

Research Article

Supply Chain Inventories of Engineered Shipping Containers

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Manufacturing operations that assemble parts often receive components in expensive highly engineered shipping containers. As these containers circulate among suppliers, assembly operations, and logistic providers, they require inspections and repairs. This paper presents mathematical models that predict the number of available containers as functions of damage, repair times, and scheduled daily production. The models allow making complex decisions with a few basic parameters. Results not only show a minimal investment in the number of containers and safety stock but also quantify the dependence on damage rates and repair times for ordering additional containers.

1. Introduction

Many studies on shipping containers emphasize repositioning empty shipping containers [1–4]. However these and other studies, for example [5–7], that stress other aspects of supply chains and include empty shipping containers refer to large box containers, or twenty-foot equivalent units (TEUs) convenient for multitransportation modes, ports, fleet terminals, modal transfers, and so forth.

While many articles on large box containers have been published, very little if any literature addresses the problem of maintaining the availability of highly engineered reusable containers required for shipping easily damaged parts in a manufacturing operation. Manufacturing each container can cost considerably more than \$1,000 USD. When manufacturing operations such as the assembly of automobiles requires thousands of such containers, millimeter differences in the product and container dimensions can cost many millions of dollars for extra containers. Moreover, expensive engineering analyses for stresses, strength, packaging, and transportation robustness in preventing damage to sensitive parts become important because the cost and time for repairing containers can become serious issues. Predictive mathematical models for the availability of containers can save millions of dollars in up front and ongoing cost for manufacturing a product whose limited production lasts a few years.

The main contribution of this paper analyses management of highly engineered containers. Our paper first presents a mathematical model for a supply chain consisting of a supplier, a general assembly plant, and a container maintenance center (CMC); see Figure 1. Typically the assembly plant and a CMC are situated closer together than the supplier.

At each node in the loop the number of containers that exceed the daily requirement constitutes a safety stock. The quantities of containers at each node and the number of containers required for a steady state production have been chosen for easy scalability when used with proprietary data. The paper then creates predictive mathematical models that explore and highlight the consequences of different assumptions on the availability of highly engineered containers. These models can also show where to optimize cash flow. A minimal number of containers plus a small safety stock can reduce the initial investment. Only as the number of damaged containers under repair grows should additional containers be purchased. The models allow making complex decisions with a few basic parameters.

Recent research has found that the excess of containers in manufacturers' supply chains can be as high as 30% [8]. As an example of the importance of this paper, in the automotive industry, easily damaged parts such as doors,

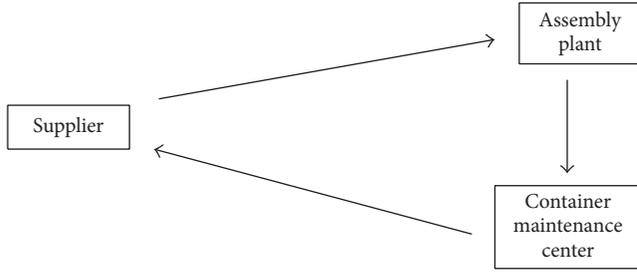


FIGURE 1: Depiction of the logistical flow of containers from a CMC to a supplier to an assembly plant and back to a CMC.

hoods, roofs, and exhaust assemblies require containers. Consequently, each car model under current production requires many thousands of expensive highly engineered reusable containers.

The second section of this paper develops a basic mathematical model and a simulation to demonstrate the predicted behaviors. Explicit and implicit assumptions and their consequences are clarified. The third section establishes a more general model that can accommodate a variety of probability distributions. Two distributions illustrate the model. A section containing remarks and a summary section conclude this paper.

2. A Basic Mathematical Model

This section develops a basic mathematical model from which extensions will lead to increasingly realistic models. This model clarifies explicit and implicit assumptions whose reassessment in Section 3 will guide the generation of a more general mathematical model. The following subsections describe the basic model, give its assumptions, supply notation, derive a steady state formulation, and add a simulation.

2.1. Description and Assumptions. Although the motivation for modeling a supply chain loop comes from supplying an automotive assembly plant, the basic aspects of the modeling apply to any manufacturing that relies on reusable engineered containers supplying components for a manufactured product. Assuming that the supply chain does not lose containers due to theft, damage to containers and their repair impact the availability of containers most severely. Our first model represents a basic supply chain having three essential elements; a supplier, an assembly plant, and a container maintenance center (CMC) for inspection and repair of damaged containers.

Let A_{DP} denote the number of containers required to meet the scheduled Daily Production on an average day. The model assumes that the assembly plant initially has $3A_{DP}$ containers of parts, $2A_{DP}$ in the safety stock, and A_{DP} for an average day's production. With $2A_{DP}$ more containers at the supplier, the plant can operate for one week. The CMC has a safety stock of $5A_{DP}$ containers, enough containers needed for a week of production. The total number of containers

equaling $10A_{DP}$ provides a convenient scalable quantity for mathematical modeling.

Note that the mathematical models in this paper do not include times for transporting containers between locations. The models assume that transportation of containers starts at the end of a workday and continues overnight if necessary so that containers arrive at their destination before an 8-hour shift of work begins. The models also assume that empty containers arriving at the supplier in the morning will be filled and ready for shipping by the end of the same day. Similarly, the assembly plant sends all the emptied containers to the CMC for inspection. After inspection all undamaged containers will be available for shipment to the supplier.

A steady state loop without any damage to containers and guaranteed overnight deliveries would not require safety stocks. Nonetheless containers often sustain damage and must be repaired. The following model assumes a geometric distribution for the probability ρ of a container sustaining damage. The discrete geometric distribution has a basis on sequences of independent Bernoulli trials [9, p. 367]. We can model the number of times a container arrives at the CMC before the first damage is observed as the number of trials followed by the first "success." If ρ , $0 \leq \rho \leq 1$, denotes the probability of a "success" and k denotes the number of trials before the first "success," then the discrete geometric probability mass function distribution $f(k)$,

$$f(k) = \rho(1 - \rho)^{k-1}, \quad k \in \{1, 2, \dots\}, \quad (1)$$

has the cumulative distribution function $F(k)$,

$$F(k) = 1 - (1 - \rho)^k, \quad 1 \leq k. \quad (2)$$

This very basic model also includes the following assumptions. Containers are inspected upon arrival at the CMC. The available repair time at the CMC equals 480 minutes (an 8-hour day). Repair time per container takes a finite time within minimum and maximum values. No damage occurs at the CMC. The total number of containers in the model remains fixed, that is, no purchases nor losses. Furthermore it will be shown in the next section that the model lacks memory, that managing undamaged and damaged containers at the CMC with a first in first out (FIFO) and other container management strategies are equivalent, that containers repaired as good as new (RAN) or to the condition prior to damage (RTPC) are also equivalent, and that identifying a damaged container has a fixed probability. These assumptions capture the essential nature of the problem while keeping the model simple to provide insight.

2.2. Formulation and Notation. At the initialization of the model the first containers shipped to the CMC from the assembly plant have been away from the CMC for 5 workdays; 2 days at the supplier and 3 days at the assembly plant. In a FIFO system the undamaged containers will spend another 5 days before leaving the CMC again. Measure time t in days and let a circuit denote the 10 days it takes an undamaged container to travel a complete loop leaving and returning to the CMC. Let u count the circuits traveled by a container.

The conditional probability of a random variable X

$$\text{Prob}(X \leq u + \Delta u \mid X \geq u), \quad (3)$$

where Δu equals one circuit, expresses the probability that a container needs repair after u circuits given that it has *never been repaired*. Applying the geometric distribution in (1) to evaluate the probability in (3) yields

$$\begin{aligned} \text{Prob}(X \leq u + \Delta u \mid X \geq u) &= \frac{\text{Prob}(u \leq X \leq u + \Delta u)}{\text{Prob}(u \geq X)} \\ &= \frac{1 - (1 - \rho)^{u+1} - (1 - (1 - \rho)^u)}{(1 - \rho)^u} = \rho. \end{aligned} \quad (4)$$

Equation (4) implies that a container entering the CMC has fixed a probability ρ of requiring repair regardless of many circuits the container has traveled. Therefore this model lacks memory. Consequently a simulation of this model need not identify individual containers nor record the number of circuits they have traveled; also see [10]. Furthermore, whether the CMC uses FIFO or any other order for shipping and repairing containers becomes irrelevant. The lack of memory also implies that using RAN or RTPC for repairing a damaged container does not influence its probability of needing repair.

For sufficiently small values of ρ the daily average number of damaged containers arriving at the CMC will be less than the average number of containers that can be repaired daily. Since these values negate the need of a safety stock at the CMC, the models formulated in this section will assume ρ has a value that will produce more damaged containers each day than the average daily repair rate. The following notation will be used in our first mathematical model representing the supply chain described in the previous subsection.

$\mathbf{N}(t)$ is the number of containers not in the repair queue at the start of the t th day of production.

t is time measured in days.

ρ is the probability of a container requiring repair on arrival at the CMC.

W is the number of hours in a workday at the CMC.

A_{RT} is the average repair time per damaged container.

A_{DP} is the average number of containers used in daily production and sent to the CMC.

Represent the daily number of available containers by

$$\begin{aligned} \mathbf{N}(t) &= 10A_{DP} \\ &+ \begin{cases} \left(\frac{W}{A_{RT}} - \rho A_{DP}\right)(t-1), & \text{if } \rho A_{DP} > \frac{W}{A_{RT}}, \\ 0, & \text{if } \rho A_{DP} \leq \frac{W}{A_{RT}}. \end{cases} \end{aligned} \quad (5)$$

This first mathematical model assumes steady states in daily production, repair rates, and no delays due to transportation.

This model remains a valid continuous approximation of a discreet process as long as the assembly plant has A_{DP} containers of parts for production.

When $\rho A_{DP} > W/A_{RT}$, the number of containers available for shipment from the CMC to the supplier decreases by $\rho A_{DP} - W/A_{RT}$ each day until the CMC ships a steady state of $(1 - \rho)A_{DP} + W/A_{RT}$ containers. Since the CMC initially has $5A_{DP}$ new containers, this steady state number takes t_{CMC} days to be reached.

$$t_{CMC} = 2 + \frac{4A_{DP}}{\rho A_{DP} - W/A_{RT}}. \quad (6)$$

On the $(t_{CMC} + 1)$ th day and thereafter the supplier receives $(1 - \rho)A_{DP} + W/A_{RT}$ containers. Consequently, the number of containers at the supplier also decreases each day after the t_{CMC} th day to a steady state of $(1 - \rho)A_{DP} + W/A_{RT}$ containers available for shipping to the assembly plant. This depletion takes another t_S days.

$$t_S = 1 + \frac{A_{DP}}{\rho A_{DP} - W/A_{RT}}. \quad (7)$$

A similar analysis of the model shows that the assembly plant no longer maintains a steady average rate of using A_{DP} containers on the morning when the assembly plant has less than A_{DP} containers. Consequently the basic model ends after another t_{DP} days.

$$t_{DP} = 1 + \frac{2A_{DP}}{\rho A_{DP} - W/A_{RT}}. \quad (8)$$

Therefore the basic linear model ends after t_T days where

$$t_T = t_{CMC} + t_S + t_{DP} = 4 + \frac{7A_{DP}}{\rho A_{DP} - W/A_{RT}}. \quad (9)$$

Equations (5)–(9) provide an opportunity to plot the number of available containers at the CMC, supplier, and assembly plant. For example, suppose the manufacturing life of the product requiring shipments in containers lasts one year with 240 manufacturing days, a typical number that includes a plant shut down for plant repairs, production enhancements, and work holidays. Let $A_{DP} = 100$ containers, $\rho = 0.05$, $W = 8$ hours, and $A_{RT} = 4$ hours. The dark broken line segments in Figure 2 display the number of containers in the morning at the CMC, assembly plant, and the supplier. The gray line indicates the average number of containers used in daily production.

With the same values for A_{DP} and W , the area above the gray curve in Figure 3 captures the pairs of values for damage rates, ρ , and average repair times, A_{RT} , in (9), that produce positive values of t_T for the basic linear model. The gray curve indicates the values of ρ and A_{RT} in (9) that render the denominator equal to zero. The values of ρ and A_{RT} on the black curve produce a value of $t_T = 240$. In Figure 2 $t_T = 237(1/3)$. The arrow in Figure 3 points to the location of ρ and A_{RT} used in Figure 2. The arrow shows that a damage rate of 5% requires an average repair time of slightly less than 4 hours. Damage rates and repair times are key performance indicators [11].

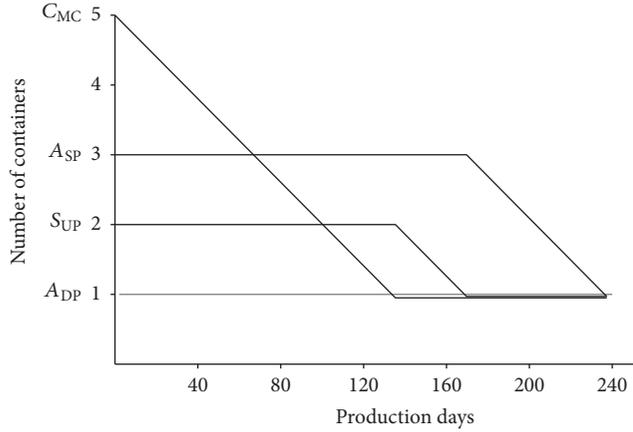


FIGURE 2: The continuous approximation of the basic mathematical model in (5). The curves C_{MC} , A_{SP} , and S_{UP} starting on the vertical axis denote the number of containers at the CMC, the assembly plant, and the supplier. A_{DP} denotes the average number of containers used in daily production.

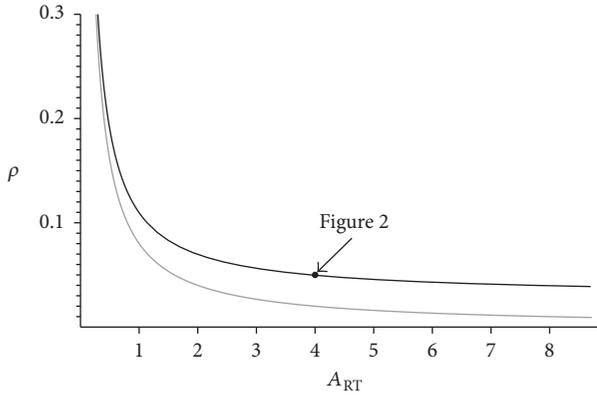


FIGURE 3: Values for ρ and A_{DP} above the gray plot produce a valid basic model in (5). On the black curve the model terminates at $t_T = 240$. The arrow points to values used in Figure 2.

Scheduled production and repair times vary. Nonetheless, the basic linear model in (5) can be modified to accommodate these fluctuations. The inequalities in (10) revise (5) to incorporate standard deviations σ_{DP} and σ_{RT} in production and repair times, respectively.

$$10A_{DP} + \left(\frac{W}{A_{RT} + \sigma_{RT}} - \rho(A_{DP} - \sigma_{DP}) \right) t \leq \mathbf{N}(t) \quad (10)$$

$$\leq 10A_{DP} + \left(\frac{W}{A_{RT} - \sigma_{RT}} - \rho(A_{DP} + \sigma_{DP}) \right) t.$$

Assume that the number of containers used for daily production varies uniformly by 5% and the repair times vary uniformly from 2 to 6 hours. Figure 4 shows the result of simulating the daily total number of available containers in the basic model and the number of containers at the CMC, the assembly plant, and the supplier. The dashed lines above and below the line indicate the total number of available containers computed from standard deviations in

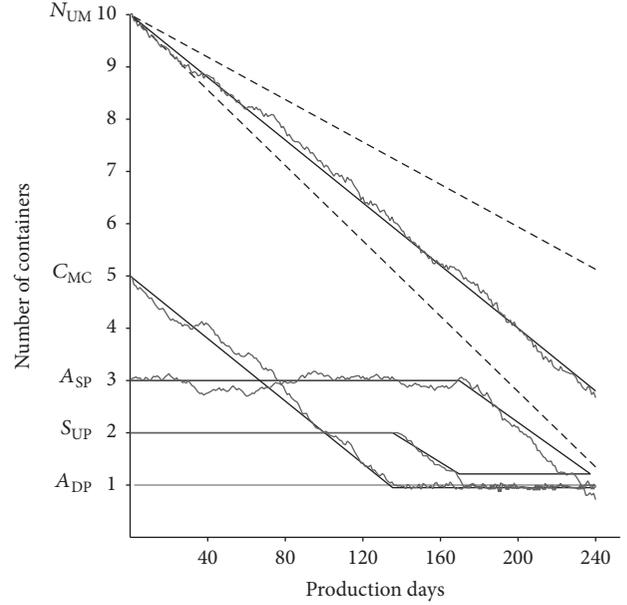


FIGURE 4: A simulation of the basic model in (5). The dashed lines indicate the total number of available containers computed with standard deviations in the probability distributions of A_{DP} and A_{RT} .

the probability distributions of A_{DP} and A_{RT} . The distances above and below the linearly decreasing total reveal the stronger influence of A_{RT} in the denominator of (5). Note that in Figure 4 the number of containers at the assembly plant at the end of each day can be less than $0.95A_{DP}$ because each day the morning shipment of containers will have arrived from the supplier.

Remarks. Overnight deliveries imply that transportation times do not appear in the basic model. To accommodate transportation times and have the same safety stocks at the three nodes in the basic model, initialize the model by adding multiples of A_{DP} containers based on transportation times, measured to the nearest average whole day, to the recipients in the respective shipments between nodes. On the other hand, depending on the transportation times, considering containers on route as rolling safety stock may not require an increase in safety stocks at the shipment recipients.

The basic model yields linear depletion rates of available containers at the three locations in the loop. With the variables, lengths of a production run, hours in a workday, a steady average daily production schedule, and a set of safety stocks, the basic model yields easily computable values for a fixed probability of damage to a container and average repair times that produce valid mathematical models. The gray plot in Figure 3 shows that the asymptotic damage rate slightly less than 3% keeps the model going to term (240 days) regardless of the average repair rate. The black plot shows the pair of probabilities and repair times which the model terminates at 240 days. The simulations of the basic model and other models in this paper use SRAND, the random number generator supplied in UNIX operating systems and suggested in [12].

The basic model does not address stolen containers coveted for their lucrative scrap steel. Nevertheless the model can accommodate lost and stolen containers next to $10A_{DP}$ in (5) by adding terms with negative values for the number of containers at supplier, the assembly plant, and the CMC. Attribute losing containers during transportation between locations to the point of departure.

3. A Length of Service Model

The punishment endured by engineered containers during shipments and in plant mishaps requires inspections and repairs. Unlike the basic model in the previous section, this sections assumes that the probability of damage requiring repair increases over time. The probabilities for requiring repair depend on the number of circuits each container has traveled since its delivery from its manufacturer or since its most recent repair. In this section containers that do not require repair upon arrival and inspection at the CMC will be sent to the supplier at the end of the day. Repaired containers will be considered new containers.

With a steady average daily production requiring A_{DP} full containers at the assembly plant, initialize the model as follows. Before the first day the CMC has shipped A_{DP} empty new containers to the supplier, the supplier has shipped A_{DP} full containers to the assembly plant, and the assembly plant has shipped A_{DP} used empty containers to the CMC. Consequently at the beginning of the first day the containers from the assembly plant arrive at the CMC after having made *one circuit* around the loop from the CMC to the supplier to the assembly plant and returned to the CMC.

Each container arriving at the CMC has a probability ρ_n of requiring repair, where n denotes that the container has completed n circuits. ρ_n , a decreasing function of n , will eventually produce more damaged containers than can be repaired each workday. Along with the containers that did not require repair upon arrival and inspection at the CMC, the CMC sends to the supplier the containers repaired during that day. If these containers do not total A_{DP} containers, the CMC compensates by adding containers from its safety stock.

Represent the daily shipments to the supplier with the following additional notation.

ρ_n is the probability that a container requires repair given that it has traveled n circuits since being new or since its repair to be new.

S_n is the number of containers sent to the supplier from the CMC on the n th day.

N_n is the number of new containers sent to the supplier on the n th day.

D_n is the number of containers deducted from the safety stock at the CMC on the n th day.

The following equations assume that the daily shipments of containers leaving the CMC remain together each day as they move from the CMC to the supplier to the assembly plant

and return to the CMC. For simplicity assume that $\rho_1 A_{DP} > W/A_{RT}$.

$$S_1 = (1 - \rho_1) A_{DP} + \frac{W}{A_{RT}} + D_1, \quad (11)$$

where

$$D_1 = \rho_1 A_{DP} - \frac{W}{A_{RT}}, \quad (12)$$

$$N_1 = \rho_1 A_{DP}.$$

The shipments to the supplier emulate (11) and (13) and until the 7th day when, at the end of the day, the CMC ships the used containers requiring no repairs that arrived on the 1st day at the CMC. On the 7th day

$$S_7 = (1 - \rho_1)(1 - \rho_2) A_{DP} + (1 - \rho_1) \left(\frac{W}{A_{RT}} + D_1 \right) + D_7, \quad (13)$$

where

$$D_7 = \rho_2 (1 - \rho_1) A_{DP} + \rho_1 \left(\frac{W}{A_{RT}} + D_1 \right) - \frac{W}{A_{RT}}, \quad (14)$$

$$N_2 = (\rho_2 (1 - \rho_1) + \rho_1^2) A_{DP}.$$

Every 6 days the composition of the containers sent to the supplier changes. In general,

$$S_n = \left(\sum_{j=0}^{\lfloor n/6 \rfloor} \left(\prod_{i=1}^{\lfloor n/6 \rfloor + 1 - j} (1 - \rho_i) \right) N_{6j-5} \right) A_{DP} + N_{\lfloor (n-1)/6 \rfloor + 1} A_{DP}, \quad (15)$$

where $\lfloor x \rfloor$ equals the largest integer less than or equal to x , and the number of used containers sent to the supplier satisfies

$$N_n = \left(\sum_{j=0}^{\lfloor n/6 \rfloor} \rho_{\lfloor n/6 \rfloor + 1 - j} \left(\prod_{i=1}^{\lfloor n/6 \rfloor + 1 - j} (1 - \rho_i) \right) N_{6j-5} \right) A_{DP} + N_{\lfloor (n-1)/6 \rfloor + 1} A_{DP}, \quad n \geq 1, \quad N_{-5} = 1. \quad (16)$$

S_n includes used containers, repaired containers, and containers taken for the safety stock. From generalizing (12) and (14) the daily number of containers depleted from the safety stock can be expressed as

$$D_n = N_{\lfloor (n-1)/6 \rfloor + 1} - \frac{W}{A_{RT}}. \quad (17)$$

For some probability distributions $\rho_n A_{DP} < W/A_{RT}$ for initial values of n . For these values of n , D_n and N_n will be zero.

As a mathematical model, (15)–(17) remain valid until the CMC no longer can send A_{DP} containers to the supplier.

In order to extend the model, the supplier can make up the shortfall of sending A_{DP} containers to the assembly plant by using containers available from its safety stock. When the safety stock at the supplier ends, the same strategic decision can be employed at the assembly plant until the extended model fails.

To compare this model to the basic model we create probabilities naturally related to the geometric distribution used in the simulation of basic model. Let $p_n = 1 - q^n$, $q = 0.995$ so that the probability of repair for a container arriving at the CMC after n circuits increases with n . The values of A_{DP} , A_{RT} , and W and the safety stocks remain the same for both models.

In Figure 5 the gray horizontal line benchmarks A_{DP} with respect to the other plots. The black plots show continuous approximations of the daily total number of available containers and the available containers at the supplier, the assembly plant, and the CMC. The initialization of this service dependent model starts on the 0th day and ends on the 227th day. The darker gray plots present the result of a simulation of this service dependent q -model.

Figures 4 and 5 show that the number of available containers at the supplier and assembly plant behaves similarly with the lengths of their horizontal portions differing in length and the curves connecting them in the service dependent model. The most noticeable difference occurs in the graphs of available containers at the CMC where their plot has a curved decrease between two linear portions. The lengths of the horizontal portions of the various plots and the life expectancy of the models depend highly on the repair times of damaged containers.

The Weibull distribution [13, 14] has earned popularity in modeling engineering reliability and failure analyses during a product's life. For this reason we examine the service dependent model with the Weibull distribution. A random variable X has a *Weibull distribution* with shape and scale parameters $\alpha > 0$ and $\beta > 0$ when the probability distribution function $f(t; \alpha, \beta)$ of X can be expressed as

$$f(t; \alpha, \beta) = \begin{cases} \frac{\alpha}{\beta} \left(\frac{t}{\beta}\right)^{\alpha-1} e^{-(t/\beta)^\alpha}, & t \geq 0 \\ 0, & t \leq 0. \end{cases} \quad (18)$$

Integrating $f(t; \alpha, \beta)$ yields its cumulative distribution function $F(t; \alpha, \beta)$,

$$F(t; \alpha, \beta) = \begin{cases} 1 - e^{-(t/\beta)^\alpha}, & t \geq 0 \\ 0, & t \leq 0. \end{cases} \quad (19)$$

Applying the cumulative distribution $F(t; \alpha, \beta)$ in (19) to evaluate the conditional probability in (4) yields

$$\begin{aligned} \text{Prob}(X \leq u + \Delta t \mid X \geq u) &= \frac{\text{Prob}(u \leq X \leq u + \Delta t)}{\text{Prob}(u \leq X)} \\ &= \frac{(1 - e^{-(u+\Delta t)/\beta^\alpha}) - (1 - e^{-u/\beta^\alpha})}{1 - (1 - e^{-u/\beta^\alpha})} \\ &= 1 - e^{-((u+\Delta t)/\beta)^\alpha + (u/\beta)^\alpha}. \end{aligned} \quad (20)$$

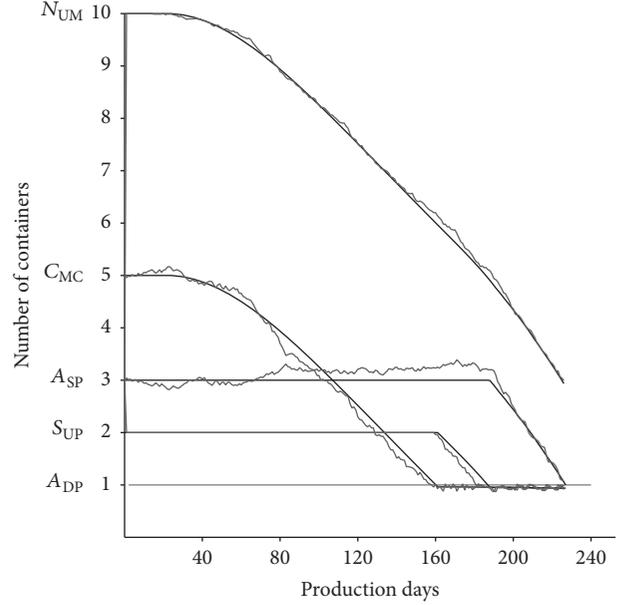


FIGURE 5: The continuous approximation and a simulation of the service dependent model in (11)–(17) for $p_n = 1 - q^n$ and $q = 0.995$. The curves C_{MC} , A_{SP} , and S_{UP} starting on the vertical axis denote the number of containers at the CMC, the assembly plant, and the supplier. A_{DP} denotes the average number of containers used in daily production.

This Weibull service dependent model applies the probability in (20) to every container arriving at the CMC. Note that Weibull models normally set repairs to “condition prior to failure” by subtracting one from the number of circuits traveled by a repaired container. The RAN condition in this paper resets the number of circuits to zero after repairing a damaged container.

The black plots in Figure 6 evaluate the continuous approximations of service dependent mathematical model with the Weibull distribution for $\alpha = 10.0$ and $\beta = 3.5$ recommended in [15]. An interval of $[0, 7]$ for the Weibull cumulative distribution function was divided into 40 subintervals to accommodate the 6-day circuit that containers need to return to the CMC. The plots maintain the general shape of the plots in Figures 4 and 5 except for the more precipitous decreases. The service dependent mathematical model using the Weibull distribution starts on the 0th day and ends on the 223th day. The lighter gray horizontal line benchmarks A_{DP} with respect to the other plots. The darker gray plots present the result of a simulation of this Weibull service dependent model.

4. Remarks

Other important factors also influence the availability of engineered containers. For example, there may be more than one supplier, transportation may take more than overnight, and, most importantly, there may be different probability distributions in repair time and scheduled production. These factors can be incorporated into the basic steady state model

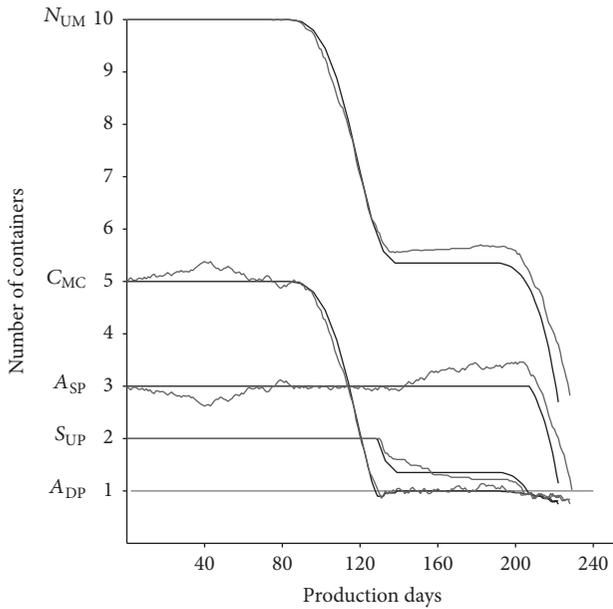


FIGURE 6: The continuous approximation and a simulation of the service dependent model in (11)–(17) with the Weibull distribution for $\alpha = 10.0$ and $\beta = 3.5$. The curves C_{MC} , A_{SP} , and S_{UP} starting on the vertical axis denote the number of containers at the CMC, the assembly plant, and the supplier. A_{DP} denotes the average number of containers used in daily production.

in a number of ways. The following paragraph provides an example.

By averaging the contributions of the suppliers to the probabilities of their containers requiring repairs, the basic model can still use one value for ρ while accommodating multiple suppliers. Suppose k suppliers send full containers to the assembly plant and the i th supplier sends an α_i th fraction of the total number of containers. If a container from the i th supplier has a ρ_i probability of needing repair when observed at its arrival at the CMC then let

$$\rho = \sum_{i=1}^k \alpha_i \rho_i, \quad 0 < \alpha_i, \quad 0 < \rho_i < 1, \quad \sum_{i=1}^k \alpha_i = 1. \quad (21)$$

Equation (21) which lumps multiple suppliers as one supplier suggests adding safety stocks based on the same percentages multiplied by transportation days to morning arrivals.

5. Summary

This paper explored the availability of highly engineered containers for shipping parts from suppliers to assembly plants by taking into account that damaged containers require repair and therefore stay temporarily out of service.

The paper first developed a basic model for a supply chain consisting of a supplier, an assembly plant, and a container maintenance center (CMC) used for inspection and repair of damaged containers. This basic model assumed steady average daily production and repair rates and a Bernoulli probability distribution for requiring repair. It also assumed

next day deliveries of containers between each facility. The model provided feasible pairs of values for the probability of repair and average repair time. Plotting the continuous model illustrated the number of containers at each facility as a function of production days, given the average daily production, probability of repair, and average repair time. The model offered straight forward and easily calculated parameters. The basic model also accommodated variability in scheduled production and repair times through their standard deviations. An illustrative simulation used uniform distributions for the production and repair parameters. This basic model exhibited linear behaviors.

Another model introduced the probability of a container requiring repair as an increasing function of circuits a container has traveled. The generality of this model enabled alternative probability distributions of circuit based damage and repair. Examples with a geometric based and a Weibull based probability distribution featured linear and nonlinear characteristics. In particular, a Weibull distribution produced more precipitous decreases in the availability of containers at the three locations in the supply chain.

The original model and its extensions which allowed variations in production and damage rates provided analytical tools to observe how the availability of engineered containers can change over time at the supplier, assembly plant, and CMC. These models depended on easily scalable repair and production rates and gave insight into managerial decisions regarding the fleet size of shipping containers needed in a supply chain.

These models can also show where to optimize cash flow. A minimal number of containers plus a small safety stock can reduce the initial investment. Only as the number of damaged containers under repair grows should additional containers be purchased. Thus the models allow making important decisions with a few basic parameters.

Competing Interests

The authors declare that they have no competing interests.

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