

Factory Physics[®] Principles for Managers—Fourth in a Series

A series of articles designed to help managers and executives better control and optimize their operations through a solid understanding of the practical science that governs their environments.

Managing Variability

Variability is an unavoidable fact of life that is best managed through understanding the tradeoffs it presents. Variability is a double-edged sword—it can be good, e.g. having more than one product to offer to your customers, or variability can be bad, e.g. machine breakdowns or order cancellations. As an executive, your strategic solutions for managing variability in your environment are two fold:

- **First, determine the amount of “good” variability that you require to be successful in your market and**
- **Second, determine the lowest cost combination of buffers (inventory, capacity and time) and efforts at reduction of “bad” variability to ensure you succeed in your market.**

For most manufacturing and supply chain managers, the luxury of setting demand levels and product offerings is not one of your options. However, Factory Physics principles provide practical scientific relationships such as the VUT equation and practical buffer management strategies for getting the best possible performance out of the operations in your span of control. In any case, the key to success is in understanding the effects of variability on value stream behavior and then managing the tradeoffs to your advantage.

To review, the Factory Physics framework starts with a fundamental definition of a value stream: a value stream is a structure of flows and stocks providing transformation to meet demand (see “Defining a Value Stream” in the third article in this series). The most profitable situation is when demand and transformation are completely synchronized. Unfortunately, perfect synchronization of transformation and demand is impossible. This is a law of nature, stated differently—variability is never zero. In other words, we will always be dealing with variability, or uncertainty, so we can never exactly know what demand will be or what our transformation (supply) will be to meet demand. Notice we are not saying that is a bad thing, it’s just the way things are. The bad things start to happen when executives and

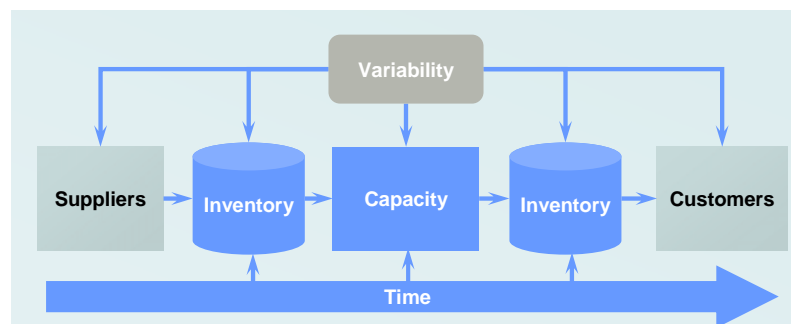
managers expect manufacturing and supply chain operations to behave differently than nature permits—the classic example is scheduling at 100% capacity utilization and expecting to be able to control performance well.

Fundamental Behavior of Operations

So how do operations behave? Well, since transformation never exactly meets demand, buffers appear. Notice we didn't say, "Buffers should appear." Or, "It sure would be cool if buffers could appear." Or, "Wow, we wish buffers would appear." Buffers will appear and there are **only three kinds of buffers: inventory, capacity and time**. As a manager or executive, you and your associates have four elements to balance (see Figure 1) in managing the performance of your manufacturing and supply chain operations:

- variability
- inventory
- capacity
- time

Balance is Key



- ***Optimal “portfolio” of:***
 - Inventory buffer
 - Time buffer
 - Capacity buffer
 - Variability reduction

A primary consideration for operations management strategy.

Figure 1

Now it would be a colossal oversight to presume that people aren't part of the mix or that pricing or good leadership aren't important factors—they certainly are. Employees are a

source of capacity and a source of variability. In that regard, the “soft” elements are considered though this discussion is centered mainly on basic Factory Physics principles to enable employees and their leaders to better control and manage their organizations.

More and more, people are realizing that the goals of “eliminate variability” (from Six Sigma) and “reduce waste” (from Lean Manufacturing) are admirable goals but only state the obvious. If “eliminate variability,” is used to mean achieve zero variability, it is an impossible goal. If one accepts that zero variability is not possible so the mantra is changed to “reduce variability,” there still is no good description of what is a reasonable level of variability—as described earlier, some variability is bad and some is good. In the classic Lean Manufacturing approach, “reduce waste” is like saying, “Do the right thing.” It sounds great but doesn’t provide much direction.

While both Six Sigma and Lean Manufacturing have provided very successful tools for improving performance, Factory Physics principles and applications enable you to get to best possible performance as quickly as possible. This means better deployment of your existing Lean and Six Sigma resources—certainly not replacement of those resources. We would never advocate throwing out the baby with the bathwater! Using the Factory Physics framework, you will waste less time discussing where to prioritize efforts and will make better decisions about how to approach and implement performance improvement. Factory Physics principles and applications enable you to understand variability and effectively implement your most profitable portfolio of inventory, capacity, time and reduction of “bad” variability.

Variability Relationships in Your World

The classic definition of variability usually involves the **parameters** known as the **variance** or **standard deviation** (the square root of the variance) that indicate the amount of dispersion that a given measurement has about its mean or average. **Statistics** with the same name are used to estimate the corresponding parameters using available data. But neither these parameters nor their corresponding statistics are sufficient without also considering the mean. For instance a standard deviation of process time of only 0.1 seconds sounds very small until you discover that the mean is also 0.1 seconds. Likewise, if the mean time to machine a part is 10 minutes and the standard deviation is 1 minute, we would think of this as low variability. However if the mean were 1 minute and the standard deviation was, say, 10 minutes, then we would consider this variability to be quite high.

A better parameter is to take the ratio represented by the standard deviation divided by the mean. This is known as the **coefficient of variation** or **CV**. This is an important measure for estimating the effect of variability in flow and in effective process times.

The idea of the three buffers and variability can be tied together in one equation known as Kingman's equation or, in laymen's terms, the "VUT equation" which states that the cycle time in queue is equal to a variability factor (V) times a utilization factor (U) times the effective process time (T), or

$$CTq = VUT$$

More detailed description of the components of VUT is left to the book *Factory Physics*; we focus here on applications in practice.

The total cycle time at the station is equal to the cycle time in queue plus batching time plus move time plus the effective process time or,

$$CT = VUT + BT + MT + T,$$

where BT is time due to batching and un-batching (we won't go into batching time in this article). Note that if we have perfect one-piece flow, $BT = 0$ (which is a good reason why people want to do this). If there is zero variability, perfect one piece flow becomes possible, $V=0$, **there is no batching**, and cycle time reduces to the process time plus move time. If we have been able to establish process centers right next to each other, move time is negligible and cycle time reduces to process time alone—but, since there is always variability and there is never perfect layout of equipment, this never happens.

The utilization factor depends on the effective utilization of the station but in a highly non-linear way. Capacity is the upper limit of utilization. For the VUT equation, in simple cases,

$$U = u/(1-u)$$

where "little u" is the effective utilization. Thus, if you try to schedule your line or fab or shop to 100% utilization, u goes to 1, the U factor goes to infinity, and so do your cycle times! The reason you never see infinite cycle times is that you *never* have 100% utilization *over the long term!* Eventually things become so bad that something gives—you either reduce the load or add capacity—but you never reach infinite cycle times. The cycle looks like this:

1. Schedule your plant at 100% capacity
2. Start working. Variability happens.
3. Cycle time starts to get long, WIP piles up, orders begin to ship late.
4. Add capacity (overtime or outsourcing) or reduce the amount of jobs in your plant
5. Things get back under control.
6. Go back to step 1.

We call this the **“overtime vicious cycle”** and have seen it in operation in many plants. The point is that you cannot have 100% utilization over the long term. If you try, things will eventually get messed up to the point where you must decrease utilization. You can plan to have less than 100% utilization or you can schedule job starts at 100% of capacity until things become so bad that you have to reduce the start rate. Either way, **you will not work at 100% utilization over the long term.** Figure 2 shows what would happen if you scheduled at 100% utilization and allowed things to run indefinitely.

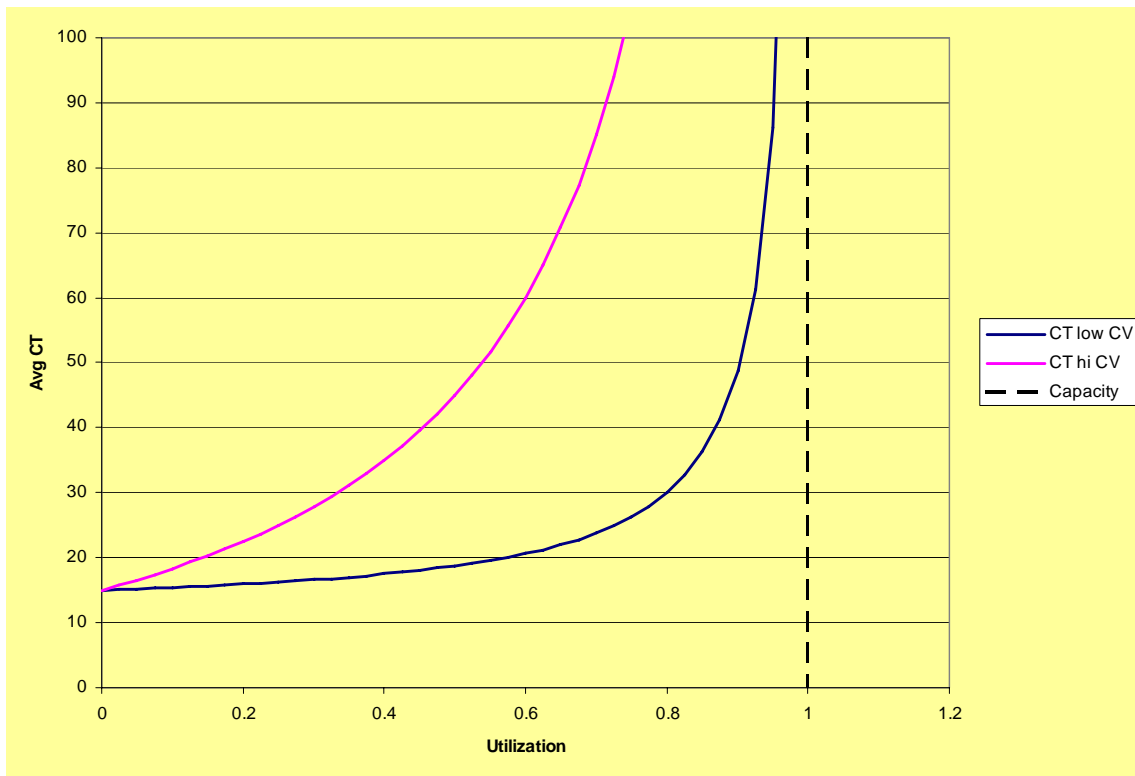


Figure 2

As you approach 100% utilization, cycle time increases dramatically. However, once cycle times have become excessive, additional capacity (i.e., reduction in utilization) brings cycle times down equally dramatically. Unfortunately, by then things

have become a big mess. This utilization law is a fundamental Factory Physics principle. It's a law that should be taken to heart by all executives and managers, including those in the accounting and finance functions!

Managing Variability in Practice

While the VUT equation is an approximation, it does provide fundamental insight into the relationship between variability and the three buffers (though we haven't talked about inventory yet). Application of the relationships in the real world is more complex but understanding the general behavior of variability and the three buffers provides good *intuition* that leads to consistently better management decisions.

- Example: The combination of reducing inventory, doing nothing about variability, and expecting on-time delivery to improve or stay the same is a recipe for trouble. With a good understanding of Factory Physics principles, your intuition would tell you not to approach inventory reduction goals by just mandating reduced inventory levels (we've seen it happen!). You would accept the goal and then use your understanding of Factory Physics principles to determine what is required to achieve reduced inventory levels and direct your organization on how to proceed most quickly to achieve the inventory reduction goals with no loss in on-time delivery performance.

The VUT equation is very useful since it describes the relationship of the three buffers in succinct form. If we want to have a low time buffer, then either V or U *must* be small. If V is not small, then U will have to be small. This means that if we have variability and want to have a small time buffer, we will need to have a large capacity buffer in order to keep U small.

- Example: If you are constantly making schedule changes because you allow customers to make changes to their orders at any time, you should also have plenty of extra capacity available or be prepared to ship orders late.

What about inventory? For WIP we can use Little's Law and get,

$$WIP = CT \times TH = (VUT + BT + MT + T) TH$$

So to keep the inventory (WIP) buffer low we will also have to have a large capacity buffer in the presence of high variability. The VUT Equation combined with Little's

Law shows us that high variability at highly utilized work centers results in *both* a large time buffer and a large inventory buffer.

➤ Example: What if we force WIP to be low? Managers do this all the time by limiting how much WIP is allowed in the system through use of pull systems such as kanban or CONWIP. If the VUT equation is to hold, something has to give. If variability is not reduced and process time is not decreased then U will go down with less WIP in the system. The only way for U to go down is for the throughput to go down. This is exactly what happens in manufacturing plants that are overzealous about reducing WIP. As discussed in the third article in this series, such plants go beyond lean and become anorexic. WIP and cycle time will come down but so will output of the plant if variability is not reduced. So if you are making management decisions and you are focusing on reducing WIP, make sure you understand how much WIP is needed to maintain maximum throughput given the variability levels in your operations.

In a recent email newsletter from Supply Chain Management Review, the following solutions were promoted as keys to future success:

- real-time response
- demand driven supply network
- agile supply chains

We agree that these are all good things to have. To paraphrase John Kennedy, "...be aware of the danger—but recognize the opportunity." Too often executives and managers recognize the opportunity and ignore the danger in pursuit of better performance. If you want to be agile/demand driven/real-time, you are stipulating that you require a very small time buffer and typically executives want this fast response with little or no inventory. If you attempt to have a very small time buffer, very little inventory, and you do not reduce variability, you will need a large increase in your capacity buffer. A large capacity buffer is typically very expensive. If you do not add the necessary capacity buffer, do nothing to reduce variability, and reduce your inventory buffer, the time buffer will increase. This means longer response times, reduction in on-time delivery performance and is typically also very expensive in terms of lost customers.

The solution to managing variability in your environment is to determine the amount of “good” variability that is required to be profitable in your market (e.g. range of demand volume, different product offerings, promised lead times, on-time delivery) and then implement and maintain the most profitable portfolio of:

- buffers (inventory, capacity and time)
- investment in reduction of “bad” variability (e.g. more fixtures to reduce setup times, stocking replacement parts to reduce downtime, dynamic scheduling, demand shaping).

Too often, executives and managers embark on great challenges or slogan-based initiatives to improve performance without a good understanding of the potential consequences of their actions. For you to be successful as an executive or manager of a manufacturing or supply chain operation, it is vital that you understand these fundamental relationships of Factory Physics principles and manage the tradeoffs proactively.

For copies of the previous articles in the “Factory Physics Principles for Managers” series, go to www.factoryphysics.com and select the Press Room link. Viewing and downloading the articles requires registration on the website if you have not already registered.

If you would like to speak to someone directly, contact:

In the US and outside Europe: Ed Pound Factory Physics, Inc. +1 (630) 870-1163 Email: pound@factoryphysics.com	In Europe: Marc Colpaert Factory Physics Europe +32 (0)479-784634 Email: colpaert@factoryphysics.com
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Web site: <http://www.factoryphysics.com>

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