Mixed Model Assembly

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Introduction

Mixed Model Production is the practice of assembling several distinct models of a product on the same assembly line without changeovers and then sequencing those models in a way that smoothes the demand for upstream components.

The objective is to smooth demand on upstream workcenters, manufacturing cells or suppliers and thereby reduce inventory, eliminate changeovers, improve kanban operation. It also eliminates difficult assembly line changeovers.

To illustrate conventional assembly practice, consider the three products shown in figure 1. Note that the upper components are physically different and assume they are built at three separate workcenters. Demand shown in figure 2 is perfectly stable, uniform and predictable.

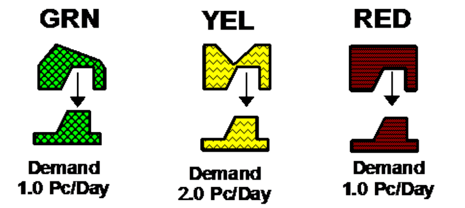

Figure 1 A Stable Product Mix

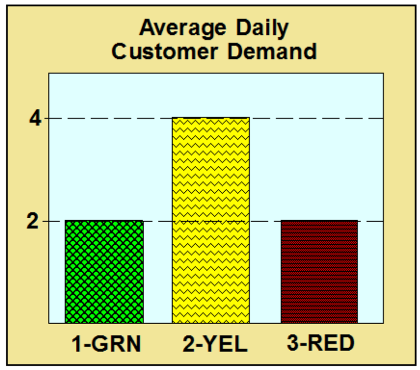

Figure 2 Daily Customer Demand

Conventional Assembly Line Practice

Figures 3 and 4 illustrate the conventional assembly line practice as developed by Henry Ford and Charles Sorensen. A single product moves along a conveyor and at each station, workers assemble various items. The entire line changes to a different product on a fixed schedule and then assembles this product for a scheduled period before changing to the next product.

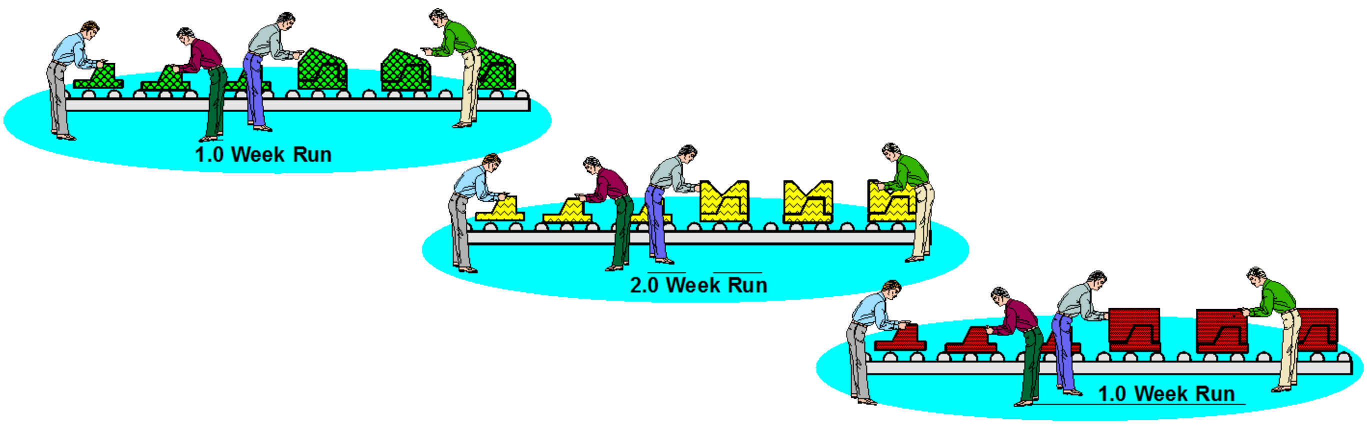

Figure 3 Conventional Assembly Line Practice

On large assembly lines, setup is often problematic. Parts are brought in for a new job and remaining parts taken away for the just-completed job. Such lines often need re-balancing with different stations and task assignments. Then, there is the initial startup as everyone gets accustomed to the new configuration. If parts do not fit, or cannot be found, there is more disturbance. When, at last, the line is humming, nobody wants to disturb it with another changeover. Such is the case with our hypothetical assembly line.

And so, once setup, the line runs for a week on the first product, 1-GRN. At the end of a week, 40 units are complete even though the customers only need 10 units. The remaining 30 units must go into inventory to carry the customer demand for the next three weeks. The figures below illustrate.

After another frenetic changeover to product 2-YEL, the line runs for 2.0 weeks since the demand for this part is higher. Eighty units are built. Twenty of these units supply customer demand during the run. The remaining 60 go into inventory.

Another changeover and, for a week, the line runs 3-RED. Forty units are made. Ten for customers and the remaining 30 for inventory.

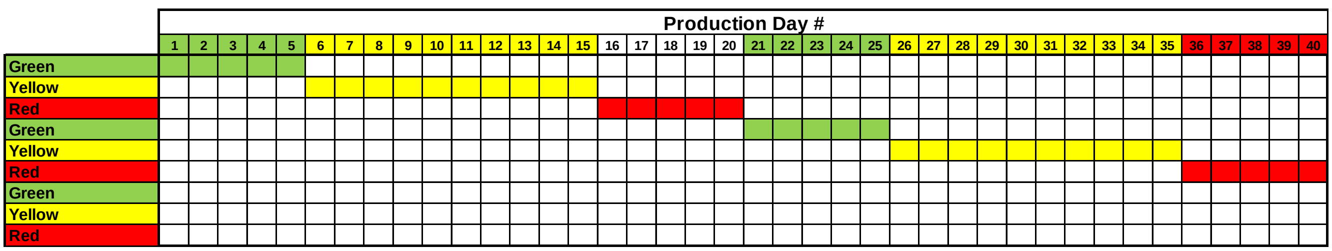

Figure 4 Gantt Chart for Conventional Assembly Line Practice

Figure 4 shows the schedule for eight weeks of production. The first week produces the Green product at 8.0 units per day. Since the demand for Yellow is twice that of Green, Yellow is made for two weeks. Red is built for one week. This cycle then repeats continuously.

Mixed Model Assembly Line Practice

With mixed model assembly, figure 4, multiple models are interspersed on the same assembly line. The ratio of each model to total output is consistent with customer demand. Thus, in figure 4, there are two "Yellows" for every "Green" and two "Yellows" for every "Red". These are the same ratios shown in figure 2.

Figure 5 Mixed Model Assembly Practice

The Gantt chart of figure 6 shows how this looks with respect to time and corresponds to the chart of figure 4. Figure 4 shows hourly production but for only three days. In this case, every model coming down the line is different from the model that precedes it.

Mixed model assembly, at first glance, seems overly complicated. It presents difficulties in part stocking, setup, skills, training and general confusion that must be overcome.

However, if we can address these difficulties, there are major benefits both upstream and downstream in the process. Benefits come from the effects of mixed model assembly on:

- **Upstream Demand Variability**
- **Upstream Capacity**
- **Upstream Inventory**
- **Space Requirements**
- **Changeover Time**
- **Scheduling**

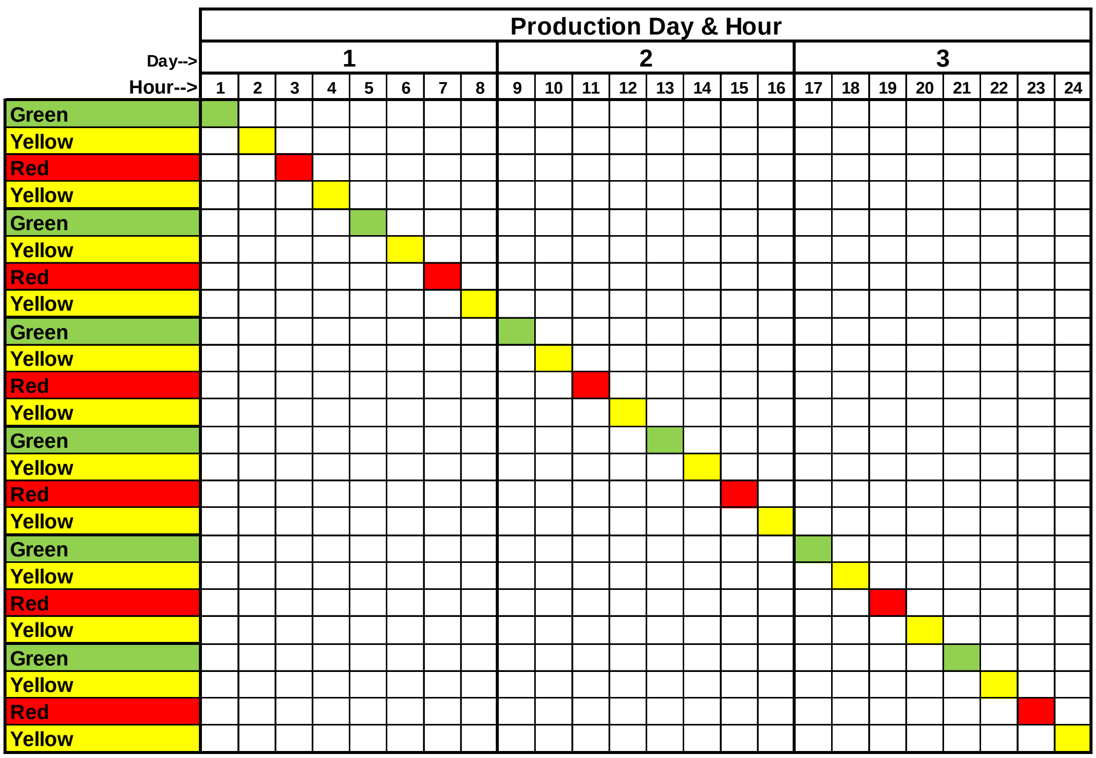

Figure 6 Gantt Chart for Mixed Model Assembly Line Practice

Benefits of Mixed Model Assembly

Upstream Demand Variability

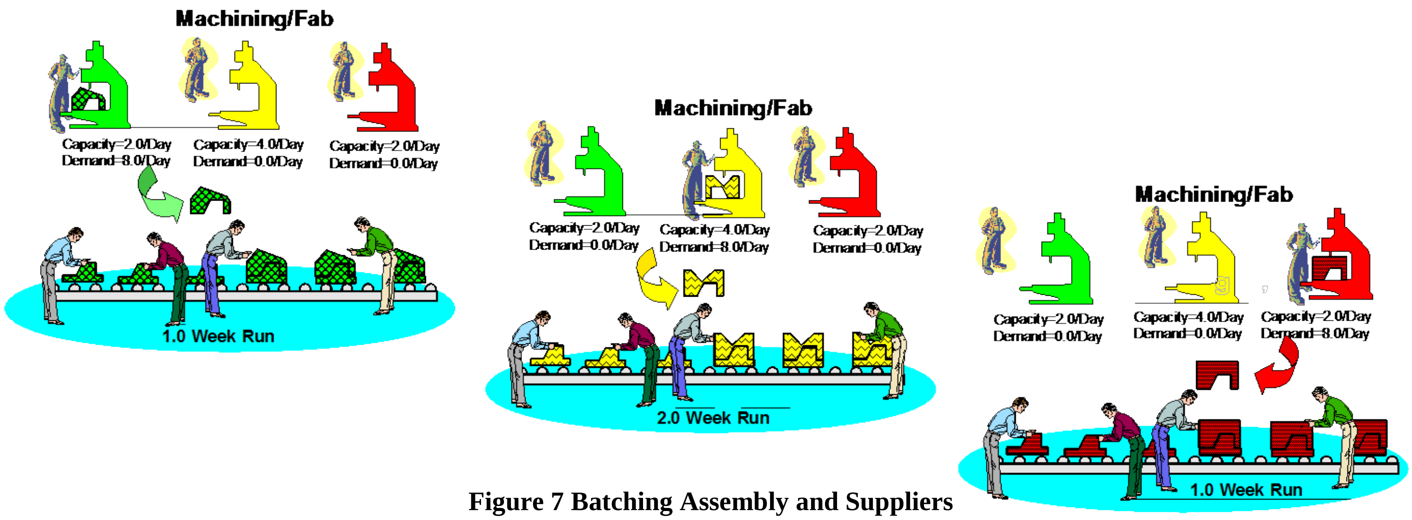

Figure 7 Batching Assembly and Suppliers

Consider the batching assembly line of figure 3 and, also include the upstream suppliers of the top component. Assume that the three components are built at three separate work centers or come from three separate vendors. Figure 7 illustrates.

Figure 8 shows the daily demand for the three components. The demand at each supplier is highly variable, either 0.0 or 8.0 units per day. This variation occurs in spite of the fact that the ultimate customer demand is stable and predictable.

The supplier might cope with this demand pattern several ways:

Excess Capacity

The supplier can provide equipment and people that meets the daily demand of eight units per day rather than the average demand of either two or four units per day. Suppliers would then operate only when the assembly line was running their particular component.

This is an acceptable solution when capacity is inexpensive. For example, if the Green component were a manual weldment, a welding booth and fixture could be setup for eight units per day. On days when demand was zero, the operators would be put on other workstations.

However, if the Green component required an expensive and large CNC machining center the excess capacity approach might not be feasible. One would not want such a machine sitting idle 75% of the time.

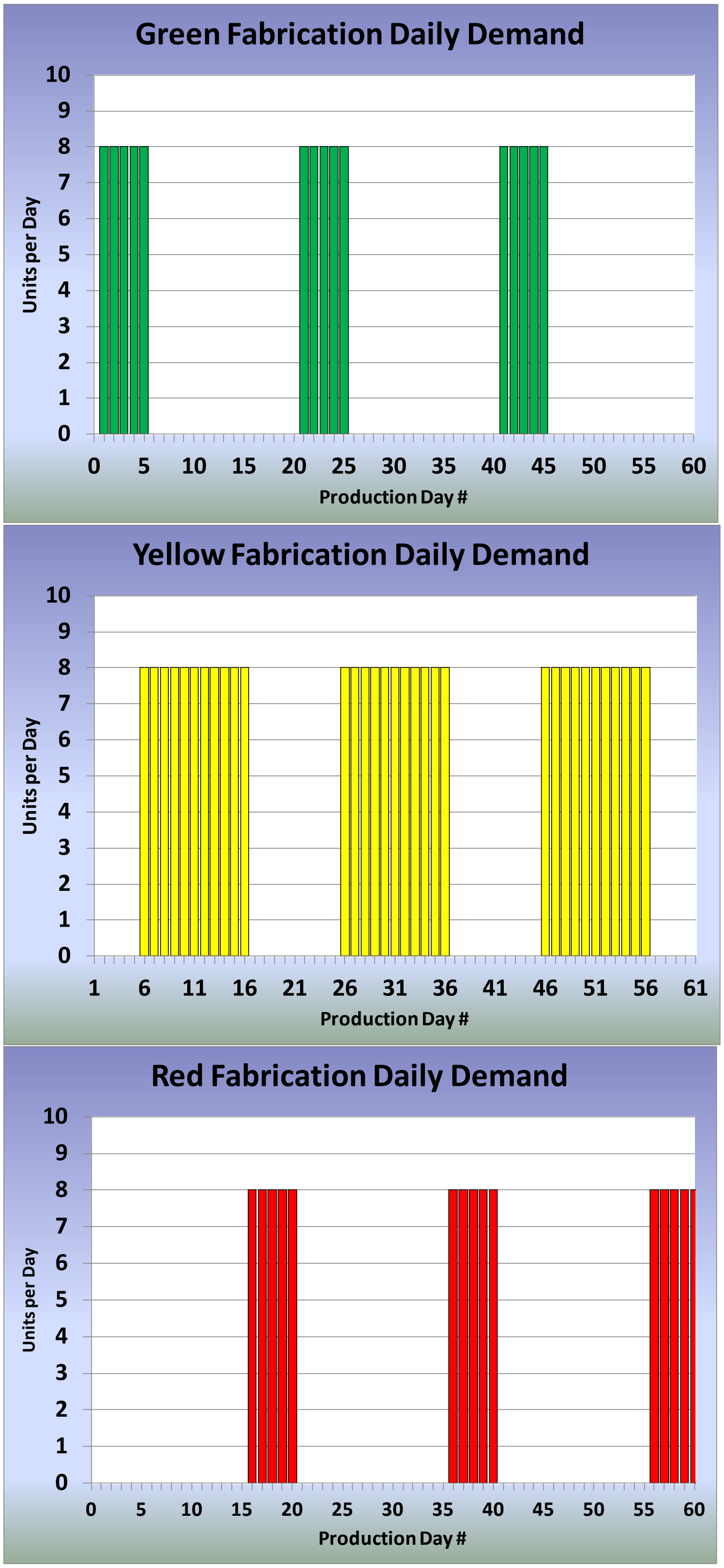

Figure 8 Daily Component Demand with Batching

Inventory Buffer

If WIP inventory is held, the supplier operation can run continuously at the average demand rate of two or four units per day and build inventory for those days when daily demand exceeds capacity. The inventory approach is acceptable when components are small and inexpensive. However, large and expensive items may require considerable space and working capital.

Figure 9 shows how the inventory buffer approach might work with our example. A simple spreadsheet model was built based on the batching approach of figures 4, 7 and 8. If the fabrication operations are sized for customer demand, rather than the peak daily assembly line demand. This is absolutely the minimum inventory required under perfectly stable and predictable conditions. Practical conditions would increase inventory significantly.

Significant inventory is required for both finished goods and work in process. This is 50 units or 6.25 days for each category.

Figure 10 shows how this might affect the plant layout. This inventory requires space and often tends to isolate processes from one another.

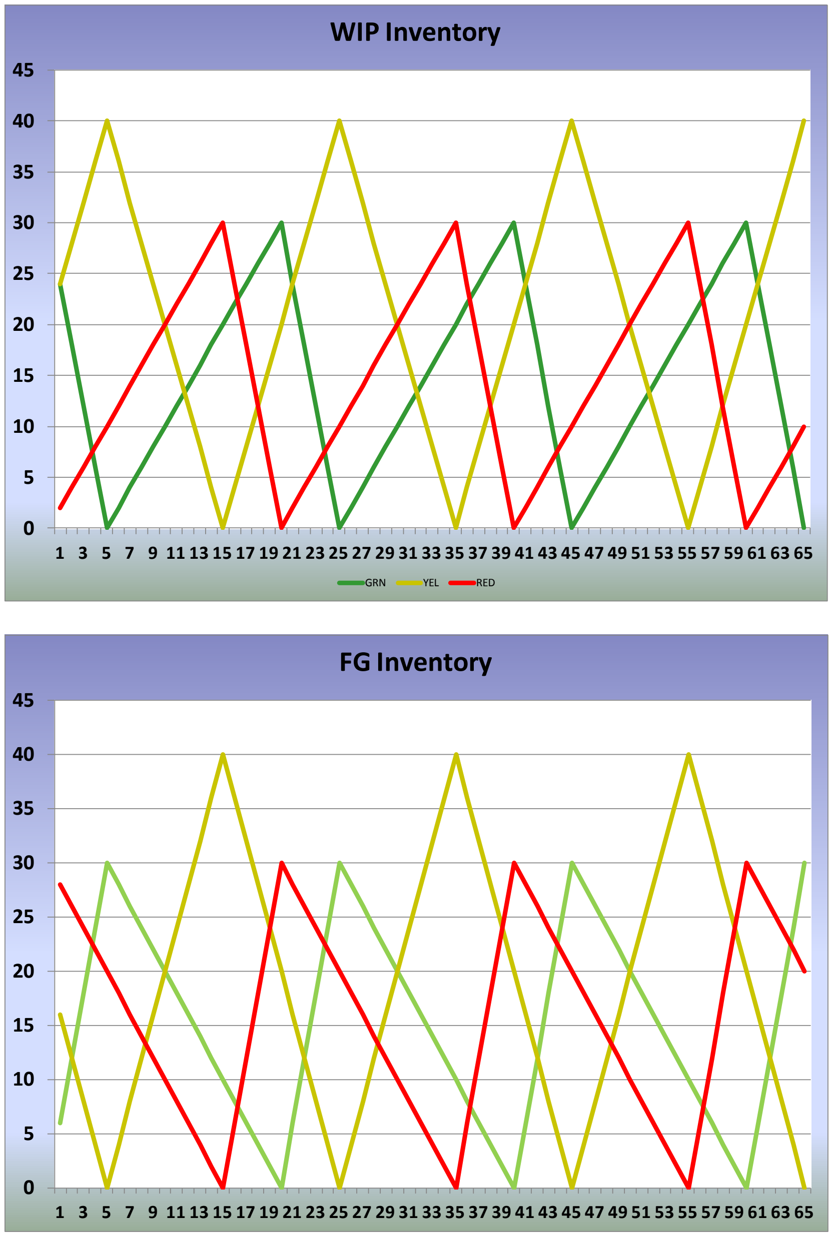

Figure 9 Minimum Inventory for Batching Assembly with Buffers

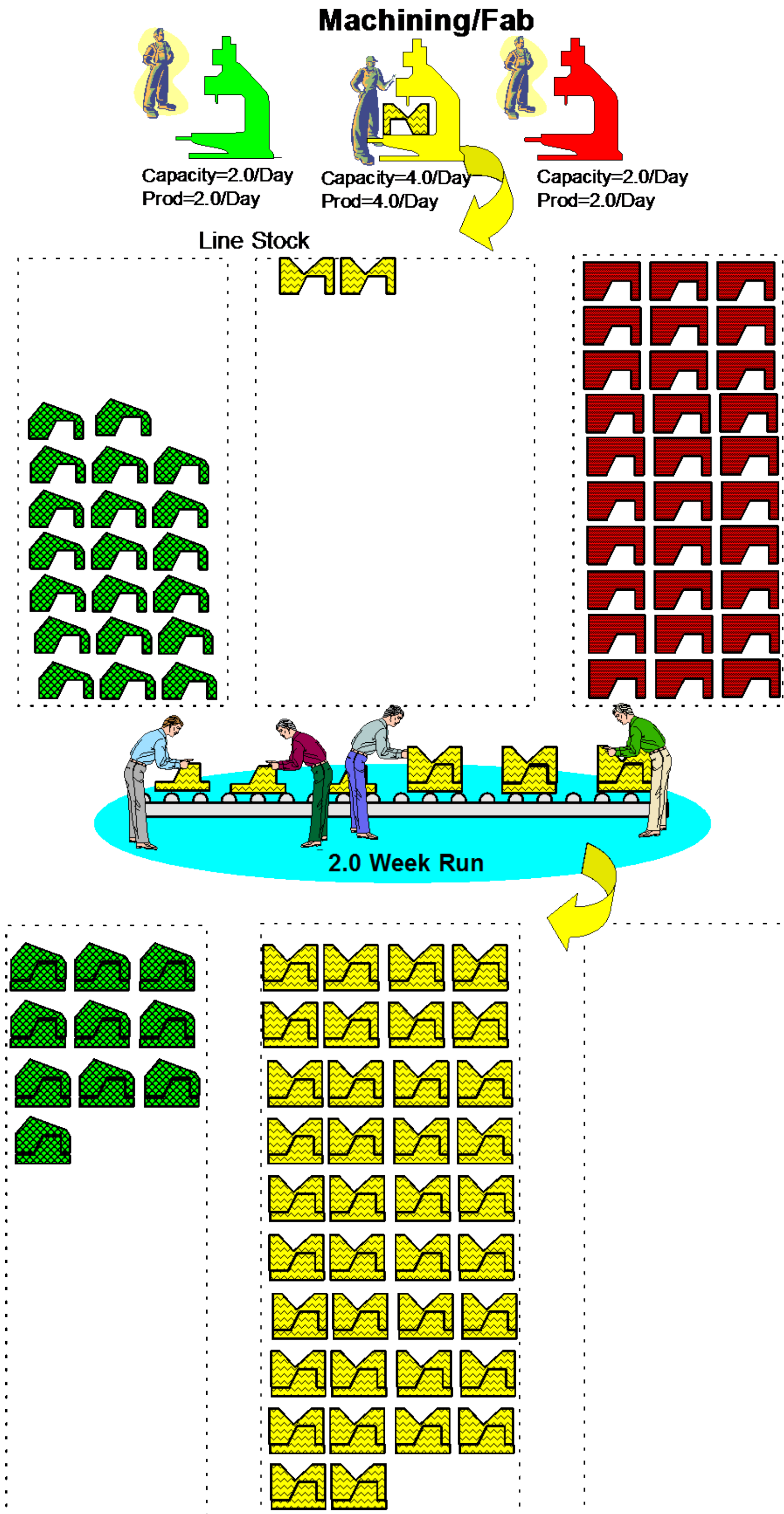

Figure 10 Batch Assembly with Inventory Buffers

Multi-Product Equipment

A supplier might address the problem by sizing equipment for the peak daily demand of eight units per day and then using this equipment to produce different products for different customers during the days when there is no demand from the assembly line.

One problem here is that there may be conflicts between the demands for the various products. Another problem is changeovers with all of the time, difficulties and uncertainties that they typically entail. Scheduling also becomes more complex, sometimes incredibly complex.

Hybrid Approaches

When faced with this problem of variable demand, most suppliers combine several of the fundamental methods described in some sort of hybrid combination.

To varying degrees, all of these methods are inconsistent with the simple, smooth and synchronized material flows of a truly Lean operation. They all introduce complexity into the coordination and scheduling task. They all increase waste in some form or another.

Eliminating Demand Variability with Mixed Model Assembly

Mixing models on the assembly line smoothes demand at fabrication. Figures 11 and 12 illustrate this. This eliminates the need for a large inventory buffer between fabrication and assembly. At four and two units per day, a buffer of only one piece would suffice,

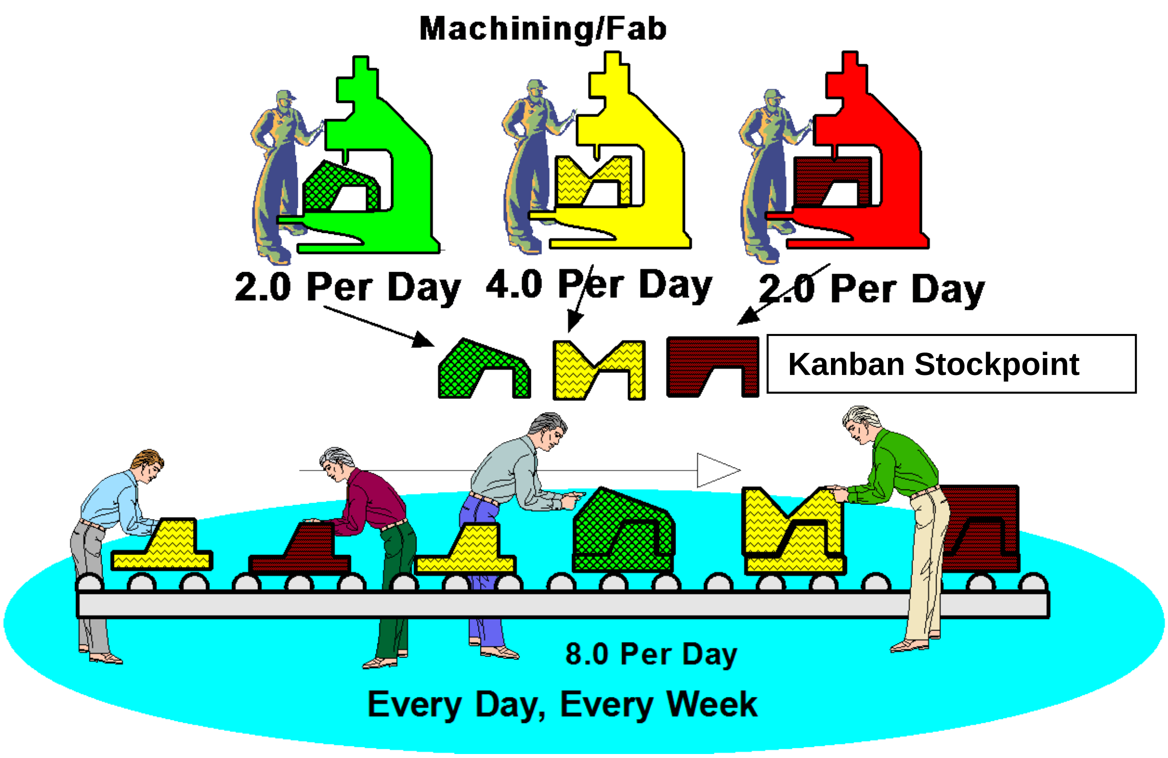

Figure 11 Mixed Model Assembly and Upstream Fabrication

A similar inventory reduction occurs on the Finished Goods side since the line is scheduled to synchronize with daily demand.

A kanban system between assembly and fabrication will further simplify operations and scheduling. It would use the buffer as a kanban signal to prevent overproduction at fabrication.

Scheduling of the assembly line might be done in either of two ways:

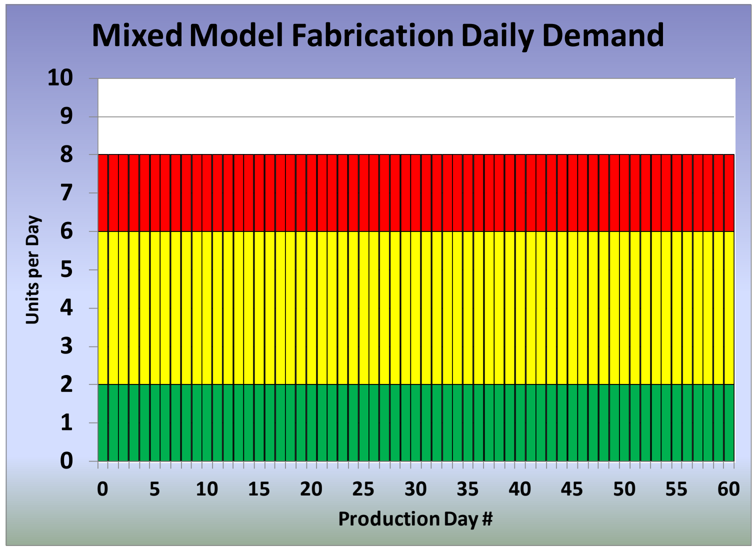

Figure 12 Mixed Model Daily Demand Pattern

1) A ***kanban system*** would hold a few of each finished item and the line would be scheduled and sequence to replenish the kanban stock.
2) The line might be scheduled on a ***Make-To-Order*** basis and build only what customers have actually ordered.

With either system, there is no formal scheduling required upstream at fabrication because the kanban system provides the signal for what to produce and when.

What Makes Models Different?

Various models of a product have a wide range of similarity and difference. Whether two models are actually "different" or the same depends on your perspective. "Different models" from a Sales & Marketing perspective may be identical from a "Manufacturing" perspective. For example:

Sales & Marketing

Here, functionality and styling are usually the key differentiators. If a customer wants a black product, a white product will not suffice. They are different models. If a customer pays for 128 gb of memory, the same item with 32 gb of memory are not acceptable.

Engineering

Engineering thinks in terms of components. When two models have all components that are completely interchangeable, they are the same; otherwise, they are not the same and require different identification numbers.

Manufacturing

In manufacturing, differences are not always so clear. When two models go through the same processes, with the same equipment, and with many of the same components, they are considered highly similar and can be thought of as a single product or product family. The differences may be significant for the customer or the Bill of Materials, but have little effect on manufacturing. As a case in point, two models are assembled on a line but the only difference is the capacity of the memory chip. The chips are the same size and go in the same location. It is such a simple matter for the operator to choose one chip or the other that the models may be considered identical for most manufacturing purposes.

So it is that when we discuss Mixed Model Assembly, there is some vagueness about what should be considered a model. This vagueness is not always easy to resolve. It is the "art" in engineering a production system. Here are some factors to consider when thinking about the differences and similarities of models for manufacturing:

- Degree of Component Commonality
- Physical Characteristics of Components
- Tooling Changeover Time

An engineer's intuition and general knowledge is usually sufficient for resolving this issue for assembly operations. In more complex situations, the discipline of Group Technology may be helpful.

Enabling Mixed Model Lines

Production Smoothing

Production smoothing in the upstream processes is normally the result and an objective of Mixed Model Assembly and Mixed Model Assembly can cope with considerable variation in customer demand. However, the smoothing of demand downstream of assembly can help a mixed model line run better and further improve the demand variation of the upstream processes. It is always beneficial to examine downstream demand and find ways to reduce day-to-day variation. Smoothing customer may be remarkably simple and easy.

One pharmaceutical manufacturer experienced frequent short-term demand for one or another product. Investigation revealed that this was the result of a sales promotion policy in which certain items were put on sale to veterinarians across the entire country on a regular basis. The solution was simply to rotate the sale items among different regions.

Material Staging

Every part for every model must be staged immediately adjacent to a Mixed Model line. This may be problematic when the product has many parts and there are many models. However, the need for each part is less when running mixed models as opposed to a batched line.

A kanban system is often ideal for this situation. A small stock is carried at the line and is replenished from an upstream workcenter, a warehouse or directly from an outside supplier. It all depends on usage, demand patterns and the physical size of the components.

Inline Equipment

Many assembly lines have integrated equipment for forming, flipping, assembling, wrapping or testing, as in figure 13. If such equipment requires long changeovers from one product to the next, the changeover may prevent mixed model assembly. Every effort should be made to reduce the changeover time of such equipment using SMED techniques.

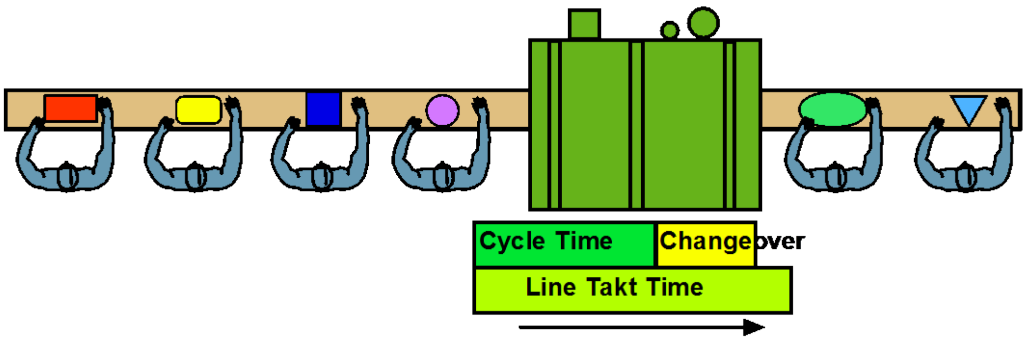

Figure 13 Integrating Automation in A Mixed Model Line

Work Balance

Henry Ford's highly balanced assembly line has been the dominant production model for almost 80 years. However, such lines have significant problems. Most short-cycle lines that appear to be balanced actually have significant balance losses that exceed 20%.

Production lines can have perfect average or static balance and yet be highly unbalanced from cycle-to-cycle (dynamic balance). Understanding these factors is important when selecting balance methods.

Inherent Balance

Inherent balance attempts to provide each workstation with precisely the same amount of work. With high-volume assembly lines, this may be achievable, to some degree. Manual assembly is flexible because people are flexible. Analysts divide the work into minute tasks. They reassign these tasks to work stations such that each station has the same cycle time. Balancing mechanized or automated production lines with this method is more difficult since it is rarely possible to find equipment with identical cycle times. Figure 1 shows inherent equipment balance.

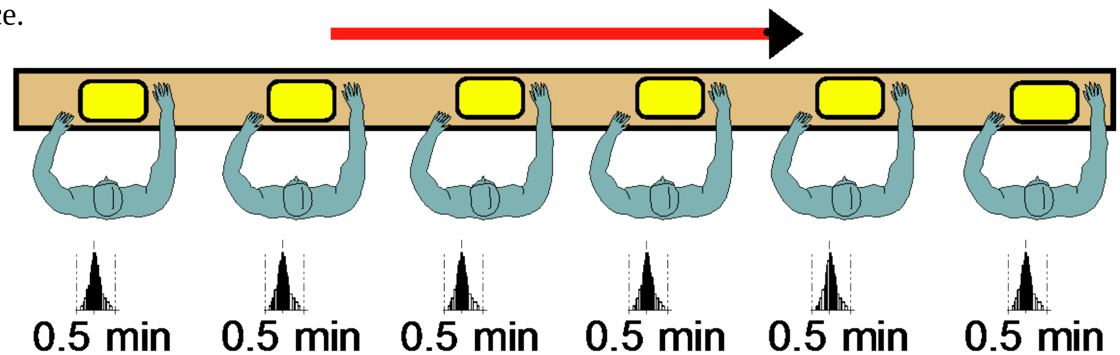

Figure 14 Inherent Balance

Inherent balance presents additional difficulties as well. It tends to be inflexible. For new products, the line must be re-configured and re-balanced. When multiple products run on an inherently balanced line and require differing cycle times at some operations, the line must be stopped and re-balanced at each changeover. This forces batch production.

Perhaps the most formidable problem of inherent balance comes from variation from one cycle to the next. The work times developed by traditional time study show average deterministic times of great accuracy. In reality, these times may vary significantly from one cycle to the next. The time at a given station is, in fact, a distribution. When the time on a station is longer than the average, it slows the entire line. When the time on a given station on a particular cycle is less than average, it cannot speed up the line. Thus, the real performance is less than the average cycle times indicate. The more stations, the more this variation affects performance.

Surplus People Balance

While surplus capacity is a reasonable method for balancing machines, particularly inexpensive machines, it rarely is acceptable for balancing people. When customer delivery is critical and customer demand irregular, surplus capacity may be used to ensure fast delivery. In figure 6, one of the six operators requires more work than any of the others. This is the bottleneck. Other operators have surplus capacity.

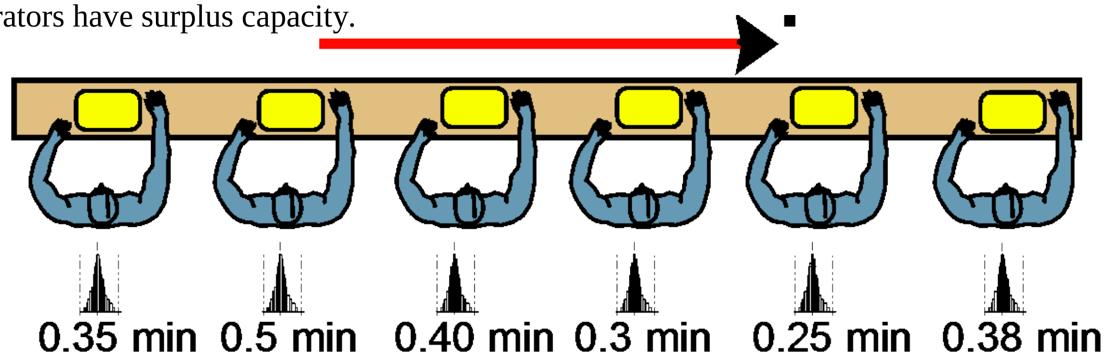

Figure 15 Surplus Labor for Line Balance

Queuing Balance

When operators have permanent stations in a cell or line, queuing between them compensates for cycle-to-cycle variation. Floating-fixture assembly lines work on this principle. If the average work times differ, queuing alone is insufficient. Queuing alone balances the short-term or dynamic variations but it will not compensate for longer-term static variation. Figure 7 shows how these small queues buffer short-term variation. The size of the queues relates to the amount of variation. From Theory of Constraints, we know that by observing the queues, we can see which operators are most imbalanced.

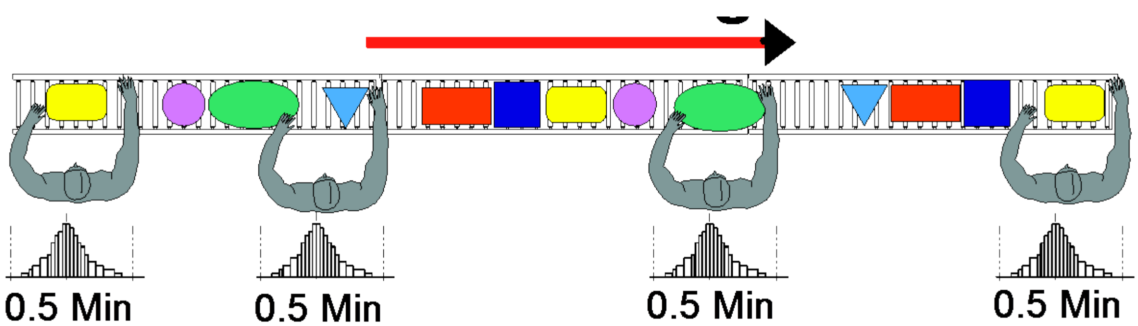

Figure 16 Queuing for Dynamic (Short-Term) Balance

Floating Balance

Floating balance, usually combined with queuing, is frequently a good method for balancing people. Here, operators monitor the queues to determine which stations are working ahead and which are falling behind. Operators move to the stations that are falling behind and assist until that station is caught up. This requires that stations allow for multiple operators when necessary. Figure 8 illustrates.

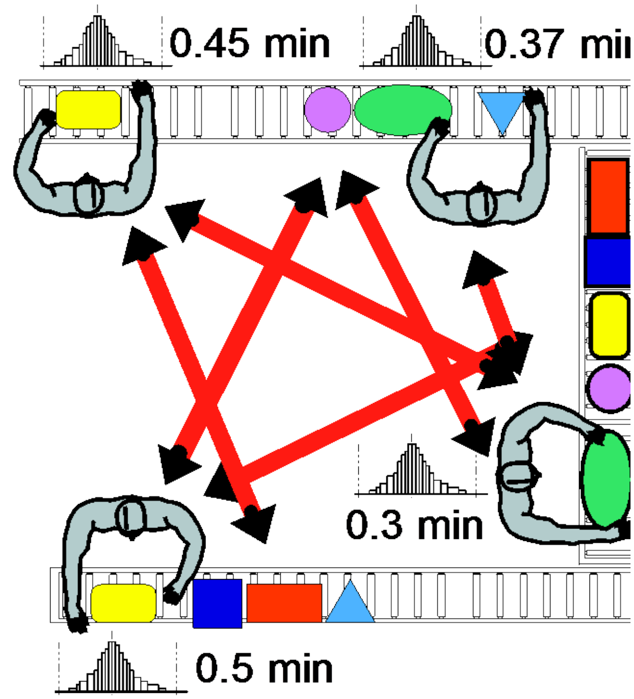

Figure 17 Floating Balance in a Workcell

Circulation

With circulation, an operator carries the workpiece through all operations in sequence. This method is very flexible and perfectly balances operations. It requires that operators be completely cross-trained. It also requires surplus equipment capacity on most or all stations. Figure 9 illustrates.

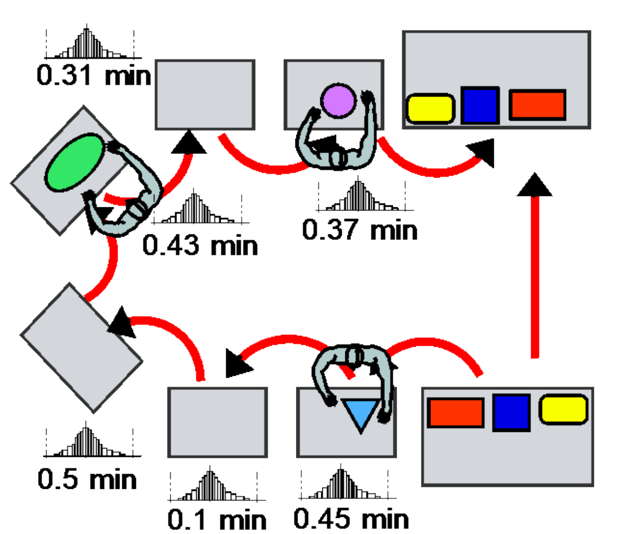

Figure 18 Circulation Balance in a Workcell

Mixed Model Assembly Lines

Problem	Description	Solutions
Work Balance	When different models have different work content, operations must be flexible enough to deal with the product mix.	▪ A constantly moving line only lends itself to mixed model production when work content is nearly identical for each station. ▪ Small Queues between stations to accommodate short-term variation. ▪ Adjacent workers share tasks and help each other. ▪ Fewer stations and longer task times.
Part Availability	For a mixed model assembly line to function, every part for every product must be immediately available.	▪ Small quantity of every part replenished by Kanban.
Tool Availability	Tools and special fixtures must be readily available. (This is seldom a problem when the product is small. It may be a problem with large products such as refrigerators or vehicles.)	▪ Multi-purpose fixtures & Tools ▪ Setup Reduction ▪ Dedicated cells with a permanent setup of fixtures & tools.
Fabrication Setup Reduction	Dedicated fabrication equipment is not always available. Long, expensive and/or inconsistent changeovers force large batches and high inventory between fabrication and the mixed model line.	▪ Setup Reduction In Fabrication with small lots. ▪ Redesign fabrication processes with more dedicated equipment, even (if necessary) at the cost of decreased labor efficiency. ▪ Investigate alternate processes.

Other Options

Assembly Cells

Toyota probably used Mixed Model Assembly lines because their large Detroit-style lines were already in place. It may have seemed like a natural and easy solution to the problem of upstream demand smoothing.

However, there is another method for providing smooth demand: Final Assembly Cells. In this approach, the assembly line is broken down into multiple, smaller workcells or smaller lines. Each workcell produces a single model or, perhaps, several models with a high degree of part commonality.

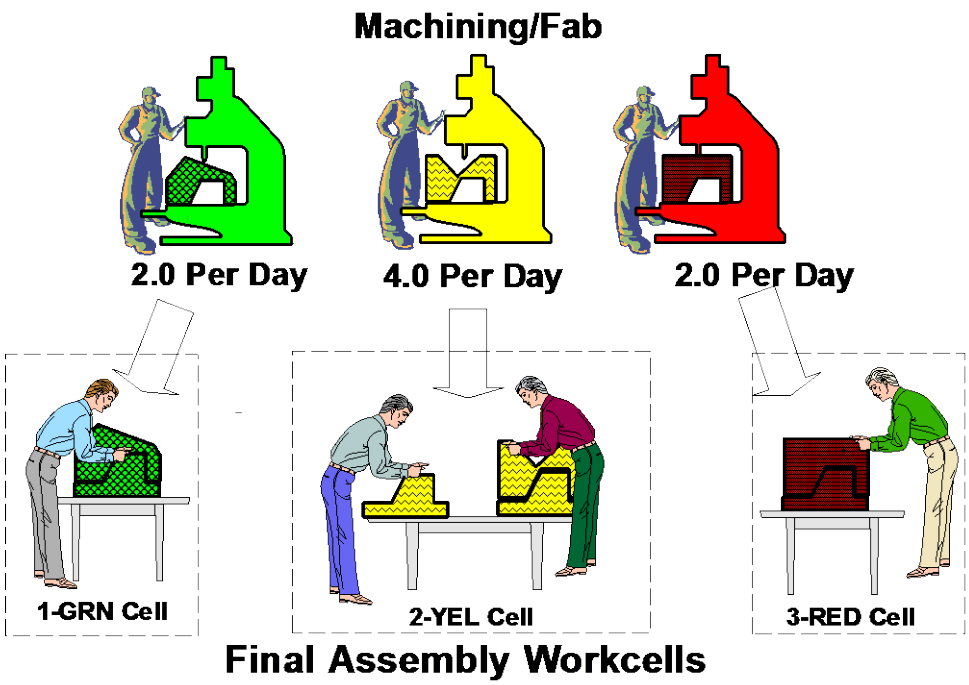

Figure 19 Final Assembly Workcells May Replace an Assembly Line

Dedicated Assembly Cells Summary

Problem	Description	Solutions
Demand Variability	Variation in demand for each dedicated cell may be larger than the variation for a single line. (Peaks and valleys of demand often cancel when combined.)	▪ Design assembly cells for multiple levels of staffing. ▪ Move people between cells to balance output & demand. ▪ Provide excess equipment capacity to handle peak demands.
Cell Design	Workcells appear simple and this is especially true for assembly cells. In reality, they are complex and sometimes sensitive socio-bio-technical systems.	▪ Design cells from fundamental principles.

Integrated Product Focused Workcells

A further evolution of mixed model assembly cells is to incorporate some (or all) upstream fabrication into the cells. The figure below shows how the fabrication equipment for each model joins with respective assembly operations in a cell or sub-cell. It provides even closer coordination and corresponding improvements in quality and inventory.

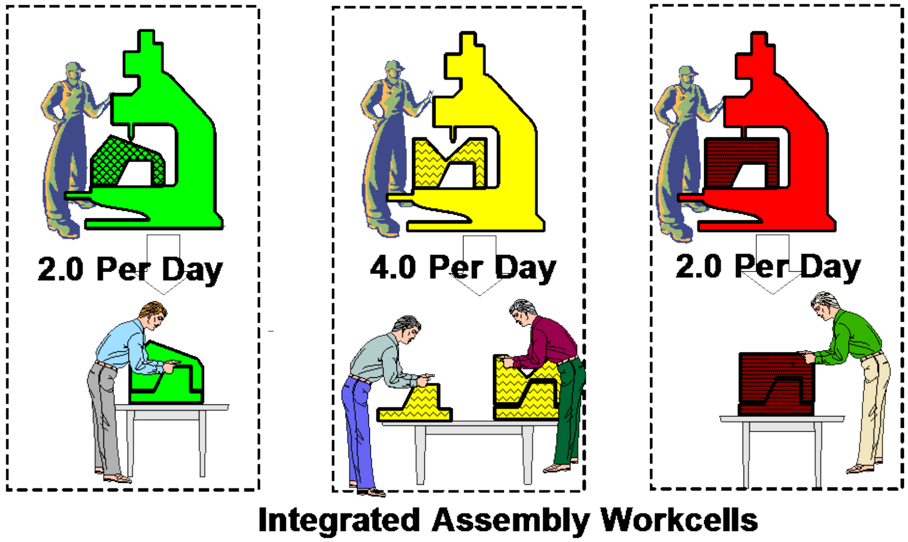

Figure 20 Integrating Fabrication Operations Into A Final Assembly Workcell

Integrated Cell Summary

Problem	Description	Solutions
Process Incompatibility	This usually involves processes that must be isolated for environmental reasons (Dust, Dirt, Chemicals or Noise).	▪ Address the environmental problem with dust control, noise control, etc. ▪ Investigate alternate processes.
Process Scale	Large-scale fabrication processes have too much capacity for a single assembly cell.	▪ Investigate alternate equipment and methods. (e.g. small, manual paint booth replacing a large paint line)
Special Skills	Certain tasks require extensive skills, experience and/or training but do not require a full-time operator for each cell.	▪ Tools, fixtures or gages that require less skill ▪ Train or cross train ▪ Train cell workers in basics with consultant employee for difficult problems. The daily tasks often do not require high skills or knowledge

5.0 Workcells versus Mixed Model—Decision making

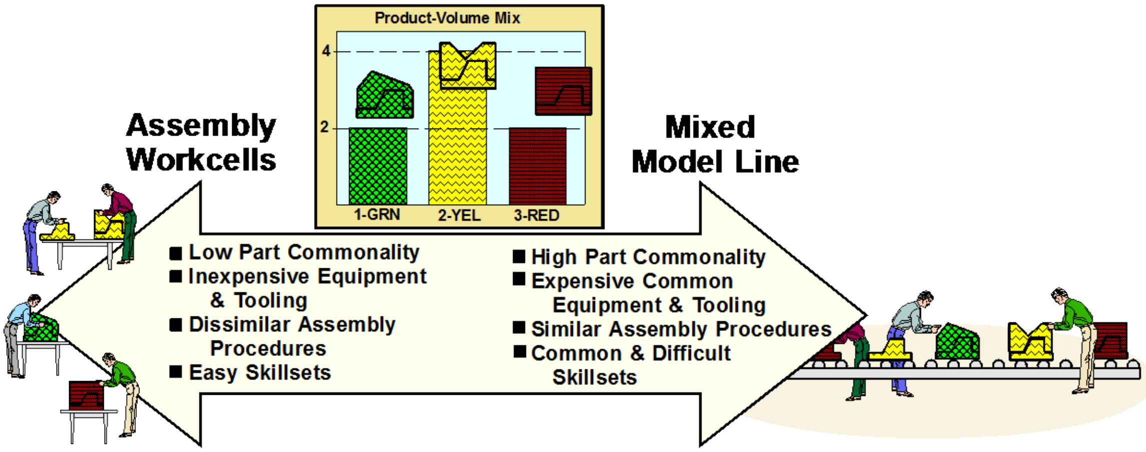

Figure 5 Decision Factors for Mixed Model Versus Dedicated Workcells

Case Example

Our case example is a company that builds commercial dishwashing machines for medium-size restaurants and institutions. Previously, the dishwashers were assembled in a fixed location in batches of four machines. Growth has made this method clumsy and inefficient. Problems included:

- Excessive Material Handling
- Delivery Failures
- Inconsistent Quality
- Lost Parts & Inventory Control
- Excessive Labor
- Training of New Workers

Planning Basis

The dishmachine product line consisted of five models. All of these models operated in a similar way and had a high part commonality for purchased parts. Sheet metal and fabricated parts were made in a separate fab shop and had fairly low commonality.

Assembly sequences and techniques were similar for all models although the average time required for each step varied. Assembly times also varied significantly even for the same step on the same model. This was caused by inconsistent quality from the fab shop and from dimensional tolerance stackups. Some machines slipped together easily while the next machine might require considerable manipulation, bending or force-fitting. It was clear from the beginning that these inconsistencies from the fab shop would not improve for some time and our assembly system would have to accommodate them.

Our design basis for the assembly operation was set at twelve machines per day with average production of the different models shown in figure 21.

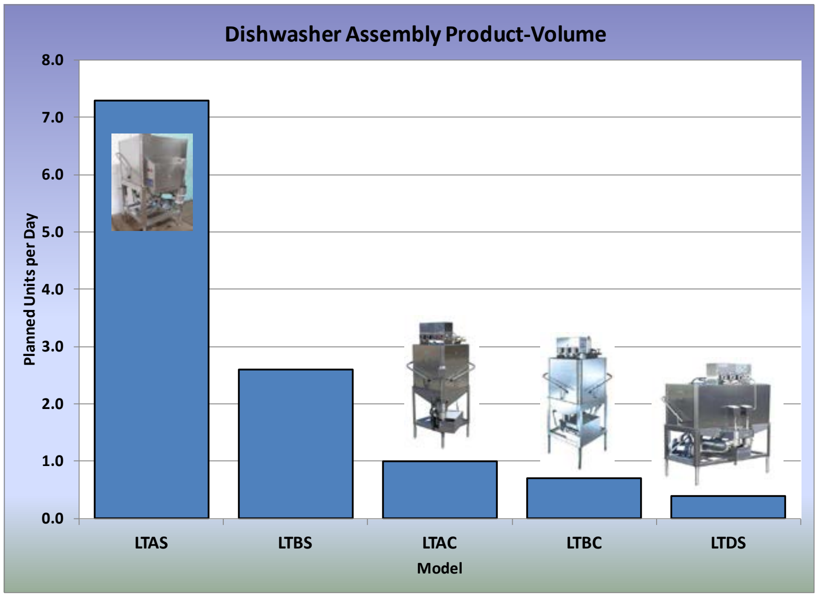

Figure 21 Dishmachine Products & Volumes

Analysis

One of the first steps in any such analysis is to prepare a Process Chart. Figure 22 shows the chart for the LTAS model and figure 23 is an enlarged portion showing some detail. These charts can become quite large for complex assemblies and the industrial engineer is often tempted to skip over this task. However, it is essential to make the chart for at least one or two representative products. Much of the value of this task comes from the doing rather than the resulting chart.

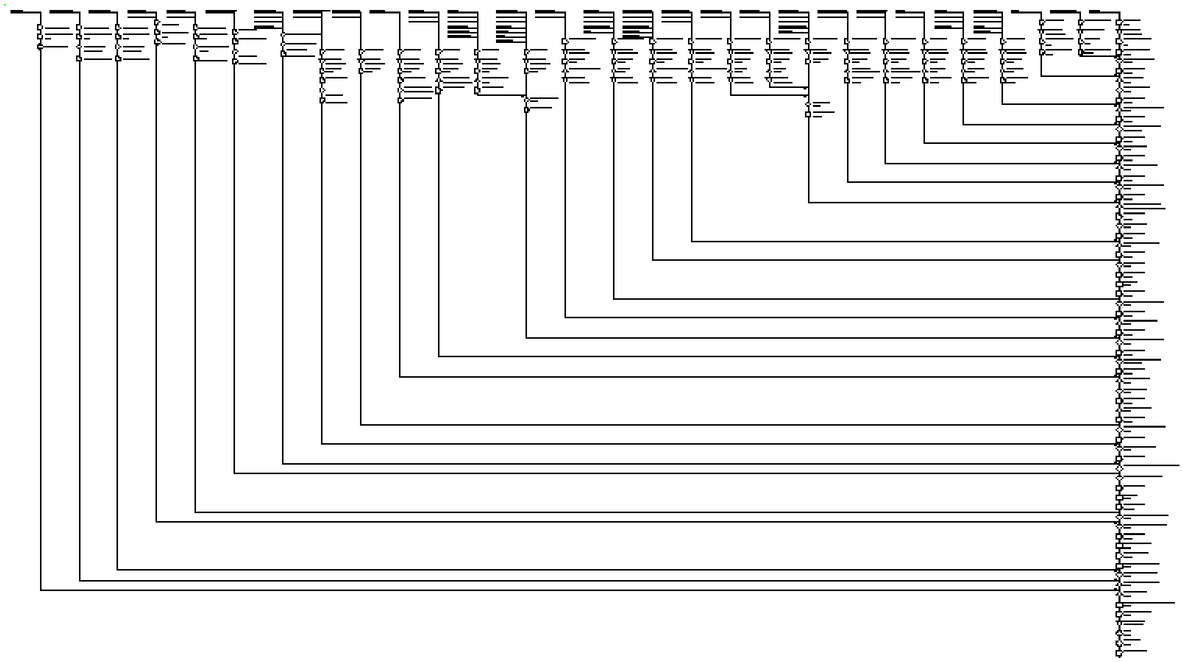

Figure 22 Model LTAS Process Chart

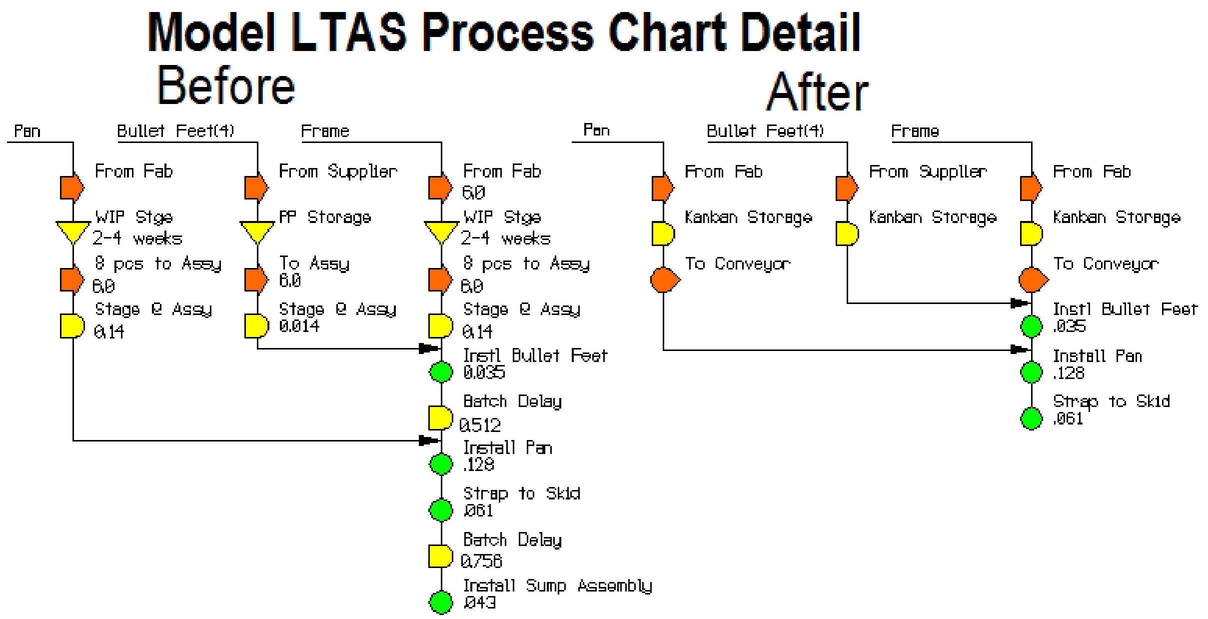

Figure 23 Process Chart Detail

Figure 23shows how the process currently appears and what it would be like with line or cellular assembly. There was a high commonality of purchased components and subassemblies across all five models and some commonality of fabricated and sheet metal components. This, along with low volumes for some products, led us towards a mixed-model assembly approach as opposed to separate workcells for each product. Another factor pointing to mixed-model assembly was the commonality in assembly tasks and sequences.

We did most of the analytical work with Model LTAS. It had the highest volume and, we assumed that a basic design for the LTAS could be modified to accommodate the other models.

Table 3 shows work times for each assembly task and our workstation assignments. It is the results of several distinct steps:

1. We listed the Operation Descriptions and assigned operation numbers for the LTAS machine.
2. Through stopwatch studies, we estimated work times for each operation.on the LTAS.
3. We assigned operations to one of four workstations based on several factors. First, we balanced the work among the stations. Second, we combined any tasks that required two people (there were several of these) at Station #1. This required some changes in assembly sequence.
4. Balance was checked as shown in figure 24. With two people at Station #1, the balance is nearly perfect.
5. Standard time for other models is added based on the times for LTAS as modified by general knowledge. Other operations peculiar to a particular model might also be added.

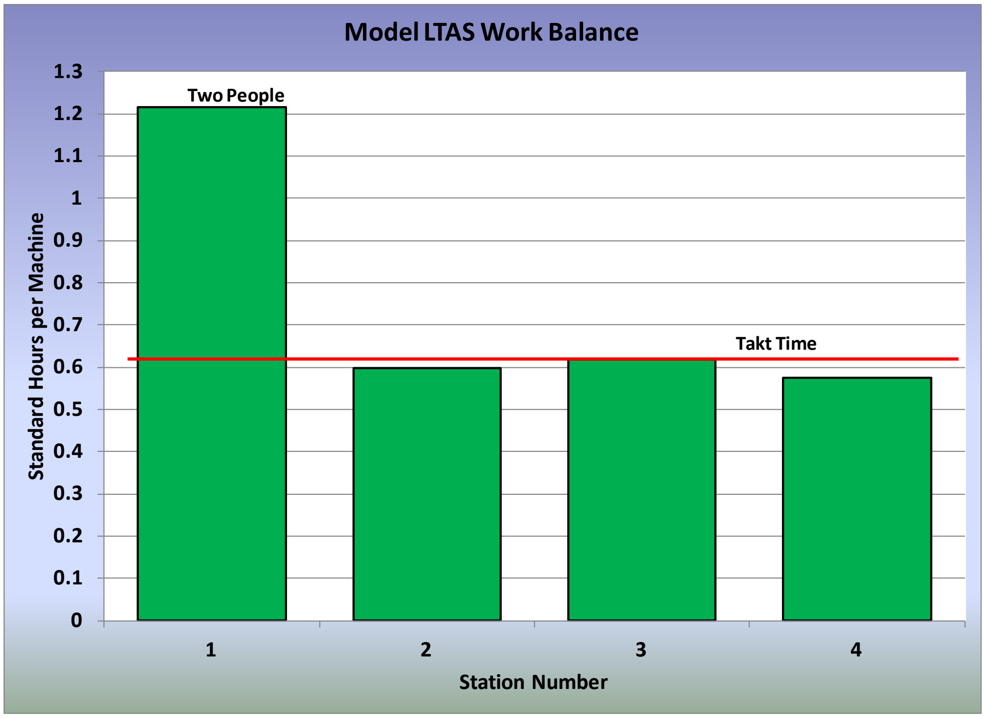

Figure 24 LTAS Work Balance

			Standard Hours				
Op#	**Description**	**Station**	**LTAS**	**LTAC**	**LTBS**	**LTBC**	**LTDS**
10	Install Bullet feet on lower frame	1	0.035	0.035	0.035	0.035	0.035
20	Install Pan	1	0.128	0.128	0.128	0.128	0.220
30	Strap to Skid	1	0.061	0.061	0.061	0.061	0.070
40	Assemble Sump	1	0.049	0.049	0.049	0.049	0.098
50	Install Sump Assy	1	0.043	0.043	0.050	0.050	0.086
60	Install lwr spray base	1	0.049	0.049	0.049	0.049	0.098
70	Install hood	1	0.216	0.288	0.216	0.288	0.332
80	Install Timer Case	1	0.088	0.102	0.101	0.102	0.088
90	Install Door Brackets	1	0.037	0.037	0.037	0.037	0.044
100	Install Fresh Water Plumbing Assy	1	0.066	0.066	0.066	0.066	0.132
110	Tighten Nuts	1	0.106	0.106	0.106	0.106	0.212
120	Install Door Guides	1	0.117	0.117	0.117	0.117	0.117
130	Install Doors	1	0.209	0.281	0.209	0.281	0.209
140	Inspect & Move	1	0.012	0.012	0.012	0.012	0.012
		1 Total	1.216	1.374	1.236	1.381	1.753
150	Move	2	0.008	0.008	0.008	0.008	0.008
160	Install Drain Solonoid Assy	2	0.034	0.05	0.078	0.078	0.068
170	Install Tray Rack	2	0.039	0.039	0.039	0.039	0.078
180	Install Pump Assy	2	0.158	0.158	0.144	0.160	0.316
190	Install Upper Spray Base	2	0.033	0.033	0.033	0.033	0.066
200	Install Manifold	2	0.033	0.033	0.033	0.033	0.066
210	Tighten Nuts	2	0.023	0.023	0.023	0.023	0.046
220	Connect Wiring	2	0.174	0.22	0.220	0.220	0.348
230	Install Chem Pumps	2	0.050	0.05	0.050	0.050	0.050
240	Install Lever Arm	2	0.027	0.044	0.027	0.044	0.041
250	Install Drain Solonoid & Cover	2	0.012	0.012	0.022	0.022	0.024
260	Move	2	0.008	0.008	0.008	0.008	0.008
		2 Total	0.599	0.678	0.685	0.718	1.119
270	Move	3	0.008	0.008	0.008	0.008	0.008
280	Install Chem Tubes	3	0.106	0.106	0.106	0.106	0.106
290	Install Tube Stiffeners	3	0.033	0.033	0.033	0.033	0.033
300	Install Nameplate	3	0.017	0.017	0.017	0.017	0.017
310	Perform dielectric test	3	0.018	0.018	0.018	0.018	0.020
320	Move	3	0.008	0.008	0.008	0.008	0.008
330	Wet test, Inspect & Repair	3	0.172	0.172	0.200	0.220	0.201
340	Install Spray Arms	3	0.015	0.015	0.015	0.015	0.015
350	Install Timer Case Cover	3	0.007	0.007	0.010	0.011	0.007
360	Apply Decals	3	0.013	0.013	0.013	0.013	0.013
370	Final Inspect & Clean	3	0.212	0.212	0.212	0.212	0.352
380	Move	3	0.008	0.008	0.008	0.008	0.008
		3 Total	0.617	0.617	0.648	0.669	0.788
390	Move	4	0.008	0.008	0.008	0.008	0.008
400	Pack	4	0.210	0.21	0.210	0.210	0.420
410	Move	4	0.008	0.008	0.008	0.008	0.008
420	Load Truck	4	0.350	0.35	0.350	0.350	0.441
		4 Total	0.576	0.576	0.576	0.576	0.877
		Grand T	**3.008**	**3.245**	**3.145**	**3.344**	**4.537**

Table 1 Assembly Operations and Work Times

In figure 25, subtotals for each station and each model, taken from Table 1, show the work balance for each model. With the exception of Model LTDS, all models are well balanced.

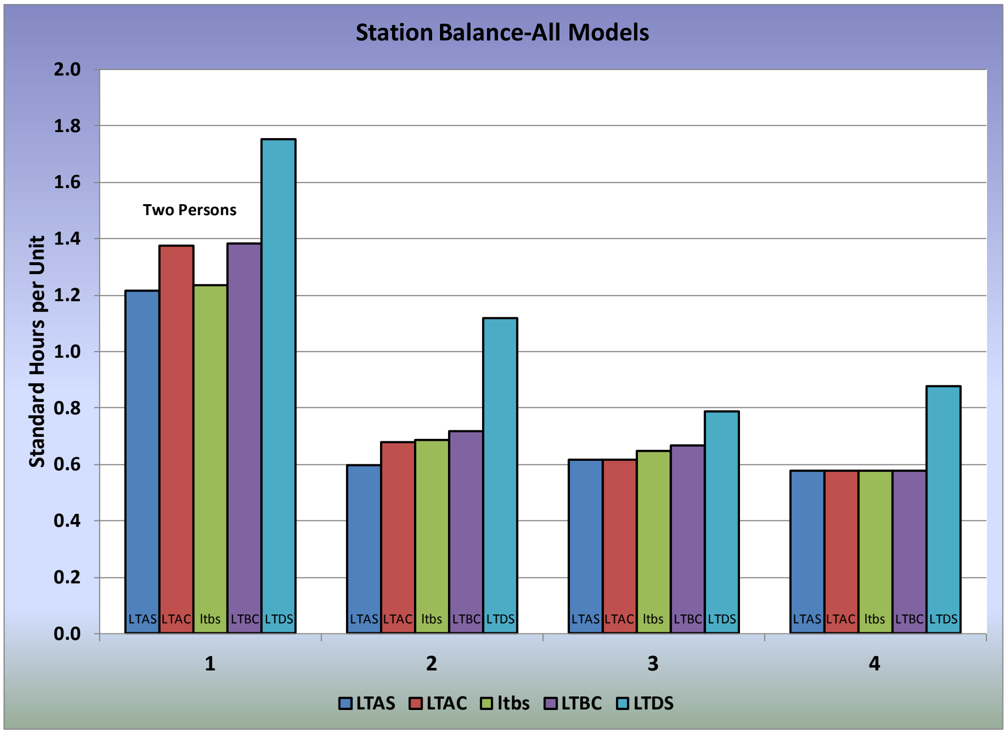

Figure 25 Station Balance by Model

If we multiply the standard hours per unit, for each station by the planned daily production, Table 3 and figure 26 are the result. Figure 26 shows that over a long time, say several weeks are more, that our stations are well balance.

	LTAS	LTAC	LTBS	LTBC	LTDS	Total
	61%	8%	22%	6%	3%	100%
Units/Day->	7.3	1.0	2.6	0.7	0.4	12.0
1	8.877	1.374	3.214	0.967	0.701	**15.132**
2	4.373	0.678	1.781	0.503	0.448	**7.782**
3	4.504	0.617	1.685	0.468	0.315	**7.589**
4	4.205	0.576	1.498	0.403	0.351	**7.032**
Hrs/Day->	21.958	3.245	8.177	2.341	1.815	37.536

Table 2 Average Daily Station Balance

While the inherent balance of this design example is quite good, this degree of balance is unnecessary. Moreover, with all the time study, calculation and graphing, we should consider the results as approximations. Many factors are only estimates and some, such as forecast demand and product mix are unlikely to be correct. These questionable estimates are simply the best estimates available. On any given day, the product mix and demand may be *very, very* different from our assumptions.

The key to making Mixed-Model Assembly successful is to build in self-balancing mechanism so that the system adapts to variation in demand, quality, staffing and all the other factors that challenge a manufacturing shop. More on this later in the paper.

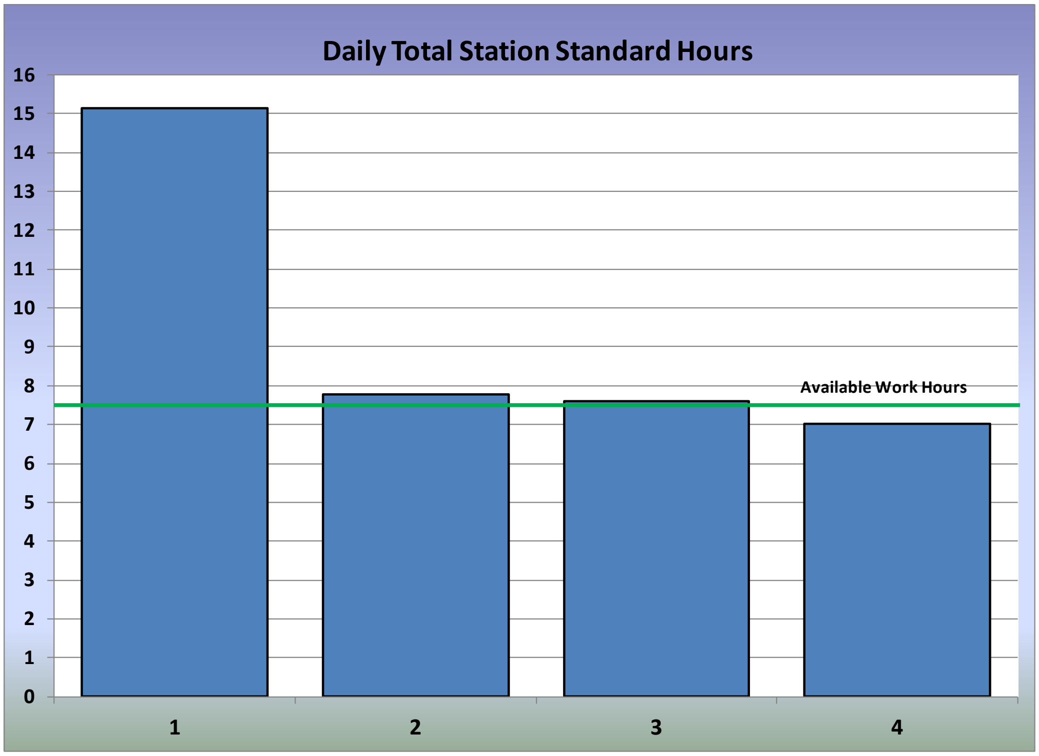

Figure 26 Total Daily Station Hours

Layout

Figure 27 is the final layout. Because of the simplicity of material flow, we were able to move directly from the process chart to the layout and bypass many of the usual layout planning steps.

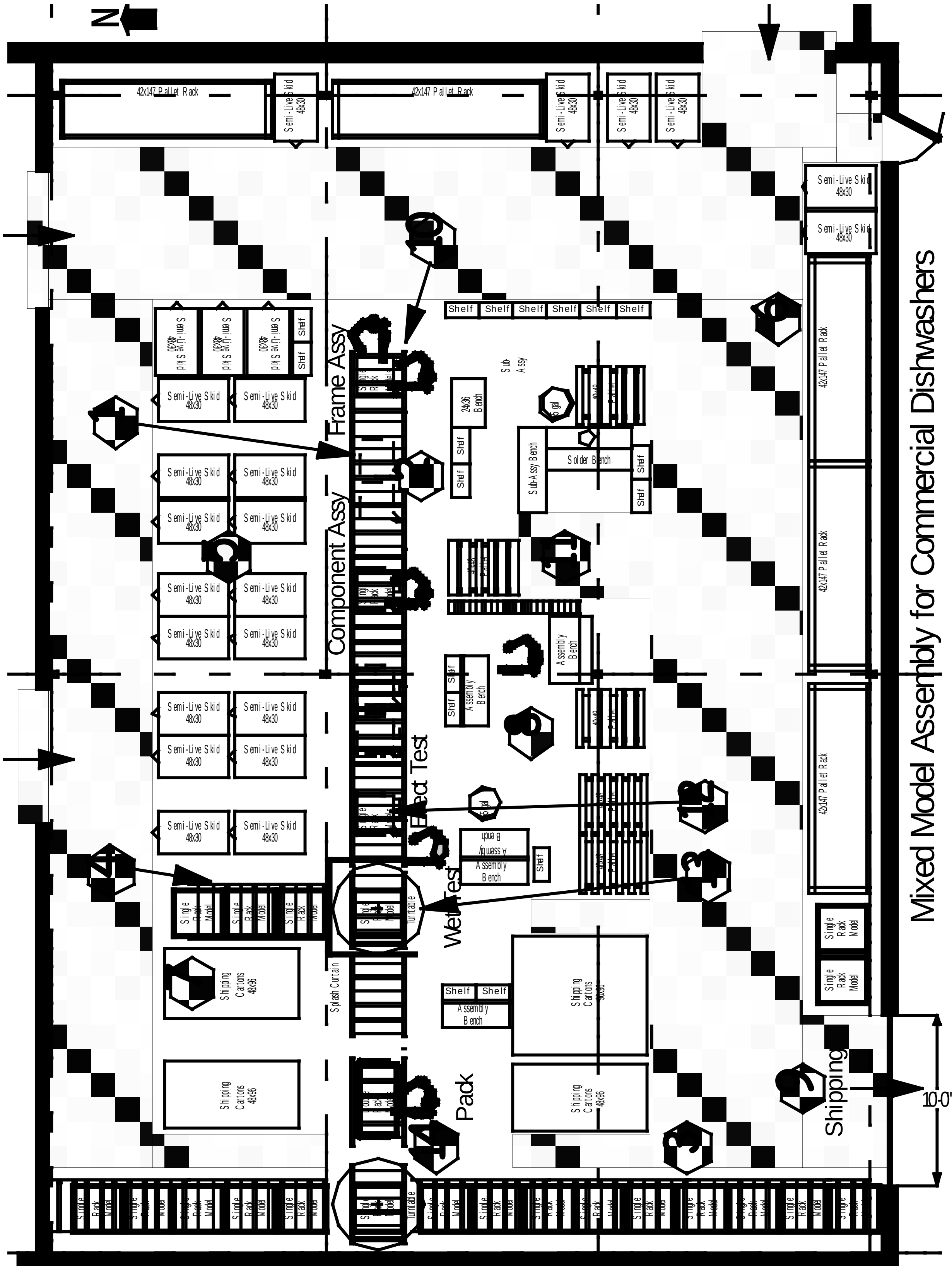

Figure 27 Final Layout, Mixed Model Line

Here are some notable features. The numbers of each element correspond to numbers in figure 27:

1. Roller conveyor main assembly line running E-W. Due to low volume, product is manually pushed along this conveyor as required.
2. Space on the assembly conveyor holds two machines (About 1.2 hours of production) between stations.
3. Finished goods staging on N-S roller conveyor holds about one-day of production. A turntable changes direction.
4. Diversion conveyor at Station #3 for machines that require significant rework or repair. A turntable changes direction.
5. Sheet metal and fabricated components are handled on semi-live skids and staged on the North side of the assembly line.
6. Purchased components staged on the South and East walls on pallet racks.
7. Large cartons for packing are on both sides of Station #4.
8. Sub-Assembly areas are to the South of Stations #1-3.
9. A walkie fork truck picks finished goods from the staging conveyor and loads them directly onto trucks at the Southwest corner.
10. Station #1 is staffed by two people and assembles most large components as well as some smaller items.
11. Station #2 completes mechanical assembly and most electrical assembly.
12. Station #3A completes several small assembly tasks and performs a dielectric test.
13. Station #3B performs a functional test with water and chemicals and makes minor repairs.
14. Station #4 cleans and packs each unit while simultaneously doing a visual inspection. The Station 4 worker also loads trucks when they arrive.

Benefits

The system worked very well almost from the first days. It is still in use after 30 years, two plant relocations and a large growth in both volume and product line. Here is a summary of the benefits:

Teamwork

Teamwork was excellent because the workers are fairly close together and can immediately see the situation along their entire line. This contributes significantly to balance between stations as well as problem-solving.

Training & Work Improvement

While the work at each station is fairly complex compared with many assembly lines, it is much simpler and repetitive than the previous batch production. This makes for easier training and encourages workers to make improvements in their tasks. Our original estimates for labor hours have steadily improved.

Schedule Predictability

The system is highly predictable from a scheduling standpoint. Once a machine is started it emerges, ready to ship, in about six hours.

Schedule Flexibility

Because orders are held in an order queue prior to the start of assembly, the schedule is easily changed if customer priorities change. New urgent orders can be moved to the head of the queue and will be ready to ship in as little as six hours.

Inventory Control

Component shortages are readily apparent without the need for a complex inventory system since the inventory is immediately visible at each workstation.

Quality

Problems that become evident in final testing are quickly communicated to the upstream operations and can be more reliable and more quickly resolved.

Product Mix Flexibility

The system is highly flexible for changes in product mix. Large orders for the more complex models may move through the process a bit more slowly but this is easily accommodated.

Volume Flexibility

The system is highly flexible with respect to product volume on a weekly or daily basis. If there are insufficient orders for the original planned takt time, the subassembly worker or even several of the station workers can be moved to another department. The line then moves more slowly as the remaining workers must do subassembly work or redistribute work between the stations. If daily requirements exceed the planned takt time, Additional workers can be inserted to assist the regular workers and speed up the line. In either of these situations, the workers redistribute tasks on their own to balance the work. They can easily see where the imbalance lies by observing the small queues between stations.

Finished Goods

The flexibility of this system results in virtual elimination of Finished Goods inventory and the space required to store it.

Summary

Mixed Model Assembly can be an important technique for achieving the smooth, simple workflows of Lean Manufacturing. However, there are problems that must be addressed. In addition, other methods may be more appropriate, particularly when a new plant is being configured.

This paper has shown practical techniques and procedures for designing a basic mixed model assembly line. It also has described some alternatives to mixed model assembly that may be more appropriate.