Little’s Law – A Practical Approach to Understanding Production System Performance

H. J. James Choo, PhD
Chief Technical Officer, Strategic Project Solutions, Inc.

ABSTRACT

Since it was first published over 50 years ago, Little’s Law has been applied, with great success, to numerous fields such as telecommunications networks, retail supply chain management, logistics and manufacturing. But is it applicable to project delivery? If so, how can we benefit from its use? In the first of what is intended to be a series of short tutorials in the Journal, we explain the application of Little’s Law to the delivery of capital projects. Little’s Law provides insight into how increasing work-in-process (WIP) has a detrimental impact on cycle time. This is counterintuitive to common practice in conventional project management, where the belief is that increasing WIP will increase throughput and ‘get more things going.’

Key Words: *Little’s Law; Project Production Management; Capital Projects*

INTRODUCTION

Little’s Law is one of the most widely known and fundamental relationships in the field of operations science. Despite its simplicity, when depicted in equational form, both its applicability and the insight that it provides are extremely valuable.

As illustrated in the previous article, the context for Little’s Law is viewed as a production system or process, where items or units are flowing through the system as inputs, and are then transformed by the system into outputs. The setting can be very general, as shown in Figure 1.

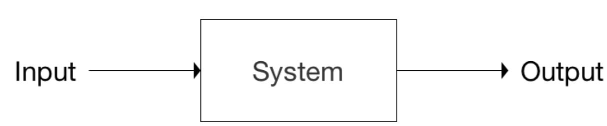

Figure 1: High-level Depiction of a Production System

This illustrates a continuous process flow, where input items are continuously being transformed by the notional production system into outputs, with the system in steady state operating over many cycles. A simple example might be a single step in any manufacturing process, such as when individual sheets of paper are assembled together into packages of paper. In the context of capital projects, an example might be the sequence of activities needed to develop an onshore field: for instance, engineering > fabrication > delivery > installation or site construction > drilling > completions > flow back.

APPLYING LITTLE'S LAW TO THE DELIVERY OF CAPITAL PROJECTS

For the setting illustrated in Figure 1, Hopp & Spearman[1] express Little's Law as:

$$TH = WIP / CT$$

where TH is throughput expressed in terms of items/unit time, WIP is work-in-process expressed in terms of items and CT is cycle time expressed in terms of time units/item. This relationship holds valid as long as the two following conditions are satisfied:

1. The values are based on a long-term average

2. The production system is stable, which includes events such as WIP rising and falling, batching, and extended cycle time due to equipment failures.[2]

Since knowing any two of the three variables (TH, WIP and CT) allows the third to be calculated, the equation above can be used to gain insight into the performance of a production system, even if one of the variables cannot be directly measured or no historical information exists.

Below are some example cases related to project delivery.

EXAMPLE 1: On-Shore Field Development

The development of onshore oil and gas fields is a temporary production system intended to put a certain number of wells on line (to produce) within a given window of time. As such, Little's Law can be applied to analyze the desired and/or actual performance of the production system. For example, if the plan is to put 100 wells on line within the current year (365 work-days), the desired average throughput can be calculated as approximately:

$$0.274 \text{ wells/day} = 100 \text{ well/365 day}$$

If the cycle time for a well from the start of the planning phase to when it is put on-line is 240 days, then the required WIP to achieve the target TH will be 66 wells (= 0.274 wells/day x 240 days). This means that at any given time, the production system should be working on 66 wells. If more than 66 wells are in the system, WIP exists that is not required. This extra WIP in turn ties up cash and oftentimes increases

---

[1] Hopp, W.J. and Spearman, M.L. (1996) Factory Physics: Foundations of Manufacturing Management, Chicago, Waveland

[2] Hopp, W.J. (2008) Supply Chain Science, Chicago, Waveland.

cycle time and cost. There are instances where more WIP is strategically introduced into the system to buffer variability; however, this is done at the expense of increased cycle time and cost.

As you can see, this is a simple law, but yet very powerful in describing the behavior of any production system, including the delivery of a project. Using the equation TH = WIP / CT, you can make two conclusions:

3. TH can be increased either by increasing WIP, decreasing CT or both, and

4. The same TH can be achieved with "large WIP & long CT" or "small WIP & short CT"

In conventional project management, it is very common to see teams focusing on increasing WIP in an attempt to increase throughput ("get more things going"), but this strategy can be very costly. Below highlights why this practice could backfire.

UNDERLYING PRINCIPLES FOR OPTIMAL WIP LEVELS

In any system, more WIP than necessary results in more capital tied up without return and a decreased ability to take advantage of technological advancements or regulatory changes. Therefore, a system will always perform better if the same throughput can be achieved using both as little WIP and CT as possible.

However, this type of performance is unattainable in the real world due to variability in flow (how often work is provided to a production unit) and variability in process (how long it takes to complete / process a unit of work). Much of the variability we deal with each day can be categorized by whether it affects the flow or the process. We pay particular attention to batching (working on or transporting many units of work simultaneously) when we examine processes in project activities, because batching increases flow variability.

What constitutes the optimal level of WIP when the same TH can be achieved with large WIP and longer cycle time (CT) or a less WIP and shorter CT – according to Little's Law (WIP=THxCT)?

A key factor in this equation is 'Critical WIP' (W_0), which Hopp & Spearman[3] define as the WIP level that achieves the maximum throughput (bottleneck rate, or r_b) and minimal cycle time (raw process time, or T_0) in a process flow with no variability.

[3] Hopp, W.J. and Spearman, M.L. (1996) Factory Physics: Foundations of Manufacturing Management, Chicago, Waveland.

Critical WIP (W_0) can be calculated using Little's law:

$$W_0 = r_b \times T_0$$

Any WIP above this level would not result in additional throughput, but rather increases CT due to additional wait time. Any WIP level below W_0 would result in lost throughput. It is important to always consider the presence of variability and its impact on system performance including throughput, use of capacity and inventory. Since there are no production systems in the real world that don't have variability, maximum throughput cannot be achieved by merely setting the target WIP as same as the critical WIP. However, Critical WIP provides a key benchmark for evaluating current production system performance.

EXAMPLE 2: Modules or Pre-Assembly Supplier Evaluation

Another example is the application of Little's Law to assess the potential CT of a supplier that will be delivering modules or pre-assemblies to a given project.

For example, if a fabricator that works 10 hours a day, has 20 modules-in-waiting to be welded within the next 25 days where each module consists of 25 welds totaling up to 500 inches of welding, the required TH can be calculated using TH = WIP / CT. The resulting answer is 40 inches per hour (= 20 modules x 500 inches per module / 25 days / 10 hours per day). If the bottleneck of the factory is the welding bay, then the overall capacity of the factory would be set by the welding bay. If the capacity of the welding bay is 50 inches per hour, the existing work would put the welding bay at 80% utilization.

Since the actual CT is not known in this case and may change, Little's Law (expressed as CT = WIP/TH) can be used to draw a quick assessment as to whether the modules will be delivered within the agreed lead-time. Little's Law helps us to understand how much WIP is currently in the system of the supplier and what the bottleneck rate of the system is. In addition, because the amount of wait time in a queue is part of the cycle time, and it increases exponentially as the utilization increases,[4] it is critical to understand the utilization of the bottleneck. Using the example above, if the fabricator takes on more work and thereby increases the welding bay's capacity utilization beyond 80-85%, the likelihood of cycle time explosion becomes very likely. If welding capacity cannot be increased, the lead-time for the new modules needs to incorporate the additional time required so that it can be delivered within the promised lead-time.

---

[4] Kingman, J. F. C. (1961). "The single server queue in heavy traffic". Mathematical Proceedings of the Cambridge Philosophical Society. 57 (4): 902.

CONCLUSION

In production systems, such as those of capital projects, where multiple production units follow each other (engineering > fabrication > delivery > installation or site construction > drilling > completions > flow back), variability that is generated by one process propagates through the system. If utilization of all production units is high in order to minimize resource cost (as is often the case, though not necessarily the best strategy), process variability will also be high. To remedy this, one has to institute standard processes within the project by working with those that are directly responsible for the work to determine the norm, and use production plans as a control mechanism to achieve high reliability.

Although we have briefly discussed how variability degrades production system performance, causing longer cycle times and either less TH or higher WIP, we will take a closer look at this relationship in the next edition of the Journal.