

A Comparison and Evaluation of Two Distinct Inventory Buffer Sizing Methods: The Functional Method and the Deterministic Processing Time Model

Introduction

“[Our competitor] wastes too much time on inventory control. Build good production machines, start with lots of inventory in front of them, and then slowly reduce the inventory buffer over time. That is good inventory management.” That is not an exact quote, but that is how inventory management was explained to the author when he was a mechanical designer at GlobalCar¹ Engineering.

An automotive welding department can be thought of as a series of machines with buffers of inventory between them. In this paper, it is not the machines that will be examined in detail but the buffers of inventory between them – this examination is not something that that author would have done at GlobalCar Engineering.

Using a project undertaken by GlobalCar Engineering in 2001, the GlobalCar Manufacturing (GCM) #2 Hood Line Retooling, the methods used by GlobalCar Engineering to initially size inventory buffers will be reviewed and contrasted with a model presented by Dr. Stanley Gershwin in his book, *Manufacturing Systems Engineering*. Specifically, the methods used by GlobalCar Engineering will be compared to the deterministic processing time model. The paper starts with an overview of the GCM #2 Hood Line, then a review of the GlobalCar inventory sizing methods, followed by the same analysis using the deterministic processing time model, and finally concludes by comparing and contrasting the results of these analyses.

The author of this paper was the project engineer and lead designer for this re-tooling project. The calculations and information within this paper are taken from his design notes and memory. Some of the information needed to apply the deterministic processing time model was not present in the design notes and this information is no longer available at GlobalCar Engineering – and may not have even been readily available four years ago. Thus, to apply the methods illustrated by Gershwin some parameters need to be estimated from existing data. Where possible these estimates were confirmed with GlobalCar associates.

The Manufacturing System

Approximately four years ago GlobalCar Engineering undertook a project at GlobalCar Manufacturing to retool the GCM #2 Hood Line, hereafter referred to as the Hood Line, to both enable GlobalCar to produce the GlobalCar MiniSUV vehicle and to facilitate a production rate increase. The GlobalCar MiniSUV was then a totally new vehicle built on the GlobalCar BasicVan platform, a vehicle already assembled at the automobile assembly plant in question. Due to the introduction of a completely new product in the assembly plant, the overall product rate of the plant was slated to increase from 800 units per day to 825 units per day. Correspondingly, the production rate of the Hood Line needed to be increased, as well as that of the GCM #2 Weld Assembly Line, the production process which the Hood Line fed.

The purpose of the Hood Line is to assemble seven distinct hood pieces to create completed, but non-painted, hoods. The individual hood pieces are brought to the Hood Line by cart and the finished hoods are transported to the main Weld Assembly line by a job-specific cart. On the

¹ The name of the actual car company and their vehicle models have been changed to protect their privacy.

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assembly line they are attached to nearly complete bodies-in-white². This attachment occurs at the Hood Attachment Station on the GCM #2 Weld Assembly Line. Other similar stations on the Weld Assembly Line are used for attaching additional main automobile sub-components.

An overall picture of this system is given below (Figure 1):

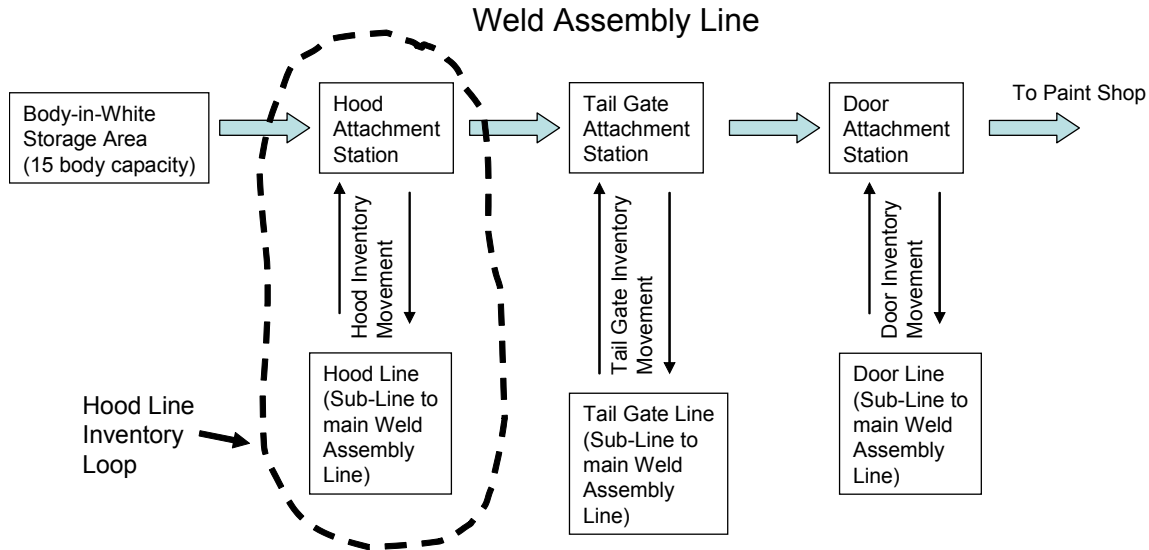


Figure 1: Overall Production Flow

Essentially, the Hood Line to Hood Attachment Station system is a set of two large machines connected by a buffer. This first of those machines is the Hood Line. The purpose of the Hood Line is five fold:

- To join reinforcing pieces to the hood reinforcing frame³.
- To join the reinforcing frame to the hood skin⁴.
- To apply mastic sealant⁵ between the hood frame and the hood skin.
- To enable the hood hinges to be attached to the completed hood.
- To enable the inspection of the completed hood assembly.

Once the above five processes are completed, then a non-painted hood has been assembled. To complete these five processes there were five distinct machines on the Hood Line. These machines were not decoupled with inventory. Due to the lack of buffers between the stations a failure of one machine caused the entire line to shutdown. Thus, the Hood Line was essentially a zero-buffer single machine. The Hood Line was manned by two-operators, one loading parts, and the other unloading parts and inspecting the final product. Upon passing inspection, all hoods were transferred to the Hood Attachment Station.

² A “body-in-white” is the non-painted sheet metal frame of an automobile.

³ The reinforcing frame is a single piece of heavy gauge sheet metal to increase the stiffness of the hood.

⁴ The hood skin is the sheet metal outer surface of the hood.

⁵ A sticky substance to both deaden noise and provide some adhesion between the hood skin and reinforcing frame.

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To allow for transfer the hoods were placed on carts. These carts were manually moved from the Hood Line to the Weld Assembly Line, Hood Attachment Station and vice versa as parts and storage racks were required. These carts consist of a series of racks on which operators can stack hoods. The hoods are individually placed in slots. Each cart has ten slots, allowing for a maximum of ten hoods to be placed on a cart at any one time.

The following diagram illustrates the hood inventory cart:

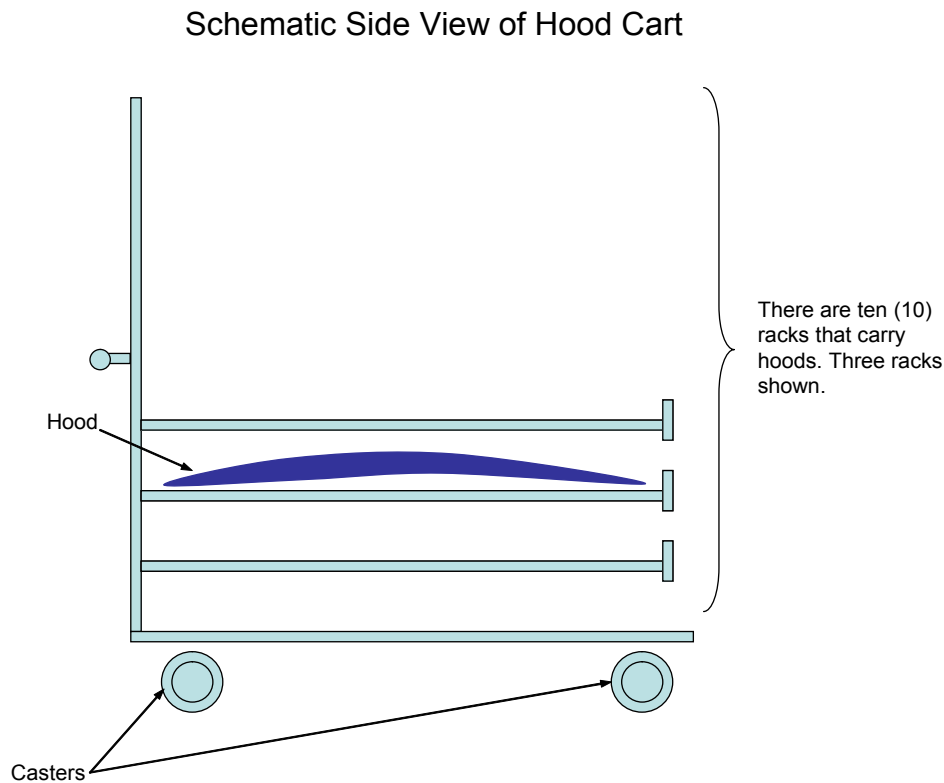


Figure 2: Hood Line Finish Goods Cart

A reasonable maximum of three carts can be kept at the Hood Line given the current floor space. Periodically (or by call), a material handling associate arrives to take completed hoods from the Hood Line to the Weld Assembly line. Generally, at the same associate will then bring empty carts to the Hood Line to be refilled.

The carts travel approximately 20 meters to the Weld Assembly line; the transfer takes under two minutes. As bodies-in-white travel down the Weld Assembly Line, hoods are manually removed from the local hood storage carts and positioned on the car body with the aid of a lifting device and positioning machine. It takes two associates to fasten the hood to the body-in-white car frame.

The overall goal of the Weld Department is to produce 825 completed body-in-white cars per day⁶. That is, the 825 body-in-white cars are to be assembled on the Weld Assembly Line per

⁶ The takt time for the product is 61.5 seconds. There are approximately two hours of breaks during a scheduled 16 production hour day.

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day. These bodies are supplied to the Paint Department for painting and additional sealant application. This is not to say that the Hood Line is required to produce 825 hoods per day, although that is an overarching goal of the Weld Department management. On average 825 hoods per day are to be produced, but with certainty, the Hood Line needs to supply 825 hoods to the Weld Assembly Line, Hood Attachment Station through a combination of existing inventory and product fabricated during the given day. Given this situation, there existed a choice between the size of the inventory buffer and the capacity/reliability of the retooled Hood Line.

Sizing the Buffer: Comparing Two Methods

Within this section, the method originally used by GlobalCar Engineering to confirm the buffer size for the project will be compared with the deterministic time processing model. The method used by GlobalCar will be called the functional method.

The Functional Method

When the GCM #2 Hood Line Retooling project was originally undertaken in 2001, a method based upon previous inventory calculations was used to confirm the existing buffer size. There did not exist a standard method of sizing inventory buffers at GlobalCar Engineering (at the time), but there were principles in existence to aid a designer in determining the appropriate amount buffer size, or in this case the appropriate number of carts.

The first key principle of the methodology that the lower bound of buffer size is to be set to the minimum operational buffer size. The minimum operational buffer size is defined as:

The minimum number of inventory carrying units that must be present in the inventory system when the system is operating smoothly.

The first step in the functional method is to determine the minimum operational buffer size. The definition may not seem useful in this task and additional explanation is warranted. First, by “operating smoothly” it is meant that both the feeder line and the line being fed at operating such that no emergency stock is required. In most cases, this means that the lines are operating at the same production rate (i.e. that neither line is under repair). The “minimum number of inventory carrying units” is the minimum number of units that hold stock that must be present in the system for it to function. In this specific design it is carts. What is the minimum number of carts required so that there is always inventory where it is needed and empty carts where they are required?

For the Hood Line system carts were used to transport inventory between the Hood Line and the Weld Assembly Line. For the system to operate smooth there needed to be a minimum of one cart at the Hood Line, one cart at the Weld Assembly Line, and two carts able to move into position if either of the parked carts become full or empty, respectively.. The function of each of the four carts is as follows:

- One cart with parts is needed at the Weld Assembly line to provide parts for that line.
- One cart is needed at the Hood Line for the operator to fill.

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- Two carts are needed for transition. A cart is needed at the Weld Assembly Line so that when the first cart is empty and is taken away the line does not stop to wait for a new cart to be delivered. The same logic applies to the extra cart at the Hood Line.

One might notice that with proper coordination that only one cart, given a sufficiently low travel time, is strictly required between the Weld Assembly Line and the Hood Line. However, at the time, it was judged that to maintain “smooth” operation that one extra cart per station was required. There is another reason for placing four carts in the loop, the existence of multiple hood models. Three distinct products were assembled on the Weld Assembly Line and carts were required for model transition. During normal operation, carts could be exchanged on a one for one basis, as the nominal line rates for each the Hood Line and the Weld Assembly Line were the same. When a model change occurred, there needed to be a second set of carts to allow for this transition. As there were a total of three models produced on both lines, carts were assigned as follows:

- Two carts to model A
- Two carts to model B
- Two carts to model C
- Two carts for inventory transition

Any one loop was constructed of four (4) carts, with two carts rotating their inventory. As each cart can carry 10 hoods, the minimum operational buffer size is 40 hoods. The following diagram illustrates the minimal number of carts and their average placement for smooth operation:

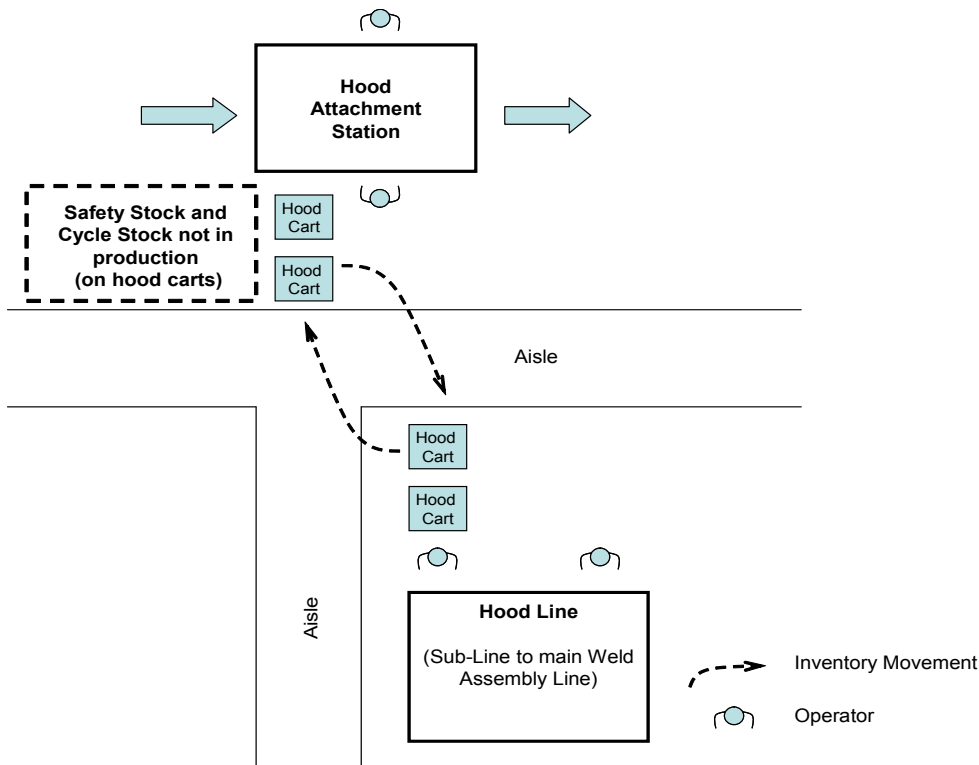


Figure 3: Detailed Hood Line to Weld Assembly Line Configuration

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Saying that this number of carts is the minimum makes the implicit assumption that a cart can be transferred from the Weld Assembly Line to the Hood Line in less time than it takes to fill a cart. This was the case for the Hood Line. It needs to be said that this step does not truly size the buffer; it only places a lower bound on the number of inventory carrying units within the buffer. As the current inventory loops for the existing models functioned properly using only the minimum operational buffer size, it was decided to maintain this level for the new GlobalCar MiniSUV inventory loop. As the capacity of the carrying units was a given, the cart sizing step was not required. Cart sizing is discussed below in more detail.

The second key step in the functional methodology is to determine the main factors of uncertainty and then provide inventory to counter these factors of uncertainty. These factors of uncertainty are used to size a safety stock. As seen in Figure 3, this safety stock is kept next to the Weld Assembly Line. This is not to say that this safety stock is actually implemented during regular production. However, it is usually kept in place during trials or during the initial ramp-up of a vehicle program. The minimum operational inventory is usually suitable for everyday operation. Standard practice is to begin the production of a new model with both the safety stock and the minimal operational inventory in-place and reduce safety stock as the production process becomes stable. There were three standard factors of uncertainty⁷ that were applied to this buffer design problem:

- *Equipment uncertainty:* The uncertainty associated with only production equipment in the Hood Line equipment group. Specifically, this uncertainty was quantified as the average downtime of the equipment per day.
- *Delivery uncertainty:* The uncertainty associated with both material delivery to the process (in this case the Hood Line) and away from the process. This uncertainty is quantified as the amount of time taken from when a call is placed to deliver/remove material from the process area to when the material arrives or is removed.
- *Operator uncertainty:* The uncertainty associated with the operators stationed at the process in question. This uncertainty relates to all problems at the process that do not arise as a result of an equipment failure. For example, if the process needed to be shut-down due to intermittent high absenteeism, some form of expected length of absenteeism per unit time would have been used as an uncertainty measure.

For this design problem the following values for these uncertainties were chosen.

Uncertainty	Value	Reasoning
Equipment	14 minutes per day	The Hood Line historically experienced approximately 12 minutes per day of downtime. The equipment modifications proposed added approximately 15% more moving parts ⁸ .
Delivery	8 minutes per delivery	The average time from when a Weld Assembly associate calls for a cart to when it arrives at the line is eight (8) minutes.
Operator	1 minute	Historically there is little operator uncertainty.

Figure 4: Uncertainty Determination

⁷ These three factors of uncertainty had been used in previous GlobalCar Engineering designs.

⁸ 12 minutes per day x 1.15 safety factor = 13.8 minutes per day

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These uncertainty values now need to be translated into required hood inventory. The following calculations were completed to transform these times into units of inventory:

Uncertainty	Transformation	Value
Equipment	<p><u>14 minutes per day</u> →</p> <p>Assume that all of the downtime occurs in one session and that any additional hoods required due to downtime each day will be fabricated on overtime daily.</p> <p><i>Therefore:</i></p> <p>14 minutes x 60 seconds/min / 61.5 second takt time = 13.7 hoods</p>	13.3 hoods
Delivery	<p><u>8 minutes per delivery</u> →</p> <p>At any one time there needs to be eight (8) minutes worth of stock at the Weld Assembly Line.</p> <p><i>Therefore:</i></p> <p>8 minutes x 60 seconds/min / 61.5 second takt time = 7.8 hoods</p>	7.8 hoods
Operator	<p><u>1 minute</u> →</p> <p>Historically there is little operator uncertainty. However, one minutes worth of inventory is credited to operator uncertainty. Translating this to pieces gives:</p> <p>1 minute x 60 seconds/min / 61.5 second takt time = 0.98 hoods</p>	0.98 hoods
Total		22.4 hoods

Figure 5: Uncertainty Translations

The total amount of inventory required due to uncertainty is 22.4 hoods. One can think of this number in terms of a safety stock of parts to compensate for line fluctuations. To maintain a simple safety stock inventory policy, those in charge of safety stock were told to maintain two full carts of safety stock in case of problems. Actual safety stock requirements were rounded down as minimal safety stock was in use with the other models and only incremental production change was being undertaken. Thus the buffer size was actually increased by 20 units.

In summary, the total buffer size for each type of inventory was 60 units (or six carts). However, four (4) of the carts were used as standard inventory and two (2) carts were kept for safety stock. The above model showed a need for an additional four carts, two for safety stock and two for the additional model.

As mentioned above, the calculations of minimum operational buffer size does define the actual number of parts required in the loop, only the number of inventory carrying units. For the Hood Line retooling project, the cart size was not changed and so determining the size of the carts was not necessary. If the carts also required design, the functional method uses a combination of principles. Two of the key principles are:

- The inventory carrying device must be ergonomic in size.
- The inventory carrying device must be capable of holding enough inventory such that it is not required to transport the device frequently between stations.

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In reality, these principles lead to the creation of inventory holding devices that are of the largest practical size. By constructing the largest practical inventory holding units, excess transportation is minimized.

In practice the above model has generally produced inventory management systems that have functioned sufficiently well for GlobalCar. However, GlobalCar has undertaken little effort to optimize the functional method. Some critiques of this functional method follow:

- The method does not account for downtime on the Weld Assembly Line, only on the Hood Line. It is assumed that the Weld Assembly Line will continuously be operating. However, this is a known fallacy.
- The method is open to interpretation by the designer. An inexperienced designer has a greater chance of constructing a system that does not function.
- The system is based upon over-sizing the inventory buffer and then gradually reducing it to remove excess inventory. This system may not be practical in all situations and it definitely adds capital cost.

The Deterministic Processing Time Model

This manufacturing system can be modeled using the deterministic processing time model presented by Gershwin. The deterministic processing time model characterizes a manufacturing system as sets of machines with buffers between these machines. The machines fail and are repaired with a known probability during each machine operation and generally run at the same maximum production rate⁹, which the Weld Assembly Line and the Hood Line are designed to do.

To utilize the inventory sizing method proposed by Gershwin, three key production parameters need to be estimated:

- The production rate for the Weld Assembly Line and the Hood Line
- The mean time to failure (MTTF) for the Weld Assembly Line and the Hood Line
- The mean time to repair (MTTR) for the Weld Assembly Line and the Hood Line

By using only these three parameters the behavior of the line is estimated.

Determining the production rate is fairly straight forward. The Hood Line and Weld Assembly Line were set to produce product at *825 units per day*. However, due to random fluctuations, the actual production rate of each system needed to be higher. From data, the set cycle time of the Weld Assembly Line was 60 seconds per product (840 units per day) and the Hood Line was scheduled to run at 60 seconds per product (840 units per day).

⁹ It may be possible to a discrete-time model in which the machines do not run at the same rate, but the model proposed by Gershwin does not allow for this event and differing production rates are not required in this case.

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Determining the MTTF and MTTR is more difficult. To the author's knowledge these statistics are and were not collected directly by GlobalCar plant personnel. They will need to be estimated from existing data. They will be estimated from design notes, the author's memory and a statistic that will be called significant downtime.

Given GlobalCar's data, it is most easy to estimate the MTTR. The method chosen to convert GlobalCar data into data compatible with the deterministic processing time model is to use a measure dubbed *significant downtime*. The current Hood Line experienced 15 minutes per day of significant downtime. Significant downtime is:

The total accumulated extra time run per day plus the negative difference in production, translated into time units, represents the significant downtime experienced by a machine that day.

For example, significant downtime for a day in which 780 hoods were created in 14.5 hours of work is calculated as follows:

1. The scheduled daily working time is 14 hours. Therefore 0.5 hours of extra time was spent running equipment.
2. Only 780 hoods were created. Thus, the machine was down for at least 20 hoods. The average hood takes 63 seconds to fabricate and thus there was an additional 1260 seconds of downtime.

The total downtime was 30 minutes for overtime and 21 minutes for absent production leading to a total of 51 minutes of significant downtime for a production day of 14.5 hours. That amount of down time is considerable in one given day.

Significant downtime captures all of the repair time between the start of the production day and the end of the production day, but it does not capture repair time on off-shifts. We will assume that this number approaches zero. Preventative maintenance and larger scale maintenance projects are scheduled on off-shifts – little reactive maintenance is completed. Moreover, the maintenance logs for the given time period show no reference to Hood Line repairs on the off-shirts. An estimate of the daily repair time can be obtained by subtracting product produced per day (multiplied by cycle time) from the total time taken to produce the product.

To convert the daily repair time to MTTR, the average number of repairs per day is required. This number is not recorded at GlobalCar. Maintenance logs provide some indication. GlobalCar associates estimated that maintenance personnel were called to the Hood Line approximately three times per day. However, the floor associates and supervisor in the area also react to downtime problems. Conservatively, the number of instances of downtime each day were doubled. MTTR is calculated by dividing the total repair time by the number of repairs per day. For the Hood Line this value is 2.5 minutes. This number seems reasonable.

For the Weld Assembly Line downtime is less frequent. The average significant downtime is 11 minutes per day. Failures are also less frequent. From maintenance records it was estimated that one visit to the portion of the line dealing with hoods was undertaken by maintenance people daily. However, the line associates and supervisors needed to interfere more frequently with the line to ensure smooth function. It was estimated that superiors interfered two times more than

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maintenance people. Thus there was also a total of three disruptions in a given day. The MTTR for the Weld Assembly Line dealing with hoods was 3.67 minutes. Again, this number seems reasonable.

The MTTF can also be estimated from the above data. The first step is to determine the average length of time that the machines are operating per day. For the Hood Line, this can be represented by the average amount of time working per day. Data shows very little variation in daily production numbers., thus this value is 14 hours or 840 minutes. In steady state the number of failures equals the number of repairs – one will repair a line every time it breaks, and thus we will assume that for both line there are six failures per day for the Hood Line and three failures per day for the Hood Attachment Station. Now we estimate that for the Hood Line the MTTF is 840 minutes divided by six failures which equals 140 minutes. For the Hood Attachment Station, the MTTF is 280 minutes.

There are three major concerns with using the above approximations for MTTR and MTTF:

- The above method to determine MTTR and MTTF is crude. That is, it highly depends on the actual number of repairs undertaken in one day. There was a distinct lack of historical data beyond that of average maintenance visits to the machine areas.
- The definition of significant downtime does not necessary imply that MTTF is in hours of operation, as required by the deterministic processing time model. The first calculation portion of significant downtime is accounts for all of the operating time during one day, whereas the second portion is really an efficiency measure. That is, the operating time per day is accounted for by the first measure of total operating time per day, whereas the second calculation measures the efficiency during that operating time. However, significant downtime is probably still a reasonable measure of total downtime since management religiously targets 825 units per day of production.
- A small portion of the significant downtime, approximately two minutes per day is related to set-up changes.

There are other concerns using the deterministic processing time model. Gershwin makes a series of assumptions in his deterministic processing time model, some of which are violated by the operating policy at GlobalCar. The concerns with the assumptions are as follows:

- Gershwin makes the assumption that equipment will not fail if it is starved. GlobalCar does not shutdown equipment when it is starved, but the equipment is not actively used and thus the chance of the equipment failing is extremely small.
- The portion of the Weld Assembly Line related to hood attachment dies not empty into an infinite buffer, although there is a small buffer downstream of this station.
- For the portion of the Weld Assembly Line related to hood attachment to function properly a car body must also be present in the hood attachment station. There is a sizeable buffer of bodies-in-white (15 units) on which to attach hoods upstream of the hood station, although a small fraction of downtime is related to lack of bodies-in-white.

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- Failures and recovery lengths are assumed to be exponential in distribution by Gershwin. No attempt to validate the actual distribution of failure and recovery lengths was undertaken
- The complete buffer is not always accessible to either associate. That is, sometime hoods are located that the Hood Line when they may be needed at the Hood Attachment Station. From the author's experience these cases are rare.

However, the model should provide at least an approximation of the buffer size. The table below summarizes the input parameters and output of the model.

<u>Hood Line</u>			<u>Weld Assembly Line</u>		
Production Data			Production Data		
Cycle Time	60	s per unit	Cycle Time	60	s per unit
Scheduled Working Time per Day	50400	seconds	Scheduled Working Time per day	50400	seconds
Maximum Production per Day	840	units	Maximum Production per Day	840	units
Downtime Data			Downtime Data		
Significant Downtime	15	minutes	Significant Downtime	11	minutes
Repairs per day	6	per day	Repairs per day	6	per day
MTTR	2.5	minutes	MTTR	1.83	minutes
MTTF	140	minutes	MTTF	140	minutes
Model Data			Model Data		
Production Rate	1.00	units per min	Production Rate	1.00	units per min
Repair rate	0.4	min per repair	Repair rate	0.545455	min per repair
Failure rate	0.007143	min per failure	Failure rate	0.007143	min per failure
Required Production Rate	0.952381	units per min	Required Production Rate	0.952381	units per min
Efficiency Data			Efficiency Data		
isolated efficiency	98%	percent	isolated efficiency	99%	percent
Isolated Production Rate	825.2632	units per day	Isolated Production Rate	829.1422	units per day
BUFFER SIZE			BUFFER SIZE		
	40	units		40	units

Figure 6: Deterministic Processing Time Model Data

As can be seen from the table, the nominal buffer size is 40 units. This is exactly the same amount as used by GlobalCar.

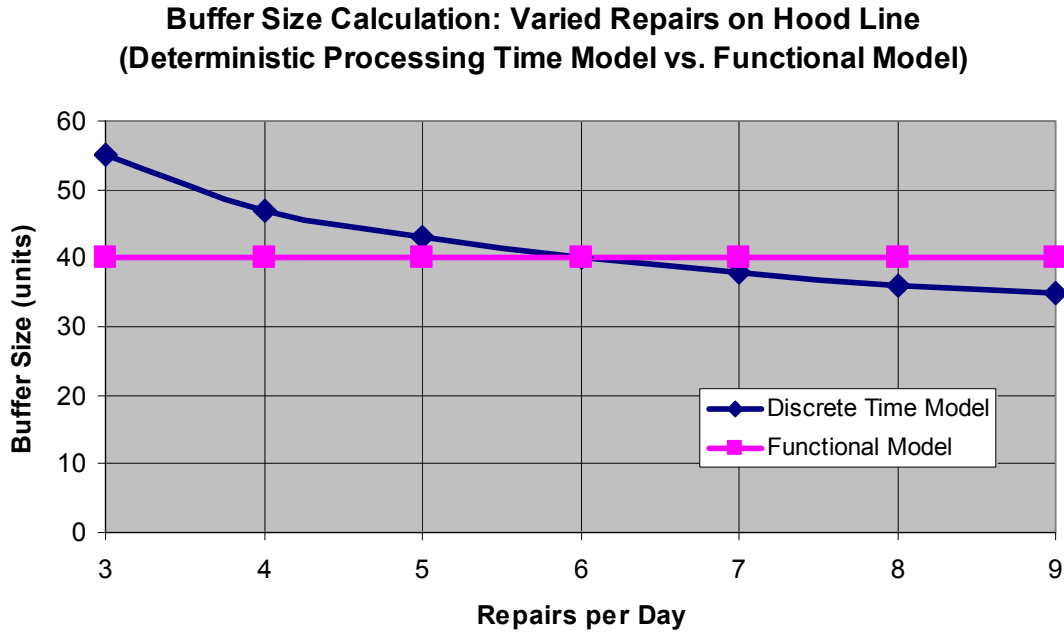
Comparing the Models

With the nominal values used above, the deterministic processing time model and the GlobalCar model produce identical results, 40 units of buffer level for the discrete time processing model and 40 unit of buffer level for the GlobalCar model. At first, the closeness of the results seems surprising. The models are based upon very different sizing methodologies. The GlobalCar model is based upon the amount of inventory carrying units required to maintain smooth system operation. When problems arise, safety stock is used to maintain the production rate. The deterministic processing time model is based upon the actual machine repair and failure data from the factory.

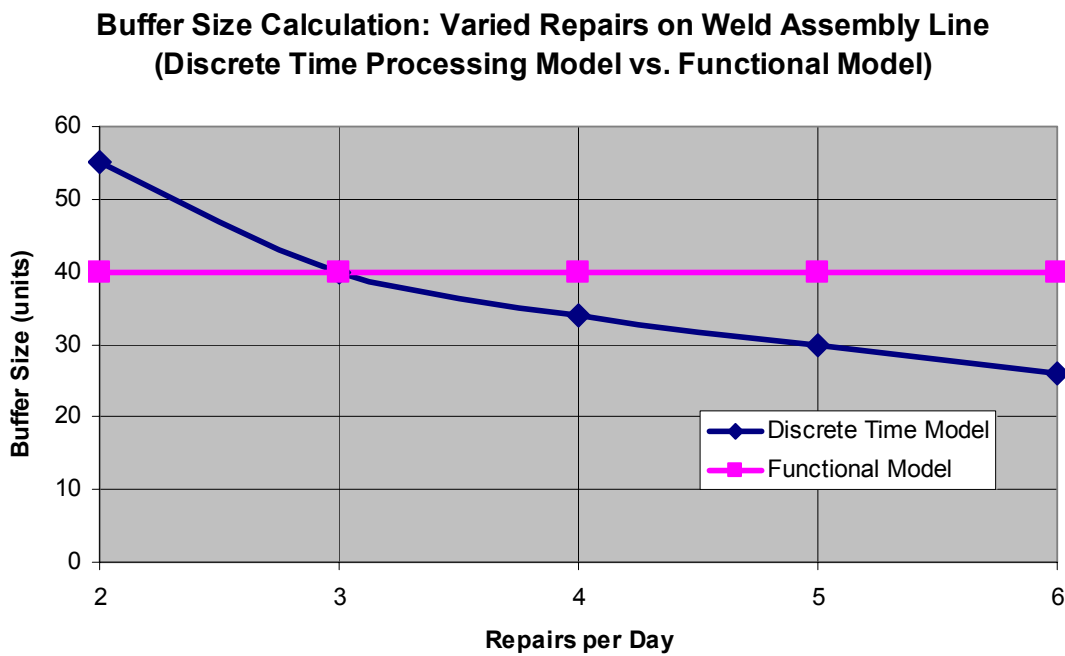
However, before drawing conclusions, as daily failure rate upon which the deterministic processing time model is based is estimated, a sensitivity analysis of the buffer size to the number of repairs per day is a useful understanding the potential concerns with the model.

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The following chart illustrates the change in inventory as the number of repairs per day increase at the Hood Line:



The graph shows that the model is relatively insensitive to the number of repairs per day. When the number of repairs per day was halved the required inventory increased by only 15 units. The next graph illustrates how the number of repairs per day at the Hood Attachment Station causes the buffer size to vary.



This graph also shows that the buffer size is fairly insensitive to the number of repairs per day.

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From the above graphs, it can be concluded that deterministic processing time model approximates the buffer size of the functional model¹⁰.

It is probably not mere coincidence the results of the models are similar. Although the functional model determines a given amount of inventory, this inventory has a reciprocal effect on the production system. As the GlobalCar system is driven on producing 825 units per day everyday, once a set number of inventory slots are available, the production system may tend towards given values of MTTR and MTTF. In other words, when management provides a given number of inventory slots, given machinery, and a production target the only variable left is the number of failures (or repairs) per day. It is natural for people to then only work as hard as necessary (to prevent failure) so as to meet the production target. For example, it may be the case the additional preventative maintenance would reduce failures significantly. However, there is little incentive to perform this maintenance as production targets are currently being met.

Given that the above is true, the deterministic processing time model would be very useful in predicting the amount of inventory required when production machinery was improved, providing that a corresponding amount of buffer space was actually removed from the system. That is, one should physically remove the slots from the carts or the same incentive structure will exist, and thus the improvement may not be sustainable.

Benefits From Reduced Inventory

The current isolated production efficiencies for the both Hood Line and the Weld Assembly Line are quite high, 98% and 99% respectively. Improving these systems may be difficult. However, let us take the case of reducing significant downtime on the Hood Line by five minutes. Assuming the other parameters stay the same, a revised Figure 6 is shown.

¹⁰ The other questionable variable is significant downtime. This variable is from design notes and it was originally collected to provide an understanding of downtime situation for machine design purposes and not for estimating MTTF and MTTR. The data sample consisted of only approximately 25 values.

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<u>Hood Line</u>			<u>Weld Assembly Line</u>		
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Scheduled Working Time per Day	50400	seconds	Scheduled Working Time per day	50400	seconds
Maximum Production per Day	840	units	Maximum Production per Day	840	units
Downtime Data					
Significant Downtime	10	minutes	Significant Downtime	11	minutes
Repairs per day	6	per day	Repairs per day	3	per day
MTTR	1.666667	minutes	MTTR	3.67	minutes
MTTF	140	minutes	MTTF	280	minutes
Model Data					
Production Rate	1.00	units per min	Production Rate	1.00	units per min
Repair rate	0.6	min per repair	Repair rate	0.272727	min per repair
Failure rate	0.007143	min per failure	Failure rate	0.003571	min per failure
Required Production Rate	0.952381	units per min	Required Production Rate	0.952381	units per min
Efficiency Data					
isolated efficiency	99%	percent	isolated efficiency	99%	percent
Isolated Production Rate	830.1176	units per day	Isolated Production Rate	829.1422	units per day
BUFFER SIZE					
	7	units			

Figure 7: Revised Production Data (Figure 6): Less Downtime

With a significant drop in repair time, an incredibly significant drop in the buffer size occurs. The required buffer size goes from 40 units to 7 units. One cannot remove any of the four carts, but each cart could be reduced to two spaces. This new system has the following benefits and costs:

Benefits	Costs
<ul style="list-style-type: none"> ○ Average work in process inventory is reduced 	<ul style="list-style-type: none"> ○ Additional manpower is needed to move carts from the Hood Line to the Weld Assembly Line more frequently ○ The carts must be modified

Although the deterministic processing time model predicts the average inventory in the system, due to the batched nature of the inventory movement, the value may be inaccurate. Assume a best case reduction of 32 hoods on average (for three models). Each completed hood costs no more than \$300. Thus GlobalCar saves \$1440 per year, assuming a reasonable cost of capital of 15%.

Compare this to the extra requirements for first modifying the carts. Assuming that the carts are modified in-house, at a representative labor rate of \$50 per hour, and that it takes four hours per cart, the cost to modify the carts is \$1600. If this were the only cost, the simple payback is just over one year. However, there is another cost.

Now examine the additional cost to transport the hoods from side to side. Currently hoods are transported back and forth once every 10.2¹¹ minutes. It takes approximately two minutes to transfer a full cart from the Hood Line to the Weld Assembly Line and two minutes to return an

¹¹ Takt time x number of hoods carried

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empty cart to the Hood Line. Each production day an associate spends 330¹² minutes transporting hoods carts. In the new system, hoods will be transferred every 2.03 minutes (just enough time to not force the purchase of extra carts). Now an associate spends 1650 minutes per day transporting hoods carts. Thus we need more people doing this job. At \$50 per hour (fully burdened), GlobalCar would spend an extra \$1100 per day transporting carts, valuing extra capacity (if it existed) at the same rate as incremental capacity.

Thus, although there is a slight savings in inventory and the initial cost to achieve this savings is low, it makes no sense to improve production in this manner. Similar scenarios can be run for different improvement projects. In all cases the additional labor to move carts does not justify any improvement in production. A radically new inventory transfer system is required to enable successful production equipment improvement projects.

General Conclusions

The basic inventory strategy of building the largest feasible inventory carrying units and then sizing the inventory loop with the minimum number of these inventory carrying units appears to have been a successful inventory control strategy for GlobalCar. The author observed this system working smoothly and the minimum buffer size determined using the Gershwin deterministic processing time model agrees with the buffer size used by GlobalCar.

However, there is a concern that this is a “chicken and egg” problem. That is, GlobalCar management demands a given number of units to be produced each day. Moreover, they provide a certain amount of buffer capacity. Investment in production improvement projects, projects affecting MTTR and MTTF, in a specific area is heavily prioritized based upon the ability of the production area to meet its daily production targets. Thus, GlobalCar management may simply be over-investing in an area to maintain its current inventory policy.

Still the deterministic processing time model did accurately reflect the amount of inventory required in the Hood-Weld Line production loop. Thus, given that the MTTR and MTTF of a line can be predicted¹³, it is reasonable to assume that once the minimum number of inventory carrying units is sized, that the deterministic processing time model can be used to size their capacity. Moreover, this model would act as a good check to determine if an unwieldy size of cart was actually required. That is, the deterministic processing time model may predict the need to have an excessive number of slots per cart, if only the minimum number of inventory carrying units is used. Maybe it is more economical to have one extra cart, and making each cart smaller. The economics of this situation could be analyzed similarly to the drop-in-repair-time case illustrated above.

¹² 840 minutes per day / 4 minutes per transport

¹³ GlobalCar has historical data that should allow for the prediction of MTTR and MTTF in a similar manner to that undertaken in this paper.