spent waiting for the onset of the passenger's destination appointment.
. • The **comfort** of the transit environment as measured by the degree to which a passenger can assume various relaxed and comfortable positions while traveling. Alternatively, this might be recorded as the time that passengers spend standing while in transit.
. • The **noise level** of the transit environment measured in decibels.
. • The **stability** of the transit environment. Stability is the amount of jostling and vibration as measured by a seismograph and/or the duration/intensity of G applied to the traveler during the trip.
. • **Safety**, the probability of public injury or death as a result of transit activity, measured by the expected number of lost days of capability per million miles traveled.
. • Passenger **effort** as measured by the outlay of personal energy and the proportion of conscious attention that is required. Drivers, walkers, and passive riders all have different effort profiles.
. • **Flexibility**, the ability to accommodate specialized trip needs, such as bulky passenger burdens, handicapped passenger needs, and groups of passengers.

In lean production systems, travel is not a value-added activity. It is no different in lean transit. The goal of transit is to minimize the effort, expense, and inconvenience of travel. It is the minimal trip, safely getting a person from Point A to Point B, which creates value. Conventionally used measures such as vehicle capacity and capacity utilization are relatively unimportant when it comes to measuring the value of transit.

Pull Production in Transit

The application of Pull principles to transit suggests that vehicles be sent to passengers as required by demand. It is obviously inefficient to direct bus operators to serve a single transit passenger. Large buses and trains are reflective of a 'Push' strategy, wherein transit service is produced with regard to anticipated demand, but not the immediate needs of passengers. (See Figure 1) To achieve pull production techniques in transit it is necessary to use smaller vehicles. The Morgantown, West Virginia, Group Rapid Transit (GRT) system is a demand-based technology that has been in operation for over twenty years. Elevators are also an example of demand-based transit. Nothing moves on an elevator until a passenger pushes a button. A key disadvantage of demand-based GRT is that **Figure 1: Push versus Pull** the trip becomes a composite of all the destinations of all the passengers that share the same vehicle. Although the Morgantown GRT system has offline stations, it would be unusual for a vehicle to avoid stopping at any of the stations during busy hours. Since trips can not be tailored to passenger demand, the measures of timeliness, duration, and passenger effort are adversely affected.



It should be no surprise that the ultimate demand-based transit systems are the automobile and PRT. In these modes batch size has been reduced to a convenient minimum. Setup time and waiting are largely eliminated. A passenger 'pulls' a trip as needed. It is passenger demand that initiates all movement of vehicles.

PRT responds directly to the need for a ride. While the system operators might make an effort to shift empty vehicles to a region of the system, anticipating demand, vehicles are for the most part only moving when needed. Even empty vehicles are managed as a consequence of passenger pull for a new vehicle trip. (Andréasson, 1997).

Eliminating Transit Waste

Inventory in a transit system is just as wasteful as it is in any other production system. Inventory in transit systems takes its most wasteful form when it becomes the stockpiling of people. All the forms of mass and group transit have the practice of gathering crowds of people together in various locations for the purpose of waiting for a vehicle. This increases cycle time without adding value to the trip. Another source of waste in some forms of transit is the construction of guideways that are utilized only briefly every five to fifteen minutes. Since a large percentage of transit infrastructure costs are typically for guideways (buses are an exception) measures which either reduce guideway costs or increase guideway utilization can minimize this source of waste. A well-formed PRT network can eliminate most of the waste associated with transit. Instead of a few widely placed and large stations, there will be ubiquitous small stations. The available-on-demand quality of PRT reduces wasted time due to waiting and transfers. A proliferation of stations can reduce the waste in traveling to and from transit stations. The reduced scale of PRT vehicles also allows a decrease in guideway size and cost, minimizing that source of waste.

Balancing and Leveling Transit Flow

Transit systems have fewer options for balancing and leveling the use of resources than other production systems. Passengers may arrive at any time and are known to arrive in large numbers at specific times. In fact, traffic follows repeated daily, weekly, and seasonal patterns. The sizing of the system has to accommodate peak demand, not only at certain times but also at designated trip origin and destination points.

By carefully selecting a larger number of more widely distributed but smaller transit centers, the load on the system at any one point can be reduced to a minimum that will still support peak loading. Once the transit machinery is sized to handle smaller loads, the transit production system becomes more flexible in accommodating a wide variety of dedicated trip requirements. Using valid measures of cost-effectiveness, the distribution and multiplication of transit resources can be balanced against the reduction in expense due to the smaller sizing of stations, vehicles, and guideways.

A transit system must be able to measure (and respond to) changes in passenger demand. It needs to measure when flow is interrupted, and then provide feedback that allows corrective measures to be taken. Automobile trips respond to changes in traffic patterns as drivers adjust their starting time or their route of travel.

Transit system operators review their train and bus schedules, and attempt to adjust them to meet changes in demand. Typically this might happen two or three times a year. By not having the flexibility to frequently adjust to changing conditions, current transit practice prevents managers from identifying and reducing waste.

PRT designers envision control software that allows the system to learn the daily, weekly, and seasonal demand patterns and anticipate where and when vehicles will be needed (Anderson). For example, it might note stations and times when passengers must wait more than a minute for a vehicle, and make adjustments to its empty vehicle management system to compensate.

Benefits to Cities of Adopting Transit based on Lean Production Theory

As economic centers, cities are producing goods and services. People produce goods and services, and so measures that allow people to be more productive in turn benefit the economy of the city they work in. A lean transit approach is a measure that can produce substantial improvements in how people transit across an urban area.

A typical worker spends 180 hours a year commuting to and from work. In each of the cities of Los Angeles and New York, over two million hours are lost to traffic congestion related delays. When one considers the time delivery vehicles are trapped in traffic and the time spent searching for parking spaces in congested areas, the amount of waste in our urban transport systems is staggering. If a city can implement a lean transit system and eliminate half the wasted time, it can unlock those hours for greater productivity and greater enjoyment of civic life.

The productivity gains within the city not only accrue direct economic benefits, but also help the city as it competes with other cities for new businesses. Companies are looking for locations that support their business objectives, the attraction and retention of employees being key among those objectives. Often the desired qualities of proximity to a large labor pool and convenient transportation for that labor pool do not co-exist. Indeed, transportation conditions are one of the things companies investigate when deciding to open operations in a new location. If one of a city's primary goals is to attract prime career and employment opportunities for its citizens, then any measure that significantly improves the flow of its citizens and eliminates wasted time should be taken.

Conclusion

Lean production principles have yielded extraordinary benefits on the manufacturing plant floor. These same principles can provide transit planners the tools they need to make vast improvements in the levels of service that transit provides to passengers. Like systems of mass production, mass transit is full of waste. In seeking to eliminate waste and create lean transit, planners will need to closely examine the merits of PRT. Of all transit modes, PRT most closely embodies lean principles. PRT focuses on passenger **flow**, allows the passenger to **pull** rides as needed, and can rapidly learn and **perfect** vehicle utilization by adjusting to changes in passenger demand. Encouragingly, the lean production experience in manufacturing plants across the world demonstrates that the same principles that underlie PRT are extremely productive and efficient. Any argument that PRT as an approach to moving people is untested is countered by these experiences. As production systems, cities can only benefit from widespread implementation of lean transit, and PRT is the transit mode that most closely embodies lean principles.

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