WHITE PAPER

Your Bally TECHNOLOGIES

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Implementing Mixed Model Production in a High Mix Production Environment

Compared to traditional batch production or non-mixed flow production

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ABSTRACT

In today's business environment, customers are expecting the ability to purchase products with a greater degree of customization, personalization, speed, and quality. These demands result in greater engineering efforts to provide an ever-increasing number of variations for ordering, producing, servicing, etc... This variation also forces difficult decisions regarding how to efficienctly and effectively manage the Operations Value Stream. The Toyota Production System (TPS) has provided an excellent model for eliminating wasteful activity, improving flow and quality, and using pull systems to drive the appropriate activity at the right time; however, it still remains a mystery in most assembly environments on how to schedule, plan, sequence, and execute in a high mix environment. Organizations typically use batch production techniques to limit the variation seen in each step. This results in wasted resources, space, and time. Toyota employs a proprietary technique called mixed model production that is largely misunderstood due to its complexity. This paper outlines how Bally Technologies has developed a mixed model strategy to greatly improve efficiency in assembly.

OVERVIEW

World-wide, most manufacturing organizations have adopted at least some of the concepts of TPS, or lean manufacturing, over the last twenty years. Since 2006, Bally Technologies has been aggressively using the Toyota Production System as a model for how to develop, manage, and improve the Operations Value Stream from quote to cash. From 2006 to 2009, Bally Technologies showed significant improvements in WIP (-98%), floor space reduction (-70%), lead time through assembly (-90%), and labor hours per game assembled (-50%). These improvements were the result of kaizen-related activity to reduce wastes in motion, conveyance, overproduction, inventory, etc...

In 2009, the first moving assembly lines were installed which forced flow throughout the facility, improved problem solving activities, and ensured cycle time discipline; however, a significant problem stagnated further improvements. As more variation was introduced into the production line, the assemblers were seen idle more frequently which was the result of cycle time differences between the different models. The assemblers with easier builds had to wait on the assemblers with harder builds. This also created a problem upstream and downstream as the line speed would often change to match the difficulty of the builds on the line at that time. This meant the line could run much faster for easier builds and slower for harder builds. With our rates constantly changing, material flow became a problem both inbound and outbound.

The only ideas that seemed reasonable were to limit the variation on the production line either by moving work externally and/or creating multiple lines specific to a given model. Both ideas introduced wasteful activity. In the first idea, this introduced extra conveyance to move the game to the 'options' area. Even with an 'options' person, this introduced wasteful conveyance as the 'options' position in the assembly line needed to be accounted for. The second idea resulted in wasteful conveyance, inventories, motion, etc... to account for a larger production area.

After thorough examination of the problem, the root cause was determined to be incomplete information. There was simply not enough information regarding the model mix to know how to properly set up the production lines including how many lines to run, how many positions, what size should each position be, what speed to set the line, what order to run the sequence, etc... A complex algorithm was developed to provide this information instantly to the production personnel. The result has been a 35% improvement in production efficiency and improved flow.

GLOSSARY OF TERMS

Term	*Definition*
EGM	Electronic Gaming Machine, a slot machine
GCD	Greatest Common Denominator. A mathematical term used to describe the largest positive integer that divides into a series of numbers without a remainder. For example, the GCD of 8 and 12 is 4 since 4 is the highest number that divides equally into both 8 and 12.
Kaizen	A Japanese word meaning “Change for the good” or continuous improvement. Kaizen in this document refers to a short-term, specific set of activities with a defined scope with the purpose of eliminating Waste.
Lead Time	The total time required, including waiting and other non-value added activities, to complete a given process
Lean Manufacturing	See TPS
Model	A given set of activities (work content) that has significant differences in total cycle time. For Bally, a significant difference is considered to be more than 6 seconds or 0.1 minutes.
Operator Cycle Time	The time required for a given operator (assembler) to complete a given set of tasks.
Pitch	On a moving line, the distance between each unit to be assembled. For Bally Technologies, the pitch is 5 feet.
Takt Time	Rate needed to ensure customer demand is satisfied (*symbol* tt)
Total Cycle Time	The time required for all operators (assemblers) to complete all tasks for a given process
TPS	Toyota Production System, a production model focused on eliminating Waste
Value Added	Any activity that directly modifies materials or information to transform a saleable product from raw material to a finished good
Waste	Any activity that does not directly modify materials or information to transform a saleable product from raw material to a finished good. Also called ‘*muda*’.
Work Zone	On a moving line, the size of the work area assigned to each operator.

ABOUT BALLY TECHNOLOGIES

Bally Technologies, Inc. is a diversified, worldwide gaming company that designs, manufactures, operates and distributes advanced technology-based gaming devices, systems and server-based solutions. The Company offers technology solutions, which provide gaming operators with a range of marketing, data management and analysis, accounting, player tracking, security, and other software applications and tools to manage their operations. It also provides technologies to utilize a networked, server-based gaming environment. Its primary hardware technologies include spinning-reel and video gaming devices, specialty gaming devices and wide-area progressive systems for traditional land-based, riverboat and Native American casinos, video lottery and central determination markets, and specialized system-based hardware products.

Bally employs 2,600 people in office throughout the world with the headquarters in Las Vegas, NV.

TIMELINE

The statistical improvements in the Bally Production System from 2006-2010 can be seen in Table 1-1:

	2006	2009	2010
	Batch Production	Non-mixed Flow	Mixed Model
Space (sq ft)	33000	3500	3500
Lead Time *through assembly*	2 days	2 hours	1 hour
WIP	1000	50	50
Labor Hours per game	8	5	3

Table 1-1: Kaizen-related improvement results normalized by volume

In 2006, Bally Technologies was a batch production facility. Each machine was touched by many people throughout the assembly process which resulted in a lot of travel for both the machine and personnel. Quality was poor as each machine required post assembly rework to ensure all defects were fixed prior to shipping. Problem solving was also poor as the facility was largely in firefighting mode. Problems were rarely solved at their root level with the same problem repeating consistently. There were no standards for execution meaning it was unknown on how to exactly assemble the product, how to train on proper techniques, and how long the assembly process should take. Overtime was frequent as the facility could never seem to run at the rate required to ensure orders were completed on-time.

Between 2007 and 2008, Bally began to use techniques learned from the Toyota Production System to drive waste out of processes. All seven wastes were abundant throughout the operation. By using kaizen, or continuous improvement, a constant focus was placed on right sizing the operation, ensuring good material flow, using pull techniques to ensure activities were properly prioritized and executed in a good, logical sequence, and empowering our associates to bring ideas for improvement. Very quickly and dramatically, changes were implemented which resulted in significant improvements. The most significant accomplishment was the development of standard work for assembly processes. Each model and variation was precisely time observed and documented. The information was powerful in that it allowed for much better planning and management of the production floor.

By 2009, it was evident more improvements were needed. The management of the process became difficult as the problems were not immediately visible. A given problem would propogate throughout the assembly floor until the entire system came to a halt. This was not efficient or optimal. If the assemblers did not meet the cycle time targets for a given operation, it was not known until the hourly status boards were updated. By then, a small problem might have become a much larger problem resulting in excessive firefighting. Clearer expectations and faster problem solving was needed, so the moving production lines were developed and implemented. This resulted in further improvements as the process became more predictable and problems were identified in near real-time. Andon systems were developed so that any operator could stop the line for any reason. Response Teams were created to ensure problems did not repeat and were solved at their root level.

2010

In 2010, improvements became minor as another major problem surfaced. It was observed the assemblers spent up to 40% of their day doing no value added activities. The root cause of the problem was the layout of the production line. Figure 1-1 shows the initial setup of the first moving production lines. The zone size was exactly equal to the distance between the games. This meant the speed of the line could be no faster than the slowest cycle time machine. As more variation was introduced, this became a significant problem.

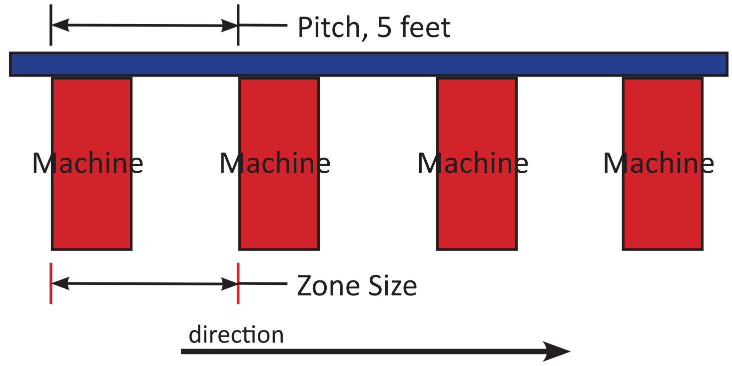


Figure 1-1: Non-mixed moving line setup

DEVELOPMENT OF MIXED MODEL THEORY AND THE 12-STEP METHOD

A mathematical method was developed in 2010 to determine the most efficient sequence to load production models. This method also determines the speed of the line, number of operators required, and work zone sizes. Using this information, the production lines can be setup to ensure demand is met for a given production volume considering the numerous variations possible while keeping the pace of production consistent.

12 STEPS REQUIRED TO GENERATE MIXED MODEL SEQUENCE

#	Activity
1	Determine model variations for a given period of demand (day, week, month, etc...)
2	Determine Greatest Common Denominator (GCD) of model quantities
3	Determine total cycle time required for each model
4	Organize models from smallest cycle time to largest cycle time
5	Divide each model quantity by GCD
6	Starting from longest cycle time model variant, sequence the model quantities determined in step 5 for each model from longest to shortest. This sequence will repeat equal to the GCD. *(i.e., if GCD is 4, pattern will repeat 4 times)*
7	Determine Takt Time
8	Determine Average Weighted Cycle Time (AWCT)
9	Divide AWCT by takt time to get the number of required operators. Round up to next highest integer.
10	Divide AWCT by # of required operators (integer determined in step 9) to get line speed
11	Divide each model cycle time by the # of operators to get operator cycle time for each model
12	Use zone size calculations to determine max zone size for pattern. This will be the operator zone size.

Table 1-2: 12 Steps required to complete mixed model sequence mathematically

MIXED MODEL 12-STEP METHOD

Once the calculations in Table 1-2 are complete, the mixed model sequence will be determined. There are 12 steps required to solve an appropriate mixed model sequence, and the 12 steps will always result in an accurate and reliable mixed model sequence - but not necessarily efficient. Bally has developed a computer algorithm to automatically use the 12 steps to determine a mixed model sequence for a given time period.

BENEFITS OF MIXED MODEL

The benefits of understanding and implementing mixed model are tremendous. At Bally, there has been a 35% increase in productivity. Mixed model ensures that no operator has to wait for someone else because of cycle time differences. The cycle time differences are used in the calculations to determine the line speed, sequence, work zone size, etc... The line speed is set to ensure demand will be met, the zone sizes ensure an operator never has to wait on another operator, and the correct number of resources is determined considering the variation in demand for a given day. Figure 1-2 shows the slight difference in setting up the zone sizes. Notice how the zone size is slightly longer than the pitch. This ensures the line is correctly sized and accounts for the variation of the machines being produced. The zone sizes will be larger for greater amounts of variation and/or smaller greatest common denominators (GCD). The zone sizes are most efficient when the GCD is as high as possible. Bally has developed a mix team that looks at demand daily to sequence models to ensure the GCD between models is as high as possible.

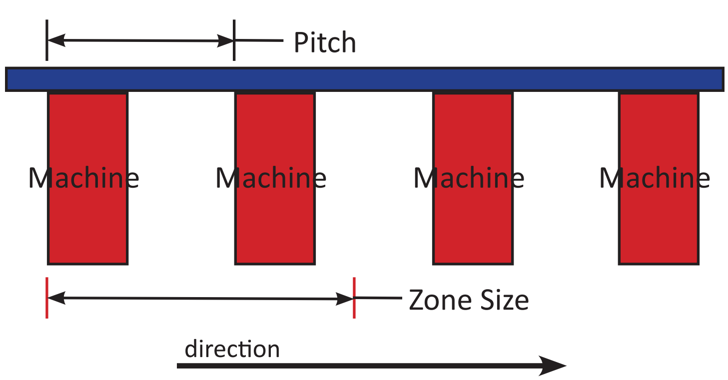


Figure 1-2: Mixed Model moving line setup

DETERMINING MANUFACTURING EQUILIBRIUM

A simple mathematical equation drives the logic in determining an efficient mixed model sequence - we call this Manufacturing Equilibrium.

$$\sum_{i=1}^{n} QTY_i * (OCT_i - tt) = 0$$

where i is the model for a given model sequence, i.e., 4 models means n = 4, OCT is the operator cycle time for a given model, QTY is the quantity the model is repeated in a given pattern (not total qty)

When this equation is true, a process is in equilibrium with the demand for a given model mix. In other words, the correct number of resources has been allocated for a given amount of demand considering the complexity and variation of the demand. For mixed model to be effective, the result of this equation must be within one takt time (at a minimum). In fact, the only time we have found this relationship to be true is when mixed model was implemented. Previous to mixed model, it was virtually impossible to determine the variance in this equation. This is due to the idle time of the operator which must be considered as part of the operator cycle time. The idle time increases the operator cycle time resulting in a positive number which means demand is not being met and overtime must be worked to increase time available (takt time) in order to achieve equilibrium. A negative number means too many resources have been allocated considering the demand.

It is worth noting that one way or another, a process must be in equilibrium with demand at some point assuming all the demand is being shipped. In other words, unless customers are cancelling orders, the orders must be filled. We find that most organizations will either overstaff or work overtime as demand fluctuates in both volume and complexity. Rarely does an organization have a precise number of employees considering the demand variation. This is due to the lack of understanding of the Manufacturing Equilibrium. This results in an organization rarely achieving equilibrium, or the company is always either ahead (overproducing) or behind demand.

Manufacturing Efficiency can be thought of as the deviation from Manufacturing Equilibrium. The further from 0 (equilibrium) an operation is, the less efficient the operation becomes. Either overtime is needed resulting in higher labor costs or excess labor is present. Both situations are not a cost efficient way to run an operation.

By constantly focusing on eliminating waste, we can constantly drive down the Operator Cycle Times. This will ensure we are improving the cost effectiveness of our production system as improvements result in a negative number (too many resources). In this case, it is preferred to spur more demand which can be easily filled with the current headcount. There should be a constant focus on ensuring an operation is at equilibrium with demand and unevenness (mura) is kept to a minimum throughout the operational value stream.

APPLICATIONS

Starting in September 2010, Bally introduced Mixed Model Production into the Bally Production System with great success. We believe this model is applicable in a variety of industries including aerospace, automotive, computer assembly, motorcycle assembly, cabinet assembly, etc... Any manufacturing environment where there is a high degree of model variation is potentially an environment that can benefit from mixed model production. At Bally, there are over 10 billion configuration variations for the wide array of EGMs.

CONSIDERATIONS

Before attempting to implement mixed model production, it is important that a few steps are considered:

First, the operator cycle times for each model variation must be determined and available for analysis. Bally has developed software which allows us to load the models and corresponding cycle times into a database. When the mixed model sequence is generated, a manufacturing code, or unique identifier for each machine, is generated and compared against the work instruction database to determine the cycle times for each variation.

Second, a moving assembly system should be created to ensure flow. We have found it very dificult to run mixed model on a non-moving line because it is difficult to ensure cycle times are being met each cycle. The important part of setting up a moving line is that it must allow for flexibility in setting the line speed and zone sizes. As the demand and mix changes, the line speed and/or zone sizes may change as well.

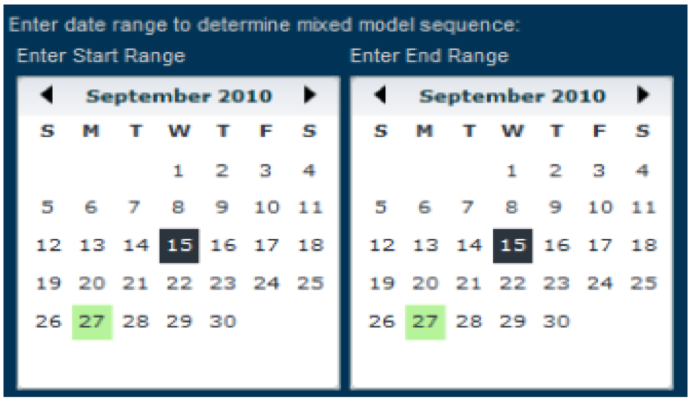
Lastly, it is a complex way to run production and it can take a long time to create the information systems necessary to pull and analyze information in real-time. Bally has developed the expertise in-house to design software and make it available to the entire staff. The key point here is that you cannot expect to buy software to do this automatically. From our research, we have not found a commercial package that can determine an efficient mixed model sequence.

EXAMPLE

To show how this algorithm can be used, an example of the 12 step method will follow

STEP 1: DETERMINE MODEL VARIATIONS

Bally has developed proprietary software to analyze the production schedule for a given period and determine the model variations. Our software is developed on a ColdFusion platform and is web based to provide the most accessibility possible. The first action is to tell the software the date range to analyze. In this case, we will analyze the schedule for September 27, 2010.



Once the date range is selected, our program will group the orders in the schedule based on the total build time for each machine. The build time is determined from the manufacturing code which is a unique identifer for each machine considering what the customer has ordered. The manufacturing code determines the complexity the machine. We have programmed this to limit the grouping to a given sales order and line item. Some manufacturing codes may be duplicated if the same code is used for multiple line items. This helps us later when we have to load the orders into our production management software, also designed in-house.

Game Code	Build Time	Mapics	Line Item	Qty	Work Order	Ship Date
S9-1V32-7G-C-N-GU-M-SP-2S-N-N-PL1-08R	36.5	603502	100	11		09/29/2010
S9-1V32-7G-C-N-GU-M-SP-2S-N-N-PL1-08R	36.5	603502	200	3		09/29/2010
S9-1V32-7G-C-N-GU-M-SP-2S-N-N-PL1-08R	36.5	603502	300	10		09/29/2010
S9-1V32-7G-C-N-GU-M-SP-2S-N-N-PL1-08R	36.5	603502	400	2		09/29/2010
S9-1V32-7G-C-N-GU-M-SP-2S-N-N-PL1-08R	36.5	603502	500	2		09/29/2010
S9-1V32-7G-C-N-GU-M-SP-2S-N-N-PL1-08R	36.5	603502	600	1		09/29/2010
S9-1V32-7G-C-N-GU-M-SP-2S-N-N-PL1-08R	36.5	603502	700	2		09/29/2010
S9-1V32-7G-C-N-GU-M-SP-2S-N-N-PL1-08H	31.8	603502	800	6		09/29/2010
S9-1V32-7G-C-N-GU-M-SP-2S-N-N-PL1-08H	31.8	603502	900	4		09/29/2010
S9-1V32-7G-C-N-GU-M-SP-2S-N-N-PL1-08H	31.8	603502	1000	4		09/29/2010
AP-1V222ST-C-E-GU-M-SP-2P-N-N-NON-14B	20.3	603502	1100	4		09/29/2010
AP-1V222ST-C-E-GU-M-SP-2P-N-N-NON-14B	20.3	603502	1200	3		09/29/2010
S9-1V32-7G-C-N-GU-M-SP-2S-N-N-PL1-08R	36.5	603493	100	3		09/29/2010
S9-1V32-7G-C-N-GU-M-SP-2S-N-N-PL1-08R	36.5	603494	100	5		09/29/2010

The software completes the grouping and assigns each variation a model code.

Model	Qty	Cycle Time
A	7	20.3
B	14	31.8
C	39	36.5

At this point, the computer begins to assemble what we call the Model Mix Matrix. This is an array that contains most of the information needed - model, build time, qty, etc... Notice that the matrix manipulations have already been performed to order the models from smallest build time to largest build time.

STEP 2: DETERMINE GREATEST COMMON DENOMINATOR

The GCD of 7, 14, and 39 is 1. 1 is the highest number that evenly divides into all three numbers. It is worth noting that computer languages rarely have a built-in function to determine GCD; however, almost all languages support modulus or mod calculations. Mod is the remainder left over after dividing two numbers. To find GCD, program a loop that starts with the largest number and divides it into all other numbers. If the mod is 0 for all numbers, the largest number is the GCD. If the mod is not 0, decrement the largest number by 1 and repeat the loop. The loop should repeat until the mod is 0 and the GCD is determined.

STEP 3: DETERMINE TOTAL CYCLE TIMES FOR EACH MODEL

Our program does this automatically as the manufacturing codes are pulled in. The cycle times are added into the Model Mix Matrix as they are calculated.

STEP 4: ORGANIZE MODELS FROM LARGEST TO SMALLEST

Once the Model Mix Matrix is determined, matrix manipulations are done to reorganize the matrix from largest to smallest. You can also go from smallest to largest (like our example). The important point is that the matrix is not a random collection. It must be ordered for the calculations to work properly.

STEP 5: DIVIDE THE MODEL QTY BY THE GCD

In this example, the GCD is 1; therefore, 7/1 = 7 = A, 14/1 = 14 = B, and 39/1 =39 = C. These numbers are added into the Model Mix Matrix.

STEP 6: GENERATE THE MIXED MODEL SEQUENCE **ORDERING FROM LONGEST CYCLE TIME TO SHORTEST CYCLE TIME**

Since the GCD is 1, there is only 1 repeatable pattern that was determined. It is as follows:

C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C B B B B B B B B B B B B B B A A A A A A A

**the looping structure needed to generate the mixed model sequence from the Model Mix Matrix is complex*

STEP 7: DETERMINE TAKT TIME

Takt Time = Time Available/Sold Units.
Time Available = 400 minutes for our production environment
Sold Units = 7 + 14 + 39 = 60 units
TT = TA/SU = 400 / 60 = 6.7 minutes (you can use any time scale but you must be consistent throughout)

STEP 8: DETERMINE AWCT

AWCT is the summation of the cycle time for a given model multiplied by the percentage how often the model is run.
Model A: 7/60 = 11.7% * 20.3 min = 2.4 min
Model B: 14/60 = 23.3% * 31.8 min = 7.4 min
Model C: 39/60 = 65% * 36.5 min = 23.7 min
AWCT = 2.4 + 7.4 + 23.7 = 33.5 min

STEP 9: DETERMINE NUMBER OF OPERATORS

of operators = AWCT / TT = 33.5 / 6.7 = 5.01. We must round this up to the nearest integer, or 6 operators. This ensures the correct number of operators are allocated to complete the demand on time.

It is worth noting that since 5.01 is very near 5, the best option here is remove waste to reduce the operator cycle time(s) which will reduce the AWCT and, ultimately, the number of operators to 5. You can also increase time available to increase takt time, if needed.

STEP 10: DETERMINE LINE SPEED

Line Speed = AWCT / # of operators = 33.6 / 6 = 5.6 minutes.
The line speed basically determines how often a machine will be completed from a moving line. This speed should be as close to takt time as possible to ensure resources are utilized in the most efficient manner.

STEP 11: DETERMINE BALANCED OPERATOR CYCLE TIMES

Operator Cycle Time = Total Cycle Time / # of operators
Model A = 20.3/6 = 3.4 min
Model B = 31.8/6 = 5.3 min
Model C = 36.5/6 = 6.1 min

STEP 12: DETERMINE ZONE SIZES

To determine the zone size, we must cycle through the entire model mix pattern. The calculation is as follows:
Start from 0 (beginning of zone)
Zone End = 0 + CT. Since we start with the longest CT first, 0 + 6.1 = 6.1.
New Zone Start = 6.1 - line speed = 6.1 - 5.6 = 0.5 min.
Repeat calculation using 0.5 as zone start and loop through the entire model mix pattern.
Find the Max value for Zone End - this is the zone size. For our example, the zone size is a little more than 22 feet.

PROGRAM OUTPUT

Our program will display this information in a consise format as seen below.

```
Mixed Model Setup
 39 is the highest model quantity
 GCD is 1
 Model     Qty   Cycle Time
 A         7     20.3
 B         14    31.8
 C         39    36.5

Mixed Model Sequence
C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C B B B B B B B B B B B B B B A A A A A A A

Line Setup
Total Games: 60
Available Min per day: 400
Total Days in Range: 1
Takt Time: 6.7 min
Average Weighted Cycle Time: 33.5 min

Number of Work Zones (Operators): 6

Line speed should be set to 5.6 minutes

Zone Size Information. Put the marker (yellow) at this position.
Zone Marker Position for zone 1: 22 ft 1 inches
Zone Marker Position for zone 2: 44 ft 6 inches
Maximum zone size exceeded. A new mix must be determined.
Zone Marker Position for zone 3: 67 ft 3 inches
Maximum zone size exceeded. A new mix must be determined.
Zone Marker Position for zone 4: 89 ft 2 inches
Maximum zone size exceeded. A new mix must be determined.
Zone Marker Position for zone 5: 111 ft 7 inches
Maximum zone size exceeded. A new mix must be determined.
Zone Marker Position for zone 6: 134 ft 0 inches
Maximum zone size exceeded. A new mix must be determined.
```

ANALYZING THE RESULTS

Developing a good mixed model sequence may take some small manipulation. Basically, the desire is to have the highest GCD possible. In this example, the low GCD of 1 (lowest GCD possible) results in a very inefficient model mix. Our zone sizes are 22 ft. The pitch of our lines is only 5 feet so this means 4 games will be in each operator's work zone at any given time. This also means that for the 6 operators needed the total line length needs to be 134 feet to ensure no one has to wait for someone with a larger game. Traditionally, production facilities would attempt to run the demand down different lines to minimize the cycle time variation. In this case, the variation is significant from 20.3 minutes to 36.5 minutes - almost double the complexity.

The other option facilities may use is to the determine what option is causing the extra 16 minutes of work and attempt to do the work externally to the production line. This is wasteful as it introduces extra motion and conveyance. This sequence can be easily optimized.

OPTIMIZING THE RESULTS

If we change the quantity of Model C from 39 to 35, we would have a much higher GCD of 7.
(7 divides evenly into 7, 14, and 35).

Using this, we can rerun the calculations to see what happens:

Mixed Model Setup

35 is the highest model quantity

GCD is 7

Model	Qty	Cycle Time
A	7	20.3
B	14	31.8
C	35	36.5

Mixed Model Sequence

C C C C C B B A C C C C C B B A C C C C C B B A C C C C C B B A C C C C C B B A C C C C C B B A C C C C C B B A

Line Setup
Total Games: 56
Available Min per day: 400
Total Days in Range: 1
Takt Time: 7.1 min
Average Weighted Cycle Time: 33.3 min

Number of Work Zones (Operators): 5

Line speed should be set to 6.7 minutes

Zone Size Information. Put the marker (yellow) at this position.
Zone Marker Position for zone 1: 7 ft 1 inches
Zone Marker Position for zone 2: 14 ft 6 inches
Zone Marker Position for zone 3: 22 ft 2 inches
Zone Marker Position for zone 4: 29 ft 3 inches
Zone Marker Position for zone 5: 36 ft 8 inches

The algorithm provides a much better model mix. A few things to notice:
- The pattern CCCCCBBA is repeated 7 times. This is because the GCD is 7.
- There are 5 C's (35/7), 2 B's (14/7), and 1 A (7/7) in the pattern.
- The number of operators went from 6 to 5
- The zone sizes were dramatically reduced from 22 ft to 7 ft, approximately.

The 4 units that were not scheduled can be added at the end of the mix without affecting zone sizes or resources required. Unscheduled units should be run from largest cycle time to smallest cycle time.

DETERMINING MANUFACTURING EQUILIBRIUM

If the mixed model was calculated correctly, the manufacturing equilibrium should be within one takt time. The equations is as follows:

$$\sum_{i=1}^{n} QTY_i*(OCT_i - tt) = 0$$

QTY = Quantity model appears for a given model mix pattern (not total qty)
OCT = Operator Cycle Time for a given model
tt = Takt Time for total demand

= 5*(7.3-7.1) + 2*(6.4-7.1) + 1*(4.1-7.1) = 5*(.2) + 2*(-.7) + 1*(-3) = -3.4 which is within ± 7.1 min (tt)

A negative number means that we have too many resources assigned. This makes sense since the line speed is slightly faster than takt time. If the equilibrium calculation results in a number outside the takt time tolerance band, this is considered to be a poor mix and adjustments are needed to either the model mix or time available.