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The impact of single product and multi-product batches on a printing operation.

Dustin Allen Fackler 1980-
University of Louisville

THE IMPACT OF SINGLE PRODUCT AND MULTI-PRODUCT BATCHES ON A PRINTING OPERATION

By

Dustin Fackler
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THE IMPACT OF SINGLE PRODUCT AND MULTI-PRODUCT BATCHES ON A PRINTING OPERATION

Submitted by:___________________________________
Dustin A. Fackler

A Thesis Approved On

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(Date)

by the Following Reading and Examination Committee:

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Dr. Gail W. Depuy, Thesis Co-Director

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Dr. Gerald W. Evans, Thesis Co-Director

____
Dr. Eric Rouchka

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ABSTRACT

This research will look at a printing operation that prints labels for paint cans. This particular printing operation is a multi-product, single-machine system with stochastic demands that uses a printing press to print the labels on large sheets that may contain one label type (dedicated sheets) or many different label types (mixed sheets). The objective of this thesis is to determine whether to set up the press to print mixed sheets or dedicated sheets in order to minimize the total cost of the current system given three scenarios: one where all label types have approximately the same monthly demand, one where 20% of the label types have very large demand and the remaining 80% have small demand, and one where half of the label types have moderately high demand and the other half have moderately low demand. Three simulation models, one for each scenario, are developed to test this objective and to see which scenarios prefer mixed sheets and which prefer dedicated sheets. The decision logic to choose the sheet to print is based on summing the differences of the inventory levels and the reorder points for each label type on the sheet, and choosing the sheet with the minimum value of this equation. The results of the simulations show that, according to this decision logic, all scenarios choose dedicated to print dedicated sheets.

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NOMENCLATURE

i	= Sheet number
j	= The j^{th} SKU on sheet i
e	= SKU
s_e	= Reorder point for SKU e
S_e	= Base inventory level for SKU e
D_e	= Average demand for SKU e
L_e	= Lead time for SKU e
SS_e	= Safety stock for SKU e
k	= Safety factor (k = 2 for model)
σ_e	= Standard deviation of the demand D for SKU e
TC	= Total cost of system
K_e	= Fixed setup cost for SKU e
H_e	= Inventory holding cost for SKU e
P_e	= Production cost for SKU e
Q_e	= Economic order quantity for SKU e
PQ	= Production order quantity
PR	= Production rate
ST	= Setup time
IL_e	= Current inventory level for SKU e
TD_i	= The total debt for sheet i

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1. INTRODUCTION

1.1. Problem Definition

This research analyzes a printing operation that is a multi-product, single-machine system with stochastic demands that uses a printing press to print labels for paint cans on large sheets. These sheets may contain one label type or many different label types. There is a large setup cost and small incremental production costs (in this case the cost to print one sheet) associated with running the printing press, both of which contribute to the total cost of the system. The objective is to determine how to set up the production and inventory system to simultaneously meet the demand for the products and minimize this total cost of the system, which includes the fixed cost of setting up the press, the variable cost of printing each sheet, and the cost of holding each label in inventory. Typically in industry machines are restricted to processing only one part type in each batch. However, the printing press can be set up to produce many different part types in a batch. As a result of this unique ability, setting up the press to print many different label types (mixed sheets) or one specific label type (dedicated sheets) could be advantageous to a company depending on the demand for their labels.

1.2. Purpose of Research

Since no closed-form analytic models exist for this problem, the purpose of this research is to develop simulation models using Arena Version 10 (Rockwell Software, 2005) to determine the preferences of mixed sheets and dedicated sheets under three different scenarios, each with their own distinct demand profiles:

- Scenario 1: All label types have approximately the same monthly demand
- Scenario 2: 20% of the label types have high demand and the remaining 80% have low demand
- Scenario 3: 25 label types have moderately high demand and 25 label types have moderately low demand

In addition, two decision rules are used to test the sheet selection. The first decision rule is based solely on inventory levels, while the second decision rule is based on setup cost per label produced and number of labels close to a reorder point *s*.

1.3. Organization of Thesis

Chapter 2 of the thesis will review previous research on stochastic inventory control, batch production, and simulation. A detailed description of the process follows in Chapter 3, and the three simulation models and the two decision rules are outlined in Chapter 4. Chapter 5 provides the results of the simulations and a discussion of the three models. The research conclusions are summarized in Chapter 6.

2. REVIEW OF LITERATURE

The problem of scheduling multiple products on a single machine with large setup times is well reviewed in the literature. The initial research into this issue, which operated under the assumptions that the demand was constant and the demand and production rates are known, evolved into the Economic Lot Scheduling Problem (ELSP). Elmaghraby (1978) provides a thorough review of the ELSP. More recently, heuristics have been developed for the ELSP case with variable demand. Several examples of these heuristics can be found in the research done by Gascon and Leachman (1988) and Leachman et al. (1988). The constant demand and variable demand cases of the ELSP works for the cases where the demand is deterministic, but there are many situations where the demand is not known.

The case where the demand is unknown and based on probability distributions is known as the Stochastic Lot Scheduling Problem (SLSP). Sox et al. (1999) describe the SLSP as a problem where multiple products, each with a random demand, are scheduled on a single machine with limited production capacity and significant changeovers between products. Vergin and Lee (1978) were the first to address the SLSP. They performed a series of tests that investigated four scheduling models for a problem with multiple products, a single machine, and stochastic demand: three based on production lot sizes and cyclic demand (one of which produced enough inventory to account for cyclic fluctuations in demand for all products) and one model they proposed that is designed to produce an item until it met any one of three conditions:

1. The inventory level of item *i* being produced rises to a proportion of the total inventory level.
2. The inventory level of item *i* rises to a maximum inventory level *S* pre-specified for that item.
3. The inventory level of some other item *j* falls below its reorder point *s*.

When any of these conditions are met, the machine is changed over to produce the item *j* with the lowest ratio of inventory on hand to usage unless that item is also at its pre-specified maximum level. In this case, a down period is taken. The results of Vergin and Lee's research showed that the two models they analyzed that were based on production lot sizes and cyclic schedules were ineffective with stochastic demand. The model that allowed for cyclic demand fluctuations demonstrated severe flaws, and the model proposed by the authors showed significant improvements over all of the models.

More recent research on the Stochastic Lot Scheduling Problem is reviewed in Zipkin (1986), Gallego (1990), and Sox et al (1999). Zipkin (1986) proposed an approach that combined standard inventory and queueing submodels into classical optimization models in a multi-product, single-machine batch production system with stochastic demand. His models optimize the approximate operating cost of the facility over simple control policies. Gallego (1990) developed a scheduling tool that calculates optimal or near-optimal cyclic inventory review schedules and used this tool to analyze its behavior after a disruption perturbs the inventories and to minimize long term average costs of following the review schedule with the recovery policy. The results of his research showed that optimal safety stocks are unique to each product and in the long run the proportion of time an item is in stock is equal to the ratio of backorder to holding cost plus backorder cost. Sox et al (1999) performed a review of the current literature on the Stochastic Lot Scheduling Problem.

Recently, simulation software has been used as a test bed for SLSP's due to its ability to simulate production and inventory control systems together in the context of the physical manufacturing environment. This ability enhances the understanding of the behavior of a particular control system and aids companies in the selection of a particular control system for the manufacturing system under study due to the fast and accurate feedback generated by the simulation model. It is stated though that in order for simulations to be of use, the models must be valid descriptors of the process (Olhager and Persson, 2006). Simulation studies on the Stochastic Lot Scheduling Problem are performed by Kelle and Peak (1996), Olhager and Persson (2006), and Narasimha and Battacharya (2007).

Kelle and Peak (1996) used simulations to compare two production/inventory systems in a chemical production operation: a push system and a pull system. They state that a switch to an adaptive inventory/production control system is appropriate when no further setup reduction costs are possible using a fixed production schedule. A pull system with adaptive production scheduling based on reorder levels and order-up-to levels calculated from the optimal target cycle lengths and safety stocks was proposed.

In their discussion of production and inventory control systems, Olhager and Persson (2006) specified that systems based on reorder levels and order-up-to levels, also known as reorder point systems, are used in situations with a rate based demand, fixed order quantities, and variable times between orders. One common approach in scheduling production on this type of system is to use a model with a maximum stock level S (order-up-to level) and a minimum stock level s (reorder point), also known as an (s, S) inventory control system or reorder point system. Whenever the inventory level of a certain product drops below the reorder point s, a production order is placed for enough of the product to bring the inventory level back up to the maximum level S.

Narasimha and Battacharya (2007) studied a two level supply chain containing a retailer and a manufacturer where the manufacturer produces N products on a single machine for the retailer, and the demand for the retailer is stochastic. The simulation model developed was used to test cyclic service policies (policies where products are produced in a cyclic order, switching from one product to another) on different plant utilization values. Their experiments showed that waiting time estimations for each product are not valid when the machine has a large setup time, but the model is effective in estimating the upper limit on the quantity produced per cycle.

Despite the wealth of research on the stochastic lot scheduling problem, there is a void in the literature regarding scheduling many items for production at the same time on one machine. The research presented in this thesis aims to look into this problem and help fill that gap.

3. DESCRIPTION OF SYSTEM

It should be first noted that the system presented in this thesis, as well as the data used, is not real but is representative of the actual system. The objective is to determine whether to set up the printing press to print only one type of label (SKU) at a time (dedicated sheets) or to print many different SKUs at a time on one sheet (mixed sheets). Once the sheet for production is picked, the press undergoes a 3.5 hour setup and the sheets are printed at a constant rate of five seconds per sheet. After printing, the sheets are separated into individual SKUs and put into inventory. A flowchart of the process can be seen in Figure 1 below.

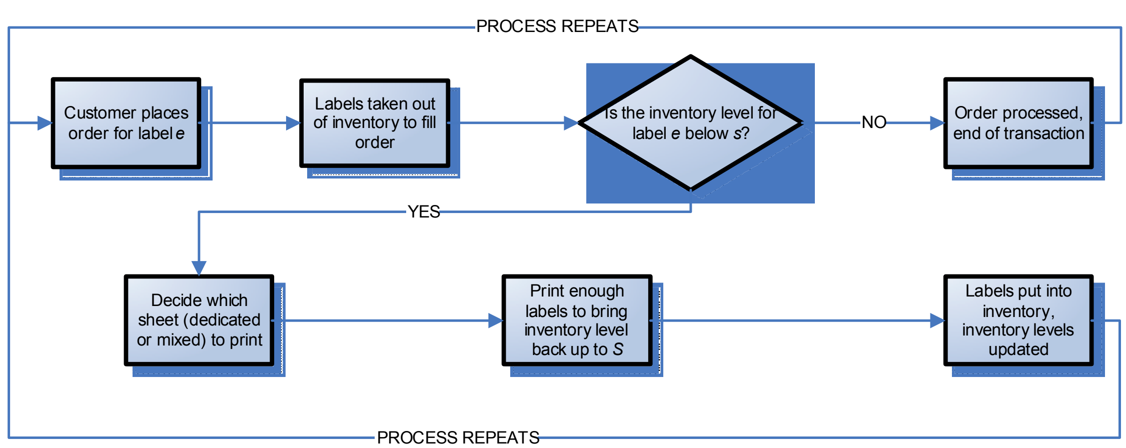

FIGURE 1 – Process Flowchart

Customer orders arrive randomly for one of 50 different SKUs, with the time between orders (interarrival time) for each SKU being exponentially distributed with means of 1, 1.5, 2, 3, or 6. Each SKU is randomly assigned one of these six interarrival times. It is assumed that customers request only one SKU at a time and that this is a round-the-clock operation. The demand for each SKU is normally distributed and their order quantities under each scenario can be found in the Demand Data section of Appendices II, III, and IV. Orders are taken out of on-hand inventory, but if the on-hand inventory is less than the customer's demand the customer gets whatever is left in inventory and the rest is backordered. The customer will get the remainder of their order when the inventory is sufficiently replenished. All customers whose orders are placed on backorder are assumed to be infinitely patient and never cancel their orders. The system does not keep track of which labels arriving in the future will satisfy which backlogged orders.

The inventory control system in use for this model runs according an (s, S) policy. Whenever the inventory level for a particular SKU drops below its predetermined reorder point s, the system sends an order to produce enough of the SKU to bring its inventory level up to its maximum inventory level S. Microsoft Excel 2003 (Microsoft® Corporation, 2003) was used to determine the values for the reorder point s and the maximum inventory level S. For each SKU, orders and their quantities were generated for a four year period using the RANDBETWEEN function. The mean and standard deviations for each SKU were calculated using this data and were then plugged into formulas set up to determine each SKU's respective s and S values.

The reorder point s for a particular SKU e can be calculated many different ways. In this thesis, the following equation was used:

$$s_e = D_e(L_e) + SS_e \tag{1}$$

The variable D is the total yearly demand for SKU e, and is multiplied by the lead time L for SKU e to get the lead time demand. A function of the standard deviation of the yearly demand σ_e and a safety factor k (set to two in this thesis), the safety stock SS for SKU e is needed as a buffer to aid in preventing stockouts. The following equation calculates the safety stock:

$$SS_e = k\sigma_e \tag{2}$$

The base stock level S is commonly calculated according to the EOQ model (Olhager and Persson 2006). The EOQ model seeks to find the order quantity that minimizes the total cost of the system, which sums the setup cost (K), inventory holding cost (H), and production cost (P) for all SKUs e.

$$TC = \sum_e K_e + H_e + P_e \tag{3}$$

The value of the economic order quantity Q for each SKU e can be calculated with the following equation, where D is the demand for the item, K is the setup cost, and H is the inventory holding cost:

$$Q_e = \sqrt{\frac{2K_e D_e}{H_e}} \tag{4}$$

The two costs used in Equation 4, the fixed setup cost and the inventory holding cost, were set to \$150.00 and \$0.0221 respectively. It is assumed that there are no seasonal fluctuations in demand for any SKU and the setup costs and inventory holding costs are the same for each SKU.

The value for the maximum inventory level S is then determined by adding the value for Q_j to the reorder point s:

$$S_e = s_e + Q_e \tag{5}$$

The lead times for Equation 1 were estimated to be the setup time (3.5 hours for all SKUs) and the time to print the EOQ for each SKU e (a production rate PR of five seconds per sheet multiplied by the EOQ for each SKU):

$$L_e = ST + PR \times Q_e \tag{6}$$

Any waiting times, transportation times, and inspection times were assumed to be minimal and consequently were not included. The values for s and S for each SKU can be found in Appendices II, III, and IV.

After an order is sent to print a particular SKU, a decision has to be made as to what specific sheet needs to be printed since each SKU can be found on many different sheets. The system must choose one sheet from among 100 available, all with eight labels per sheet. Fifty of these sheets are dedicated to one specific SKU (one dedicated sheet per SKU) and the other 50 mixed sheets (assigned in a completely random fashion) which have anywhere from two to eight different SKUs per sheet. A list of each sheet and the SKUs assigned to it can be found in Appendix I.

Two decision rules are used to determine which sheet is to be printed. Decision rule one is based on the following logic. For every sheet i containing a particular SKU that is slated for printing, the respective total debts TD for those sheets are calculated by summing the difference between the current inventory level IL and the reorder point s for each SKU e on the sheet (with sheet i containing SKUs e). The sheet containing the SKU in need that has the best (lowest) total debt value is then selected for production since this sheet has the SKUs that are the closest to their respective reorder points. Equation 7 illustrates the equation used to calculate the total debt for each sheet i:

$$Total\ Debt_i = \sum_{e} IL_e - s_e \qquad \forall i \mid SKU \subseteq i \quad (7)$$

After the sheet with the best total debt value is chosen, the production order quantity PQ is determined using Equation 8 and the S and IL values for the SKU e

originally in need. Equation 8 is used so that any backorders that may occur are accounted for and the production quantity is adjusted accordingly.

$$PQ = S_e - IL_e \tag{8}$$

Decision rule two runs off of the following logic. For each sheet that contains the needed SKU, the following equation is calculated:

$$Z = \alpha_1 F - \alpha_2 G \tag{9}$$

F is the setup cost per SKU type on the sheet and is calculated as follows:

$$F = \frac{Sheet\ Setup\ Cost}{Number\ of\ SKUs\ per\ Sheet} \tag{10}$$

G is the number of SKU types on the sheet that is within X% of its s value and will be within Y% of its S value after printing, and α_1 α_2 are constants whose values are between zero and one. Arena's (Rockewll Software, 2005) model optimizer OptQuest (OptTek Systems, 2005) is used to find the optimal values for X, Y, α_1, and α_2. The sheet that has the lowest Z value is chosen for printing.

The order then moves to a first come first serve queue for its turn to print. As stated above, the printer undergoes a 3.5 hour setup time in preparation for production and prints at a rate of five seconds per sheet. It costs the system $0.03 to print one sheet.

After the sheet is printed it is separated into individual labels and sent immediately to inventory to await a customer order.

4. SIMULATION LOGIC

Arena Version 10 (Rockwell Software, 2005) is used to develop the simulation model of this system with the same logic and same run time (a period of one year, 364 days) for all three scenarios to let inventories cycle through several times. Only the order quantity and interarrival time distributions are changed between scenarios. In order to better organize it, the model is divided into four submodels: Sheet and Inventory Data, Customer Orders, Decision Logic, and Stock Replenishment. The logic contained within each submodel will be outlined in detail. The only changes between decision rule one and decision rule two are to the Decision Logic Submodel.

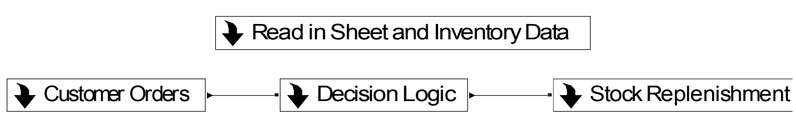

FIGURE 2 – The Submodels

4.1. Decision Rule One

4.1.1 Sheet and Inventory Data Submodel

All data regarding the sheets, initial inventories, *s* and *S* values, and the costs associated with operating the system are read into Arena at the start of the simulation via Excel spreadsheets(Microsoft® Corporation, 2003). The Sheet Data file found in

Appendix I shows each sheet *i*, the SKUs on each sheet, and number of units of each SKU on sheet *i* as read into Arena. All setup costs and printing costs are read in from this spreadsheet as well. The Inventory Data files found in the Inventory Data section of Appendices II, III, and IV show the initial inventory level, *s* and *S* value, the inventory holding cost ($/unit/year), and waiting to print inventory as read into Arena. The waiting to print inventory is defined as the quantity of a particular SKU that is waiting to be printed, or the work in process. The Sheet Data and Inventory Data files each have their own respective logic, with the sheet data logic being on the top in Figure 3. Because this logic is only executed during the startup of the simulation, it was not connected to the other submodels.

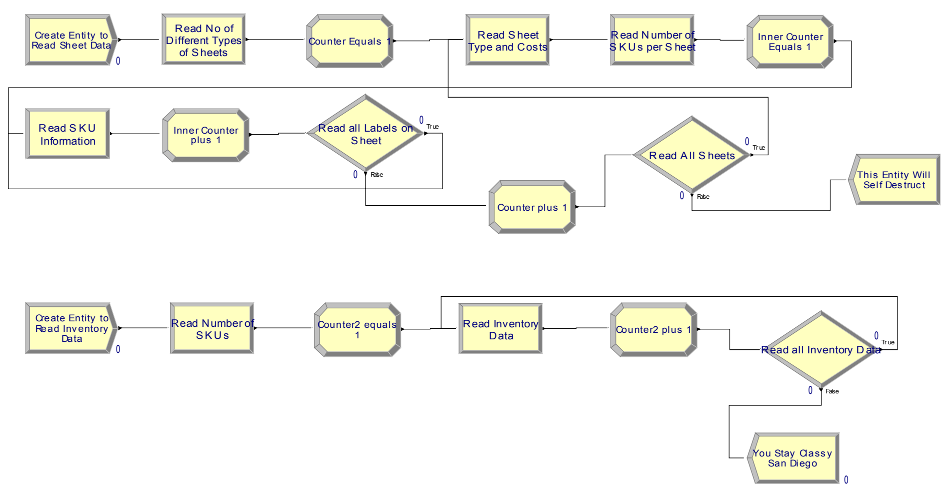

FIGURE 3 – The Sheet and Inventory Data Submodel

4.1.1.1 Sheet Data Logic

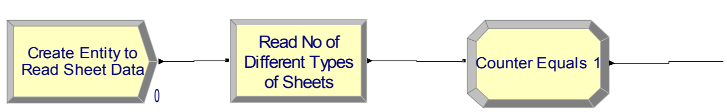

FIGURE 4 – Preliminary Sheet Data Steps

The sheet data logic begins with the modules shown in Figure 4. One entity is created at time zero with the max arrivals set to one so the data is only read once. From here the entity passes through the Read/Write module “Read No of Different Types of Sheets” which reads the variable *No of Different Types of Sheets* (which saves the number of different types of sheets as 100). Each time the entity passes through a Read/Write module, Arena reads the next successive row in Excel. The variable *Counter* (which sets an internal counter to one) is then set to one in the following Assign module. In this submodel, *Counter* is used to represent a particular sheet.

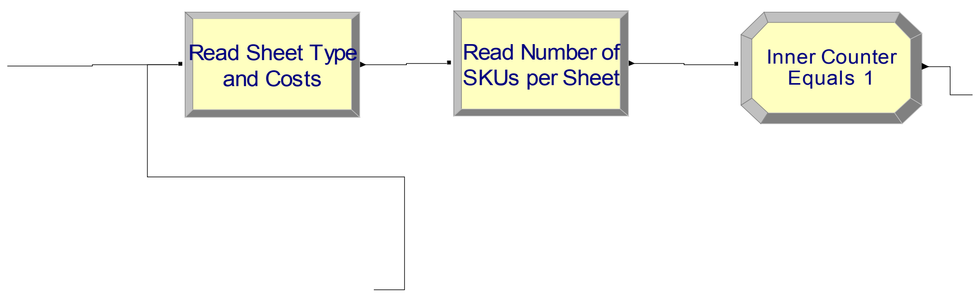

FIGURE 5 – Initial Sheet Information

Next the initial sheet information is read in the modules shown in Figure 4. The entity passes through the Read/Write modules “Read Sheet Type and Costs” and “Read Number of SKUs per Sheet” that define the variable *Sheet Type* and the one-dimensional array variables *Sheet Setup Cost(Counter)*, *Sheet Printing Cost(Counter)*, and *Number of SKUs per Sheet(Counter)*. One-dimensional array variables use a one dimensional array (*i*) to reference specific values for the variable. For example, the value of the variable

Number of SKUs per Sheet(Counter) is used to specify the number of SKUs assigned to sheet *i*. If *Counter* is set to 95, Arena will reference the 95th row of the *Number of SKUs per Sheet* array and identify the value for the number of SKUs on sheet 95 (*Number of SKUs per Sheet(95)*) as three since there are three SKUs on sheet 95. The variable *Inner Counter*, which in this submodel is used to represent the j^{th} SKU on sheet *i* is then set to one when the entity reaches the Assign module "Inner Counter equals 1".

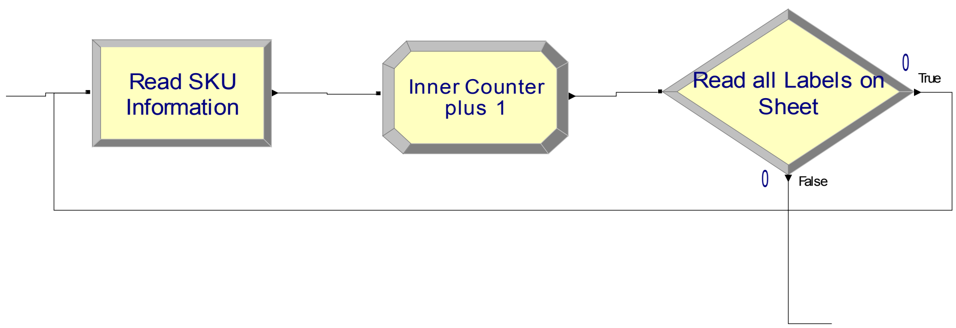

FIGURE 6 – Reading Main Sheet Information

After the initial sheet information is read into the simulation, the entity passes through the "Read SKU Information" module depicted in Figure 6 where the two-dimensional array variables *SKU(Counter, Inner Counter)* and *No of Units per SKU(Counter, Inner Counter)* are read. Similar to one-dimensional array variables, two dimensional array variables use a two-dimensional array (*i*, *j*) –in this simulation *i* represents the sheet and *j* represents the j^{th} SKU on sheet *i*- to reference specific values of the variable. For example, when *Counter* is equal to 54 and *Inner Counter* is equal to three, Arena will save the value for the third SKU on sheet 54 (*SKU(54, 3)*) as 10 and the number of units per SKU (*No of Units per SKU(54, 3)*) as two. After this information is read, the entity moves on and one is added to the value of *Inner Counter*. The *Inner Counter* is then compared to the value of the variable *Number of SKUs per Sheet(Counter)* in the Decide module "Read All Labels on Sheet"; if the value of *Inner Counter* is less than that of *Number of SKUs per Sheet(Counter)*, meaning the simulation hasn't read all of the SKUs on sheet *i*, the entity gets cycled back to read the next values for *SKU(Counter, Inne rCounter)* and *No of Units per SKU(Counter, Inner Counter)* on that sheet. This process continues until all SKUs have been read on that sheet.

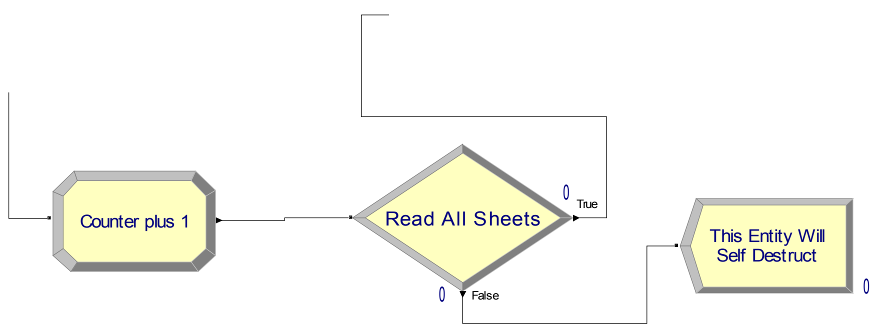

FIGURE 7 – Reading all Sheets

Once all of the SKUs on a particular sheet are read, the entity moves on as seen in Figure 7 and one is added to the value of *Counter* to represent the next sheet. In the "Read All Sheets" Decision module, if the value for *Counter* is less than or equal to the variable *Number of Different Types of Sheets* (which is 100) -meaning not all of the sheets have been read- the entity is cycled back up to the modules in Figure 4 where the process begins again. It should be noted that each time the entity is cycled back and goes through the modules in Figure 4, the value for *Inne rCounter* is reset to one in order to correctly array the variables. The entity continues to cycle through until all sheets have been read, in which case the entity is disposed.

4.1.1.2. Inventory Data Logic

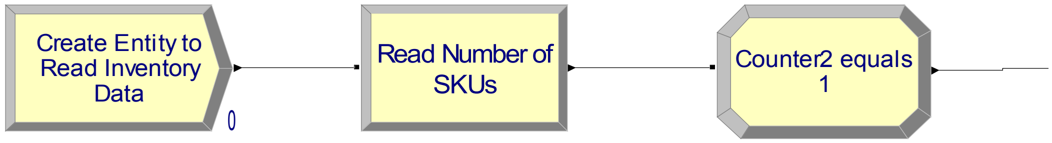

FIGURE 8 – Preliminary Inventory Data Steps

As shown in Figure 7, the inventory data logic begins the same way as the sheet data logic with a Create module that creates one entity at time zero with the max arrivals set to one. The entity is sent to the "Read Number of SKUs" module where the variables *Number of SKUs* (50 in this case) and *Counter2* are then read, with *Counter2* in the Inventory Data logic representing a particular SKU.

The inventory data is then read into the model via the modules seen in Figure 9. This section of the logic sets the values for the one-dimensional array variables *Inventory Level(Counter2)*, *Big S(Counter2)*, *Little s(Counter2)*, *Unit Holding Cost(Counter2)*, and *Waiting to Print(Counter2)* for each SKU via the "Read Inventory Data" module. After this information is read by the entity, it is sent on and one is added to *Counter2*. The

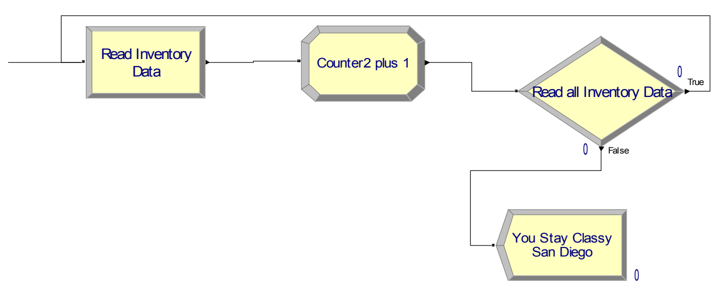

FIGURE 9 – Reading Inventory Data

resulting value is compared to the variable *Number of SKUs* in the “Read all Inventory Data” module. If *Counter2* is less than 50, the entity is cycled back around to read the data for the rest of the SKUs. If the opposite is true and all sheets have been read, the entity gets disposed. Once the sheet data and inventory data logic are read into the model, the simulation begins with orders entering the system.

4.1.2. Customer Orders Submodel

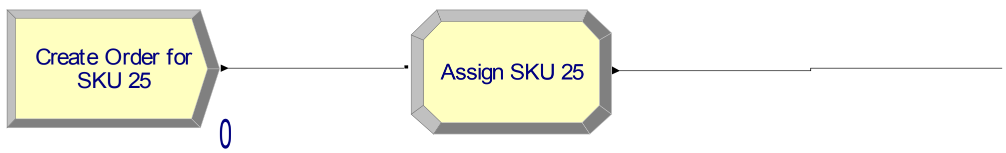

FIGURE 10 – The Create Module/Assign Module Pair for SKU 25. One Pair is Used for Each SKU

The system begins in the Customer Orders Submodel with one Create module and one Assign module per SKU, an example of which can be seen in Figure 10. Entities are created as orders (with one entity per arrival) using exponentially distributed interarrival times. Orders are then assigned two attributes: *Ordered SKU* (the SKU that was ordered) *Demand* (the quantity that was ordered), with *Demand* being generated according to triangular distributions. The attribute *Ordered SKU* is used to dimension the one and two-dimensional variables in this submodel. Both interarrival time and order quantity distributions are specific to each SKU and their values for each SKU can be found in Appendix V. The triangular distribution was used for the order quantities instead of the normal distribution because it is a good approximation of the normal distribution and it eliminates the possibility of the model generating a negative order quantity.

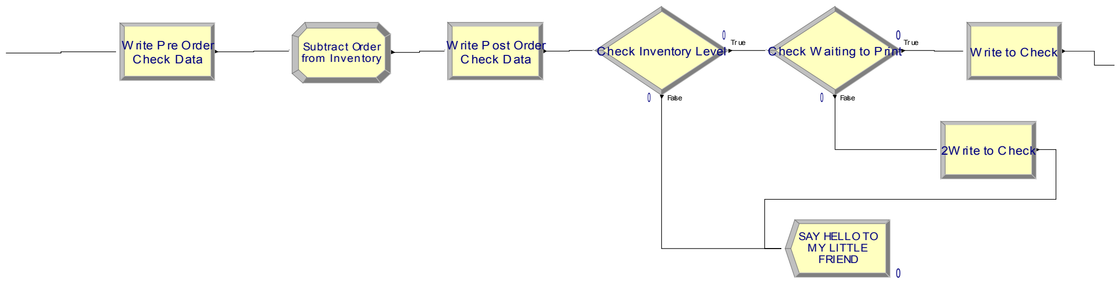

FIGURE 11 – The Order Processing Portion of the Customer Orders Submodel

The following steps are shown in Figure 11. After the order is generated and assigned a SKU and quantity, the entity is sent to the "Subtract Order From Inventory" module where the order quantity is subtracted from the inventory level for the ordered SKU to update its inventory level:

$$\textit{Inventory Level(Ordered SKU)} = \textit{Inventory Level(Ordered SKU)} - \textit{Demand} \qquad (11)$$

The entity then moves on to the "Check Inventory Level" module where *Inventory Level(Ordered SKU)* is compared to *Little s(Ordered SKU)*. If *Inventory Level(Ordered SKU)* is greater than *Little s(Ordered SKU)*, the entity is disposed, but if the opposite is true the entity gets sent to the Decide module "Check Waiting to Print". This decision is used to ensure that another order isn't sent if there is already an order waiting to be printed that will bring the inventory level for the ordered SKU above its *s* value. If the variable *Waiting to Print(Ordered SKU)* is less than or equal to the ordered

SKU's *s* value minus the minimum of its negative inventory level and 0, the entity is sent to the decision logic module in preparation for printing.

$$\textit{Waiting to Print(Ordered SKU)} \leq \textit{Little s(Ordered SKU)} - \textit{Min[Inventory Level(Ordered SKU), 0]} \tag{12}$$

The minimum of the inventory level and 0 is used to account for any negative inventory so all backorders are filled. If *Waiting to Print(Ordered SKU)* is greater than this value, the entity is disposed.

<u>4.1.3. Decision Logic Submodel</u>

The next step for the entity is the Decision Logic submodel depicted in Figure 12. This submodel determines exactly what sheet to print and how many of it is needed. When an entity first enters the Decision Logic submodel, the attribute *Best Total Debt* is defined and set to 99999 so that the model can compare the best total debt for each sheet. The value 99999 is used to initialize this variable to ensure that a sheet is chosen. Variables *Counter3* and *Inner Counter3* are also defined and set to one with *Counter3* representing a sheet i and *Inner Counter3* representing the j^{th} SKU on sheet i.

After both counters are set, the entity searches all sheets to find one that contains the ordered SKU (seen in Figure 13). This process begins with the "Search for SKU on Sheets" Decision module that is used to see if the value of *SKU(Counter3, Inner Counter3)* is equal to the value of the variable *Ordered SKU* that was assigned in the Customer Orders module. If *SKU(Counter3, Inner Counter3)* is not equal to *Ordered SKU*, the entity is sent to the Decision Module "2Read All SKUs on Sheet" to make sure

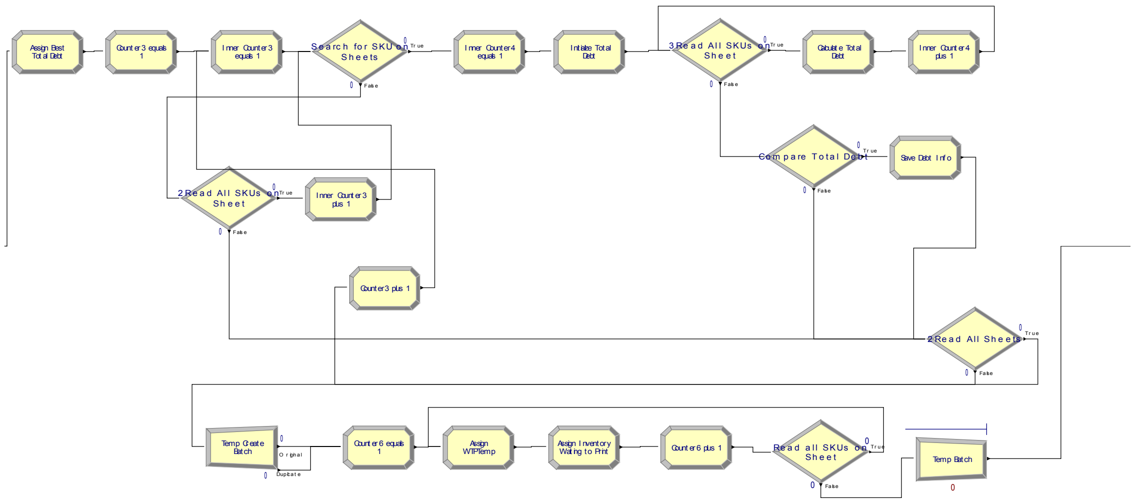

FIGURE 12 – The Decision Logic Submodel for Decision Rule One

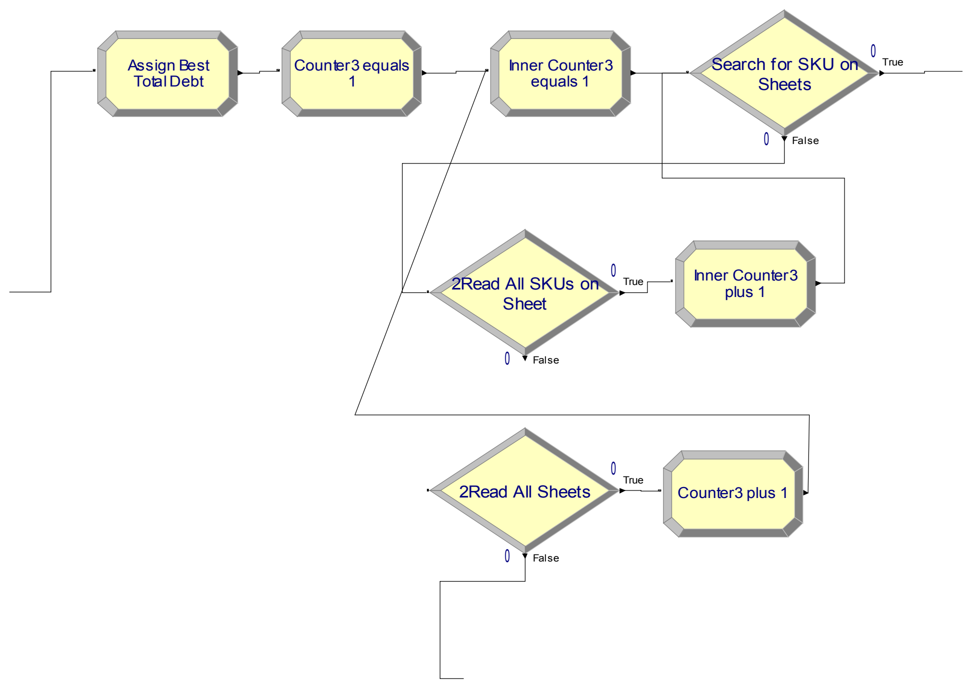

FIGURE 13 – Finding a Sheet Containing the Needed SKU

that all SKUs on sheet *i* are checked; if *Inner Counter3* is less than the value of *Number of SKUs per Sheet(Counter3)*, the entity boogies along to add one to *Inner Counter3* and is then sent back to the "Search for SKU on Sheets" module to check the new value of *SKU(Counter3, InnerCounter3)*. When all SKUs on sheet *i* are read and *Inner Counter3* is equal to *Number of SKUs per Sheet(Counter3)*, the entity moseys on down to the "2Read All Sheets" Decide module to make sure all sheets are read. In this module, if *Counter3* is less than the variable *No of Different Types of Sheets*, one is added to *Counter3* and the entity is cycled back to reset *Inner Counter3* at one and the next sheet is read.

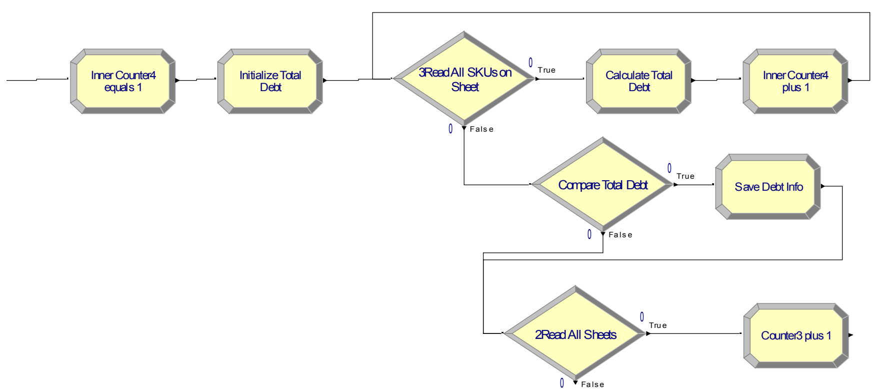

FIGURE 14 – Assigning Total Debt and Best Total Debt

Once a sheet is found in the "Search for SKUs on Sheets" Decide module that contains the ordered SKU [*SKU(Counter3, InnerCounter3) = Ordered SKU*], the entity moves on to determine the best total debt of the sheet according to the logic seen in Figure 14. A variable *InnerCounter4* is first set to one and the attribute *Total Debt* is initialized at zero. If *InnerCounter4* is less than or equal to *Number of SKUs per Sheet(Counter3)*, the entity passes on to calculate *Total Debt* according to Equation 8.

The debt for the first SKU on the sheet is calculated and added to the attribute *Total Debt* and then the value of *Inner Counter4* is increased by one.

After *InnerCounter4* is increased, the entity cycles back to the "Search for SKUs on Sheets" module where *Inner Counter4* is compared to *Number of SKUs per Sheet(Counter3)* again. The entity continues cycling until all SKUs on the sheet have been read and the total debt for the entire sheet has been calculated. After all of the SKUs on the sheet have been read, the entity is sent down to the "Compare Total Debt" module where *Total Debt* for the sheet is compared to the attribute *Best Total Debt*. If *Total Debt* for this sheet is lower than the value for *Best Total Debt*, *Best Total Debt* is reset to the value of *Total Debt* for this sheet. In addition, the sheet number for this sheet is saved as an attribute *Best Sheet* and the value of *Counter3* is saved as the attribute *CounterTemp*. If *Total Debt* is bigger than *Best Total Debt*, nothing happens. In either case, the entity moves on to the "2Read All Sheets" module to see if all sheets have been read. If *Counter3* is less than *No of Different Types of Sheets*, one is added to *Counter3* and the entity gets cycled back to the beginning of the logic to reset *InnerCounter3* to one.

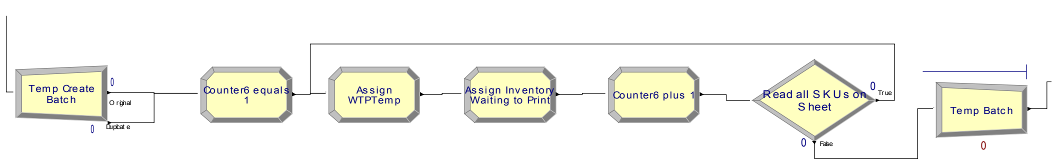

FIGURE 15 – Calculating Batch Size and Assigning SKUs to Waiting to Print

Once all sheets have been read, the entity gets sent to the logic represented in Figure 15. The production quantity PQ is determined first using a modified version of equation 6 where e is the ordered SKU.

$$PQ = \frac{S_e - IL_e}{No\ of\ Units\ \ per\ SKU(Best\ Sheet,\ Counter\ Temp)} \tag{13}$$

The entity gets duplicated into a batch based on PQ and each new entity is added to the waiting to print inventory. *Counter6* is set equal to one and the attribute *WTPTemp* is saved as the value of *SKU(Best Sheet, Counter6)*. The waiting to print inventory is now added using the following equation:

$$Waiting\ to\ Print(WTPTemp) = Waiting\ to\ Print(WTPTemp) + No\ of\ Units\ per\ SKU(Best\ Sheet,\ Counter6) \tag{14}$$

From here, all SKUs on the sheet are added and the newly created entities are temporarily batched into one entity and sent to the Stock Replenishment submodel.

4.1.4. Stock Replenishment Submodel

Once an entity enters the Stock Replenishment submodel, it goes to a first come first serve queue where orders wait until the printing press is idle before proceeding to another queue where the setup costs are calculated and the order waits 3.5 hours for the

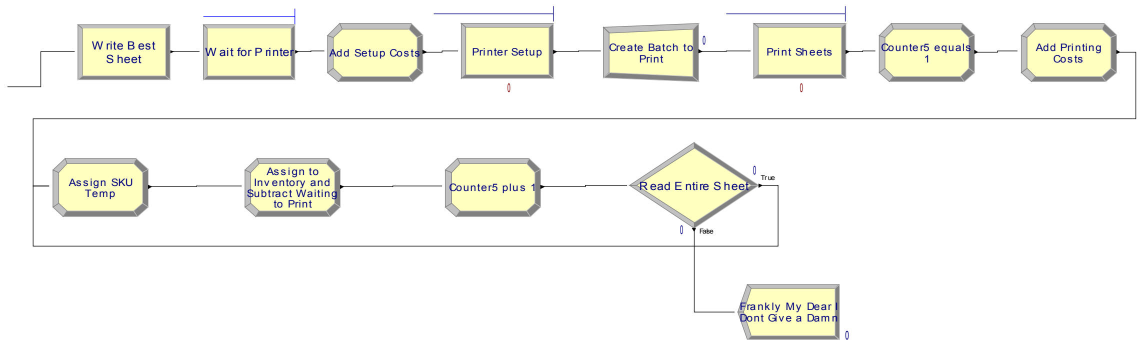

FIGURE 16 – The Stock Replenishment Submodel

printer to be set up. A running tab of the setup cost is kept via the Assign module "Add Setup Cost".

$$\text{\textit{Total Setup Cost}} = \text{\textit{Total Setup Cost}} + \text{\textit{Sheet Setup Cost(Best Sheet)}} \tag{15}$$

Before printing, the order gets separated into individual sheets and printed at a constant rate of five seconds per sheet. After printing, a variable *Counter5* is assigned and a running tab of the printing cost is calculated according to the following equation:

$$\text{\textit{Total Printing Cost}} = \text{\textit{Total Printing Cost}} + \text{\textit{Sheet Printing Cost(Best Sheet)}} \tag{16}$$

Next, each sheet is separated into individual SKUs which are subsequently added to inventory and taken out of waiting to print inventory. To do this, an attribute *SKUTemp(Best Sheet, Counter5)* is assigned to each entity in the "Assign SKU Temp" module and added to inventory in the "Assign to Inventory and Subtract From Waiting to Print" module using the following equation:

$$\textit{Inventory Level(SKUTemp) = Inventory Level(SKUTemp) + No of Units per SKU(Best Sheet, Counter5)} \tag{17}$$

The SKUs are taken out of the waiting to print inventory using Equation 16:

$$\textit{Waiting to Print(WTPTemp) = Waiting to Print(WTPTemp) - No of Units per SKU(Best Sheet, Counter6)} \tag{18}$$

The variable *Total Ordering Cost* is also calculated:

$$Total\ Ordering\ Cost = Total\ Ordering\ Cost + \frac{Sheet\ Setup\ Cost(Best\ Sheet) + Sheet\ \mathrm{Pr\,int}ing\ Cost(Best\ Sheet)}{Number\ of\ SKUs\ per\ Sheet(Best\ Sheet)} \tag{19}$$

After these calculations, one is added to *Counter5* and the entire sheet is read and then disposed once all SKUs have been added to inventory.

4.1.5. Model Performance Measures

In order to gain perspective on the performance of the system, several measures are specified in the Statistics module: Total Printing Cost, Total Setup Cost, Inventory Holding Cost, and Total Cost. Total Cost is calculated at the end of the simulation in order to add the final values of the variables *Sheet Printing Cost* and *Sheet Setup Cost*. The statistics Total Printing Cost and Total Setup Cost are also calculated upon conclusion of the simulation in order to report the final values of *Sheet Printing Cost* and *Sheet Setup Cost* in the model output. The statistic Inventory Holding Cost is calculated as a time-average sample mean of the total inventory holding cost over all SKUs. A tally statistic entitled Best Sheet Count was also used to count the number of dedicated sheets and mixed sheets chosen to be printed.

4.2. Decision Rule Two

The only submodel that changes for decision rule two is the Decision Logic submodel. The model window can be seen below in Figure 17.

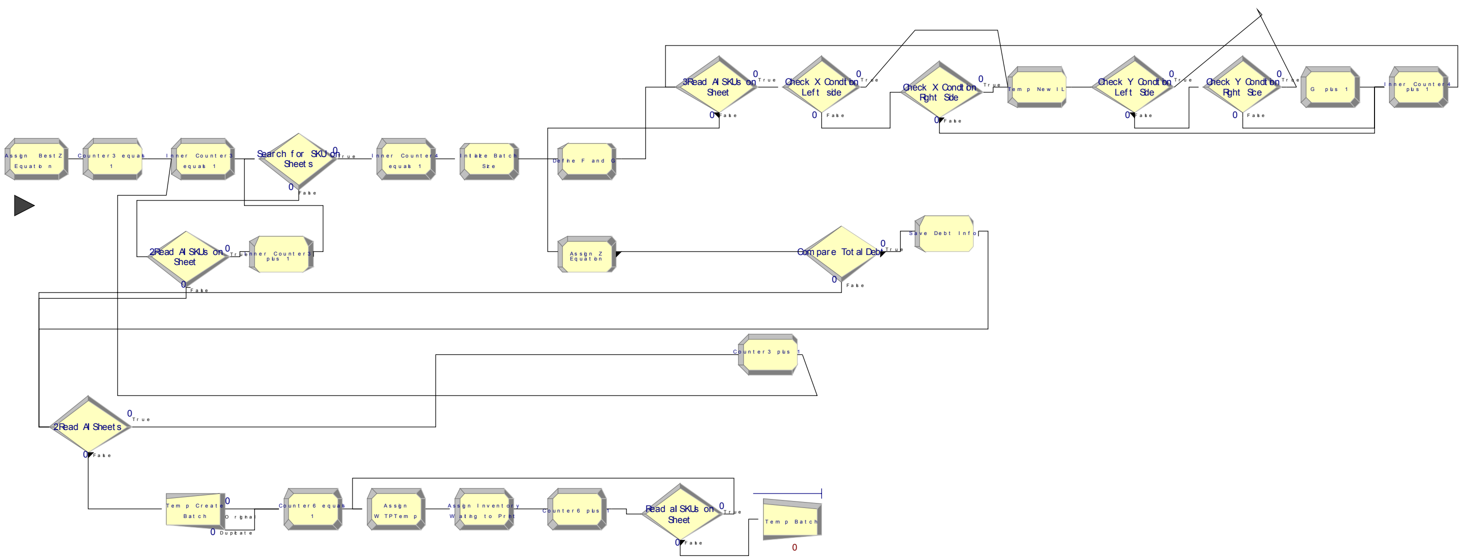

FIGURE 17 – Decision Logic Submodel for Decision Rule Two

The only changes to the logic are the following. First, instead of *Best Total Debt*, the sheet selection attribute is *Best Z Equation*. After a sheet is found that contains the needed SKU, two attributes are assigned: *Temp Batch Size*, assigned according to Equation 11, and *Sheet Temp* which is assigned as the current value of *Counter3*. The values for *F* and *G* are then assigned, with *F* being calculated according to Equation 10 and *G* being initialized at zero. *G* is then calculated by a series of decision modules.

Read all SKUs on Sheet makes sure that all SKUs on the sheet are accounted for. The current inventory level is then compared to the optimal value of X as decided by OptQuest (OptTek, 2005). If the inventory level for a SKU is not within X% of its *s* value, it is sent to add one to *Inner Counter4*, which was assigned after the logic found a sheet containing the needed SKU, and the next SKU is checked. If a SKU is within X% of its *s* value, the attribute *Temp New IL* is assigned to the entity according to Equation 13 which calculates the future inventory level of this SKU if this particular sheet is printed.

Next, *Temp New IL* is checked to see if this new value is within Y% of the SKU's *S* value after printing. If it is not, one is added to *Inner Counter4* and the next SKU is checked. If it is, one is added to *G*, then one is added to *Inner Counter4*, and the next SKU is checked. Once all SKUs are checked, the value for *Z* is calculated according to Equation 9, and this value is compared to what is saved as *Best Z Equation*. If this *Z* value is lower, it is saved as the new *Best Z Equation* and the sheet is saved as *Best Sheet* and sent on to find another sheet. If it isn't, the entity simply moves on and the current *Best Z Equation* and *Best Sheet* remain. The rest of the model for decision rule two is unchanged from that of decision rule one.

5. RESULTS

Three scenarios were modeled to see the preference for mixed sheets and dedicated sheets for different demand profiles. The same logic was used in all three scenarios, only the order quantities and interarrival times changed. Scenario 1 has approximately equal monthly demand for all 50 sheets, scenario 2 has 20% (10 SKUs) with high monthly demand and 80% (40 SKUs) with low monthly demand, and scenario 3 has 25 SKUs with moderately high monthly demand and 25 SKUs with moderately low monthly demand. Each scenario was run for a period of 364 days to allow the inventory for each SKU to cycle through their respective s and S values several times. In addition, a warm-up period of 90 days was used to let the model reach steady state before gathering statistics. For scenario one, the cost and sheet statistics from the simulation output are shown below in Tables I and II.

TABLE I

TOTAL COST FOR SCENARIO ONE

DECISION RULE #1

Statistic	Cost
Inventory Holding Cost	$30,562.28
Total Printing Cost	$20,152.17
Total Setup Cost	$19,200.00
Total Cost	$69,914.45

DECISION RULE #2

Statistic	Cost
Inventory Holding Cost	$89,611.68
Total Printing Cost	$37,504.41
Total Setup Cost	$6,150.00
Total Cost	$133,266.09

TABLE II

SHEETS CHOSEN IN SCENARIO ONE

DECISION RULE #1

Sheets	Quantity Chosen
Dedicated sheets 1-50	986
Mixed Sheets 51-100	0

DECISION RULE #2

Sheets	Quantity Chosen
Dedicated sheets 1-50	0
Mixed Sheets 51-100	1,127

The cost and sheet statistics for scenario 2 can be seen below in Tables III and IV.

TABLE III

TOTAL COST FOR SCENARIO 2

DECISION RULE #1

Statistic	Cost
Inventory Holding Cost	$24,484.12
Total Printing Cost	$17,893.38
Total Setup Cost	$15,150.00
Total Cost	$57,527.50

DECISION RULE #2

Statistic	Cost
Inventory Holding Cost	$151,672.60
Total Printing Cost	$53,754.27
Total Setup Cost	$6,450.00
Total Cost	$211,876.87

TABLE IV

SHEETS CHOSEN IN SCENARIO 2

DECISION RULE #1

Sheets	Quantity Chosen
Dedicated sheets 1-50	805
Mixed Sheets 51-100	0

DECISION RULE #2

Sheets	Quantity Chosen
Dedicated sheets 1-50	0
Mixed Sheets 51-100	1,699

Cost and sheet statistics for scenario 3 can be seen below in Tables V and VI.

TABLE V

TOTAL COST FOR SCENARIO 3

DECISION RULE #1

Statistic	Cost
Inventory Holding Cost	$31,944.82
Total Printing Cost	$25,149.30
Total Setup Cost	$20,550.00
Total Cost	$77,644.12

DECISION RULE #2

Statistic	Cost
Inventory Holding Cost	$137,637.78
Total Printing Cost	$55,228.80
Total Setup Cost	$9,450.00
Total Cost	$202,316.58

TABLE VI

SHEETS CHOSEN IN SCENARIO 3

DECISION RULE #1

Sheets	Quantity Chosen
Dedicated sheets 1-50	1,127
Mixed Sheets 51-100	0

DECISION RULE #2

Sheets	Quantity Chosen
Dedicated sheets 1-50	0
Mixed Sheets 51-100	1,872

For decision rule number one, none of the three scenarios chose a mixed sheet. When you take the *Total Debt* decision criteria into account though, this makes sense. Once an SKU *e* drops below its *s* value, the chances are slim that there will be other SKUs who share a mixed sheet with SKU *e* that will be closer to their *s* values than SKU *e*. There is too much variation among inventories of each SKU to expect this to happen. In addition to this, for dedicated sheets *Total Debt* is only calculated for one SKU while with mixed sheets it is calculated for the total debt of the ordered SKU ***plus*** up to seven more SKUs. The end result is low *Total Debt* values for dedicated sheets and very high *Total Debt* values for mixed sheets, thus ensuring that mixed sheets never get chosen.

Decision rule number two yielded the opposite results; none of the three scenarios chose a dedicated sheet. When looking at the equation, the F value is just too big for dedicated sheets to overcome compared to mixed sheets since this value is the setup cost divided by the number of SKUs on the sheet. The result is that the large F values on dedicated sheets ensure that they are not chosen.

Decision rule number one resulted in much lower inventory, printing, and total costs than decision rule number two. The only cost where decision rule number two is lower than number one is setup cost. The reason for this difference is that the mixed sheets were chosen in a completely random fashion with no rhyme or reason, so SKUs other than the needed SKU probably do not need any more inventory. As a result, decision rule number two produced a lot of SKUs that weren't needed. This drove up printing costs since so much more was produced, and drove up inventory costs since there were so many more labels to store. Since a larger variety of labels is produced at a time, though, this resulted in fewer setups, which explains the lower setup costs.

6. CONCLUSIONS

Simulations were developed in Arena to represent three different scenarios, each with its own demand pattern: one where all label types have approximately the same monthly demand, one where 10 labels have high demand and 40 have low demand, and one in-between with 25 labels having moderately high demand and 25 labels have moderately low monthly demand. Results from all three simulations suggest that if a decision on what sheet to print is chosen based on a SKU's inventory level relative to its *s* value, dedicated sheets are the preferred choice.

Since this model assumed that customers are infinitely patient and never cancel their orders, it is suggested that future research concentrates on expanding the model to include deadlines and reneging. In addition, different decision parameters for choosing a sheet should be explored in order to see if systems show the same preference for dedicated sheets as displayed in this thesis. An advanced way to design mixed sheets based on SKUs with low inventory levels at the time of printing, as opposed to sheets that are randomly assigned and fixed so they cannot change (as was done in this thesis), needs to be explored too as this "smarter" logic could help to lower costs.

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APPENDIX I: SHEET DATA FILE FOR ALL SCENARIOS

SHEET DATA

	Sheet Information	# of Units per SKU(**I**, J); **Sheet Setup Cost(I)**	**Sheet Printing Cost(I)**
Number of Different Types of Sheets	100		
SHEET #	**1**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	1	8	
SHEET #	**2**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	2	8	
SHEET #	**3**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	3	8	
SHEET #	**4**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	4	8	
SHEET #	**5**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	5	8	
SHEET #	**6**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	6	8	
SHEET #	**7**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	7	8	
SHEET #	**8**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	8	8	
SHEET #	**9**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	9	8	
SHEET #	**10**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	10	8	

SHEET #	**11**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	11	8	
SHEET #	**12**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	12	8	
SHEET #	**13**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	13	8	
SHEET #	**14**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	14	8	
SHEET #	**15**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	15	8	
SHEET #	**16**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	16	8	
SHEET #	**17**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	17	8	
SHEET #	**18**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	18	8	
SHEET #	**19**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	19	8	
SHEET #	**20**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	20	8	
SHEET #	**21**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	21	8	
SHEET #	**22**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	22	8	
SHEET #	**23**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	23	8	
SHEET #	**24**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	24	8	

SHEET #	**25**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	25	8	
SHEET #	**26**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	26	8	
SHEET #	**27**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	27	8	
SHEET #	**28**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	28	8	
SHEET #	**29**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	29	8	
SHEET #	**30**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	30	8	
SHEET #	**31**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	31	8	
SHEET #	**32**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	32	8	
SHEET #	**33**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	33	8	
SHEET #	**34**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	34	8	
SHEET #	**35**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	35	8	
SHEET #	**36**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	36	8	
SHEET #	**37**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	37	8	
SHEET #	**38**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	38	8	

SHEET #	**39**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	39	8	
SHEET #	**40**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	40	8	
SHEET #	**41**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	41	8	
SHEET #	**42**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	42	8	
SHEET #	**43**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	43	8	
SHEET #	**44**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	44	8	
SHEET #	**45**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	45	8	
SHEET #	**46**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	46	8	
SHEET #	**47**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	47	8	
SHEET #	**48**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	48	8	
SHEET #	**49**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	49	8	
SHEET #	**50**	**150**	**0.03**
Number of SKUs per Sheet(I)	1		
SKU AND # OF UNITS PER SKU	50	8	
SHEET #	**51**	**150**	**0.03**
Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	1	2	
SKU AND # OF UNITS PER SKU	2	3	
SKU AND # OF UNITS PER SKU	3	3	
SHEET #	**52**	**150**	**0.03**

Number of SKUs per Sheet(I)	5		
SKU AND # OF UNITS PER SKU	2	1	
SKU AND # OF UNITS PER SKU	3	1	
SKU AND # OF UNITS PER SKU	4	2	
SKU AND # OF UNITS PER SKU	5	2	
SKU AND # OF UNITS PER SKU	6	2	
SHEET #	**53**	**150**	**0.03**
Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	1	3	
SKU AND # OF UNITS PER SKU	6	2	
SKU AND # OF UNITS PER SKU	7	3	
SHEET #	**54**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	8	2	
SKU AND # OF UNITS PER SKU	9	2	
SKU AND # OF UNITS PER SKU	10	2	
SKU AND # OF UNITS PER SKU	11	2	
SHEET #	**55**	**150**	**0.03**
Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	31	2	
SKU AND # OF UNITS PER SKU	9	3	
SKU AND # OF UNITS PER SKU	14	3	
SHEET #	**56**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	13	2	
SKU AND # OF UNITS PER SKU	14	2	
SKU AND # OF UNITS PER SKU	15	3	
SKU AND # OF UNITS PER SKU	16	1	
SHEET #	**57**	**150**	**0.03**
Number of SKUs per Sheet(I)	2		
SKU AND # OF UNITS PER SKU	17	3	
SKU AND # OF UNITS PER SKU	18	5	
SHEET #	**58**	**150**	**0.03**
Number of SKUs per Sheet(I)	6		
SKU AND # OF UNITS PER SKU	7	1	
SKU AND # OF UNITS PER SKU	16	1	
SKU AND # OF UNITS PER SKU	19	2	
SKU AND # OF UNITS PER SKU	20	2	
SKU AND # OF UNITS PER SKU	21	1	
SKU AND # OF UNITS PER SKU	22	1	
SHEET #	**89**	**150**	**0.03**
Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	23	2	
SKU AND # OF UNITS PER SKU	24	3	
SKU AND # OF UNITS PER SKU	25	3	
SHEET #	**60**	**150**	**0.03**

Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	18	2	
SKU AND # OF UNITS PER SKU	21	2	
SKU AND # OF UNITS PER SKU	26	2	
SKU AND # OF UNITS PER SKU	27	2	
SHEET #	**61**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	16	1	
SKU AND # OF UNITS PER SKU	22	1	
SKU AND # OF UNITS PER SKU	28	1	
SKU AND # OF UNITS PER SKU	29	5	
SHEET #	**62**	**150**	**0.03**
Number of SKUs per Sheet(I)	5		
SKU AND # OF UNITS PER SKU	30	1	
SKU AND # OF UNITS PER SKU	31	1	
SKU AND # OF UNITS PER SKU	32	2	
SKU AND # OF UNITS PER SKU	33	2	
SKU AND # OF UNITS PER SKU	34	1	
SHEET #	**63**	**150**	**0.03**
Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	28	3	
SKU AND # OF UNITS PER SKU	35	3	
SKU AND # OF UNITS PER SKU	39	2	
SHEET #	**64**	**150**	**0.03**
Number of SKUs per Sheet(I)	2		
SKU AND # OF UNITS PER SKU	36	4	
SKU AND # OF UNITS PER SKU	37	4	
SHEET #	**65**	**150**	**0.03**
Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	38	2	
SKU AND # OF UNITS PER SKU	40	5	
SKU AND # OF UNITS PER SKU	41	1	
SHEET #	**66**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	41	2	
SKU AND # OF UNITS PER SKU	42	2	
SKU AND # OF UNITS PER SKU	43	2	
SKU AND # OF UNITS PER SKU	44	2	
SHEET #	**67**	**150**	**0.03**
Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	42	1	
SKU AND # OF UNITS PER SKU	45	3	
SKU AND # OF UNITS PER SKU	46	4	
SHEET #	**68**	**150**	**0.03**

Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	47	2	
SKU AND # OF UNITS PER SKU	48	2	
SKU AND # OF UNITS PER SKU	49	2	
SKU AND # OF UNITS PER SKU	50	2	
SHEET #	**69**	**150**	**0.03**
Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	46	2	
SKU AND # OF UNITS PER SKU	36	4	
SKU AND # OF UNITS PER SKU	23	2	
SHEET #	**70**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	20	2	
SKU AND # OF UNITS PER SKU	19	2	
SKU AND # OF UNITS PER SKU	16	1	
SKU AND # OF UNITS PER SKU	15	3	
SHEET #	**71**	**150**	**0.03**
Number of SKUs per Sheet(I)	8		
SKU AND # OF UNITS PER SKU	45	1	
SKU AND # OF UNITS PER SKU	14	1	
SKU AND # OF UNITS PER SKU	48	1	
SKU AND # OF UNITS PER SKU	47	1	
SKU AND # OF UNITS PER SKU	46	1	
SKU AND # OF UNITS PER SKU	45	1	
SKU AND # OF UNITS PER SKU	44	1	
SKU AND # OF UNITS PER SKU	43	1	
SHEET #	**72**	**150**	**0.03**
Number of SKUs per Sheet(I)	8		
SKU AND # OF UNITS PER SKU	32	1	
SKU AND # OF UNITS PER SKU	34	1	
SKU AND # OF UNITS PER SKU	35	1	
SKU AND # OF UNITS PER SKU	25	1	
SKU AND # OF UNITS PER SKU	36	1	
SKU AND # OF UNITS PER SKU	40	1	
SKU AND # OF UNITS PER SKU	41	1	
SKU AND # OF UNITS PER SKU	42	1	
SHEET #	**73**	**150**	**0.03**
Number of SKUs per Sheet(I)	8		
SKU AND # OF UNITS PER SKU	31	1	
SKU AND # OF UNITS PER SKU	30	1	
SKU AND # OF UNITS PER SKU	29	1	
SKU AND # OF UNITS PER SKU	3	1	
SKU AND # OF UNITS PER SKU	6	1	
SKU AND # OF UNITS PER SKU	9	1	
SKU AND # OF UNITS PER SKU	28	1	
SKU AND # OF UNITS PER SKU	15	1	
SHEET #	**74**	**150**	**0.03**

Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	13	3	
SKU AND # OF UNITS PER SKU	30	3	
SKU AND # OF UNITS PER SKU	40	2	
SHEET #	**75**	**150**	**0.03**
Number of SKUs per Sheet(I)	2		
SKU AND # OF UNITS PER SKU	17	4	
SKU AND # OF UNITS PER SKU	25	4	
SHEET #	**76**	**150**	**0.03**
Number of SKUs per Sheet(I)	2		
SKU AND # OF UNITS PER SKU	27	4	
SKU AND # OF UNITS PER SKU	46	4	
SHEET #	**77**	**150**	**0.03**
Number of SKUs per Sheet(I)	2		
SKU AND # OF UNITS PER SKU	20	4	
SKU AND # OF UNITS PER SKU	26	4	
SHEET #	**78**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	10	3	
SKU AND # OF UNITS PER SKU	74	2	
SKU AND # OF UNITS PER SKU	36	2	
SKU AND # OF UNITS PER SKU	19	1	
SHEET #	**79**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	50	2	
SKU AND # OF UNITS PER SKU	40	2	
SKU AND # OF UNITS PER SKU	33	2	
SKU AND # OF UNITS PER SKU	53	2	
SHEET #		**150**	**0.03**
Number of SKUs per Sheet(I)			
SKU AND # OF UNITS PER SKU	13	2	
SKU AND # OF UNITS PER SKU	25	2	
SKU AND # OF UNITS PER SKU	35	1	
SKU AND # OF UNITS PER SKU	38	2	
SKU AND # OF UNITS PER SKU	44	1	
SHEET #	**81**	**150**	**0.03**
Number of SKUs per Sheet(I)	5		
SKU AND # OF UNITS PER SKU	33	2	
SKU AND # OF UNITS PER SKU	22	1	
SKU AND # OF UNITS PER SKU	32	1	
SKU AND # OF UNITS PER SKU	23	1	
SKU AND # OF UNITS PER SKU	21	3	
SHEET #	**82**	**150**	**0.03**
Number of SKUs per Sheet(I)	5		
SKU AND # OF UNITS PER SKU	14	1	
SKU AND # OF UNITS PER SKU	17	1	

SKU AND # OF UNITS PER SKU	34	2	
SKU AND # OF UNITS PER SKU	32	2	
SKU AND # OF UNITS PER SKU	35	2	
SHEET #	**83**	**150**	**0.03**
Number of SKUs per Sheet(I)	5		
SKU AND # OF UNITS PER SKU	15	1	
SKU AND # OF UNITS PER SKU	25	2	
SKU AND # OF UNITS PER SKU	35	2	
SKU AND # OF UNITS PER SKU	45	1	
SKU AND # OF UNITS PER SKU	49	2	
SHEET #	**84**	**150**	**0.03**
Number of SKUs per Sheet(I)	5		
SKU AND # OF UNITS PER SKU	7	3	
SKU AND # OF UNITS PER SKU	17	2	
SKU AND # OF UNITS PER SKU	27	1	
SKU AND # OF UNITS PER SKU	71	1	
SKU AND # OF UNITS PER SKU	45	1	
SHEET #	**85**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	8	3	
SKU AND # OF UNITS PER SKU	18	1	
SKU AND # OF UNITS PER SKU	28	2	
SKU AND # OF UNITS PER SKU	24	2	
SHEET #	**86**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	1	2	
SKU AND # OF UNITS PER SKU	36	2	
SKU AND # OF UNITS PER SKU	21	2	
SKU AND # OF UNITS PER SKU	24	2	
SHEET #	**87**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	22	2	
SKU AND # OF UNITS PER SKU	35	2	
SKU AND # OF UNITS PER SKU	43	2	
SKU AND # OF UNITS PER SKU	44	2	
SHEET #	**88**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	3	2	
SKU AND # OF UNITS PER SKU	12	3	
SKU AND # OF UNITS PER SKU	9	3	
SKU AND # OF UNITS PER SKU	6	1	
SHEET #	**89**	**150**	**0.03**
Number of SKUs per Sheet(I)	2		
SKU AND # OF UNITS PER SKU	23	5	
SKU AND # OF UNITS PER SKU	38	3	
SHEET #	**90**	**150**	**0.03**

Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	22	3	
SKU AND # OF UNITS PER SKU	28	2	
SKU AND # OF UNITS PER SKU	8	3	
SHEET #	**91**	**150**	**0.03**
Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	36	2	
SKU AND # OF UNITS PER SKU	7	2	
SKU AND # OF UNITS PER SKU	43	4	
SHEET #	**92**	**150**	**0.03**
Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	6	2	
SKU AND # OF UNITS PER SKU	38	2	
SKU AND # OF UNITS PER SKU	7	4	
SHEET #	**93**	**150**	**0.03**
Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	12	3	
SKU AND # OF UNITS PER SKU	5	3	
SKU AND # OF UNITS PER SKU	3	2	
SHEET #	**94**	**150**	**0.03**
Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	4	3	
SKU AND # OF UNITS PER SKU	25	2	
SKU AND # OF UNITS PER SKU	50	3	
SHEET #	**95**	**150**	**0.03**
Number of SKUs per Sheet(I)	3		
SKU AND # OF UNITS PER SKU	2	2	
SKU AND # OF UNITS PER SKU	40	3	
SKU AND # OF UNITS PER SKU	26	3	
SHEET #	**96**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	10	2	
SKU AND # OF UNITS PER SKU	4	2	
SKU AND # OF UNITS PER SKU	39	2	
SKU AND # OF UNITS PER SKU	49	2	
SHEET #	**97**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	8	2	
SKU AND # OF UNITS PER SKU	11	2	
SKU AND # OF UNITS PER SKU	21	2	
SKU AND # OF UNITS PER SKU	47	2	
SHEET #	**98**	**150**	**0.03**
Number of SKUs per Sheet(I)	4		
SKU AND # OF UNITS PER SKU	1	2	
SKU AND # OF UNITS PER SKU	42	2	

SKU AND # OF UNITS PER SKU	46	2	
SKU AND # OF UNITS PER SKU	34	2	
SHEET #	**99**	**150**	**0.03**
Number of SKUs per Sheet(I)	2		
SKU AND # OF UNITS PER SKU	24	4	
SKU AND # OF UNITS PER SKU	44	4	
SHEET #	**100**	**150**	**0.03**
Number of SKUs per Sheet(I)	2		
SKU AND # OF UNITS PER SKU	31	4	
SKU AND # OF UNITS PER SKU	48	4	

APPENDIX II: INVENTORY DATA FILE FOR SCENARIO 1

DEMAND DATA				
SKU	Total Monthly Demand (Labels)	Avg # of Orders per Month	Mean Order Quantity (Labels)	Interarrival Time (Days)
1	11,315	20	566	1.5
2	10,455	15	697	2
3	9,073	20	454	1.5
4	9,512	10	952	3
5	9,193	10	920	3
6	7,642	20	383	1.5
7	10,879	10	1,088	3
8	9,712	20	486	1.5
9	12,588	15	840	2
10	8,904	5	1,781	6
11	12,156	15	811	2
12	9,859	20	493	1.5
13	10,580	20	529	1.5
14	9,804	10	981	3
15	10,810	10	1,081	3
16	11,153	20	558	1.5
17	8,665	5	1,733	6
18	10,115	30	338	1
19	10,023	20	502	1.5
20	8,883	20	445	1.5
21	9,547	5	1,910	6
22	10,171	20	509	1.5
23	10,393	20	520	1.5
24	10,931	20	547	1.5
25	12,629	15	842	2
26	13,145	15	877	2
27	10,638	15	710	2
28	12,037	20	602	1.5
29	9,844	5	1,969	6
30	12,718	20	636	1.5
31	11,094	10	1,110	3
32	8,822	10	883	3
33	9,953	10	996	3
34	9,741	10	975	3
35	11,150	30	372	1
36	9,933	20	497	1.5
37	9,176	20	459	1.5
38	8,885	10	889	3
39	9,165	5	1,833	6
40	7,736	10	774	3
41	10,020	10	1,002	3
42	12,191	20	610	1.5
43	12,596	20	630	1.5
44	10,643	20	533	1.5
45	10,273	30	343	1
46	8,875	20	444	1.5
47	11,045	20	553	1.5
48	10,733	20	537	1.5
49	10,121	10	1,013	3
50	10,260	20	513	1.5

SCENARIO 1 EOQ DATA

	COSTS AND DEMANDS						EOQ VALUES		
SKU	Mean (Labels/Year)	SD (Labels/Year)	Fixed Cost ($/Setup)	Holding Cost ($/Unit/Year)	Setup Time (Years)	EOQ Processing Time (Years)	EOQ (Labels)	R (Labels)	R+EOQ (Labels)
1	132,162	6,990	$150.00	$0.0221	0.0004	0.0067	42,357	14,921	57,278
2	133,447	4,082	$150.00	$0.0221	0.0004	0.0067	42,562	9,118	51,680
3	134,493	1,732	$150.00	$0.0221	0.0004	0.0068	42,729	4,429	47,158
4	122,763	1,551	$150.00	$0.0221	0.0004	0.0065	40,823	3,945	44,768
5	118,578	2,088	$150.00	$0.0221	0.0004	0.0064	40,121	4,978	45,099
6	133,694	1,775	$150.00	$0.0221	0.0004	0.0068	42,602	4,507	47,109
7	121,899	3,381	$150.00	$0.0221	0.0004	0.0064	40,679	7,596	48,275
8	134,183	3,371	$150.00	$0.0221	0.0004	0.0068	42,679	7,704	50,383
9	136,619	1,890	$150.00	$0.0221	0.0004	0.0068	43,065	4,768	47,833
10	111,881	1,986	$150.00	$0.0221	0.0004	0.0062	38,972	4,709	43,681
11	132,331	4,628	$150.00	$0.0221	0.0004	0.0067	42,384	10,199	52,583
12	131,080	4,300	$150.00	$0.0221	0.0004	0.0067	42,183	9,528	51,711
13	135,005	5,398	$150.00	$0.0221	0.0004	0.0068	42,810	11,767	54,577
14	120,968	2,280	$150.00	$0.0221	0.0004	0.0064	40,523	5,385	45,908
15	118,592	1,943	$150.00	$0.0221	0.0004	0.0064	40,123	4,687	44,810
16	130,914	2,344	$150.00	$0.0221	0.0004	0.0067	42,156	5,615	47,771
17	109,656	531	$150.00	$0.0221	0.0004	0.0061	38,582	1,777	40,359
18	125,791	968	$150.00	$0.0221	0.0004	0.0066	41,323	2,810	44,133
19	135,649	3,334	$150.00	$0.0221	0.0004	0.0068	42,912	7,646	50,558
20	128,068	4,878	$150.00	$0.0221	0.0004	0.0066	41,696	10,654	52,350
21	111,093	2,169	$150.00	$0.0221	0.0004	0.0062	38,834	5,066	43,900
22	127,856	3,635	$150.00	$0.0221	0.0004	0.0066	41,661	8,165	49,826
23	131,156	4,924	$150.00	$0.0221	0.0004	0.0067	42,195	10,778	52,973
24	131,897	2,834	$150.00	$0.0221	0.0004	0.0067	42,314	6,606	48,920
25	135,556	4,056	$150.00	$0.0221	0.0004	0.0068	42,897	9,088	51,985
26	137,689	4,175	$150.00	$0.0221	0.0004	0.0069	43,233	9,348	52,581
27	134,256	1,194	$150.00	$0.0221	0.0004	0.0068	42,691	3,350	46,041
28	131,244	2,652	$150.00	$0.0221	0.0004	0.0067	42,209	6,234	48,443
29	111,508	1,440	$150.00	$0.0221	0.0004	0.0062	38,907	3,613	42,520
30	132,280	7,582	$150.00	$0.0221	0.0004	0.0067	42,376	16,105	58,481
31	122,959	4,767	$150.00	$0.0221	0.0004	0.0065	40,855	10,379	51,234
32	119,140	2,095	$150.00	$0.0221	0.0004	0.0064	40,216	4,998	45,214
33	121,998	2,977	$150.00	$0.0221	0.0004	0.0065	40,695	6,789	47,484
34	120,450	1,864	$150.00	$0.0221	0.0004	0.0064	40,437	4,549	44,986
35	125,375	3,985	$150.00	$0.0221	0.0004	0.0065	41,255	8,840	50,095
36	131,964	4,154	$150.00	$0.0221	0.0004	0.0067	42,325	9,246	51,571
37	131,082	4,242	$150.00	$0.0221	0.0004	0.0067	42,183	9,413	51,596
38	121,156	2,654	$150.00	$0.0221	0.0004	0.0064	40,555	6,135	46,690
39	111,643	913	$150.00	$0.0221	0.0004	0.0062	38,930	2,561	41,491
40	120,396	3,669	$150.00	$0.0221	0.0004	0.0064	40,427	8,157	48,584
41	119,458	4,636	$150.00	$0.0221	0.0004	0.0064	40,270	10,083	50,353
42	128,750	2,626	$150.00	$0.0221	0.0004	0.0066	41,806	6,157	47,963
43	130,840	2,350	$150.00	$0.0221	0.0004	0.0067	42,144	5,627	47,771
44	133,890	3,405	$150.00	$0.0221	0.0004	0.0068	42,633	7,768	50,401
45	125,230	4,217	$150.00	$0.0221	0.0004	0.0065	41,231	9,302	50,533
46	134,490	8,828	$150.00	$0.0221	0.0004	0.0068	42,728	18,620	61,348
47	132,766	2,717	$150.00	$0.0221	0.0004	0.0067	42,453	6,381	48,834
48	133,001	3,880	$150.00	$0.0221	0.0004	0.0067	42,491	8,710	51,201
49	118,779	1,754	$150.00	$0.0221	0.0004	0.0064	40,155	4,312	44,467
50	129,841	1,239	$150.00	$0.0221	0.0004	0.0067	41,983	3,394	45,377

Total Yearly Demand 6,345,510 Labels

SCENARIO 1 INVENTORY DATA

SKU	Initial Inventory (Labels)	Big S (Labels)	Little s (Labels)	Unit Holding Cost ($/Unit/Year)	Waiting to Print (Labels)
# of SKUs	50				
1	57,278	57,278	14,921	$0.0221	0
2	51,680	51,680	9,118	$0.0221	0
3	47,158	47,158	4,429	$0.0221	0
4	44,768	44,768	3,945	$0.0221	0
5	45,099	45,099	4,978	$0.0221	0
6	47,109	47,109	4,507	$0.0221	0
7	48,275	48,275	7,596	$0.0221	0
8	50,383	50,383	7,704	$0.0221	0
9	47,833	47,833	4,768	$0.0221	0
10	43,681	43,681	4,709	$0.0221	0
11	52,583	52,583	10,199	$0.0221	0
12	51,711	51,711	9,528	$0.0221	0
13	54,577	54,577	11,767	$0.0221	0
14	45,908	45,908	5,385	$0.0221	0
15	44,810	44,810	4,687	$0.0221	0
16	47,771	47,771	5,615	$0.0221	0
17	40,359	40,359	1,777	$0.0221	0
18	44,133	44,133	2,810	$0.0221	0
19	50,558	50,558	7,646	$0.0221	0
20	52,350	52,350	10,654	$0.0221	0
21	43,900	43,900	5,066	$0.0221	0
22	49,826	49,826	8,165	$0.0221	0
23	52,973	52,973	10,778	$0.0221	0
24	48,920	48,920	6,606	$0.0221	0
25	51,985	51,985	9,088	$0.0221	0
26	52,581	52,581	9,348	$0.0221	0
27	46,041	46,041	3,350	$0.0221	0
28	48,443	48,443	6,234	$0.0221	0
29	42,520	42,520	3,613	$0.0221	0
30	58,481	58,481	16,105	$0.0221	0
31	51,234	51,234	10,379	$0.0221	0
32	45,214	45,214	4,998	$0.0221	0
33	47,484	47,484	6,789	$0.0221	0
34	44,986	44,986	4,549	$0.0221	0
35	50,095	50,095	8,840	$0.0221	0
36	51,571	51,571	9,246	$0.0221	0
37	51,596	51,596	9,413	$0.0221	0
38	46,690	46,690	6,135	$0.0221	0
39	41,491	41,491	2,561	$0.0221	0
40	48,584	48,584	8,157	$0.0221	0
41	50,353	50,353	10,083	$0.0221	0
42	47,963	47,963	6,157	$0.0221	0
43	47,771	47,771	5,627	$0.0221	0
44	50,401	50,401	7,768	$0.0221	0
45	50,533	50,533	9,302	$0.0221	0
46	61,348	61,348	18,620	$0.0221	0
47	48,834	48,834	6,381	$0.0221	0
48	51,201	51,201	8,710	$0.0221	0
49	44,467	44,467	4,312	$0.0221	0
50	45,377	45,377	3,394	$0.0221	0

APPENDIX III: INVENTORY DATA FILE FOR SCENARIO 2

DEMAND DATA

SKU	Mean Monthly Demand (Labels)	Avg # of Orders per Month	Quantity (Labels)	Mean Interarrival Time (Days)
1	27,704	20	1,386	1.5
2	4,055	15	271	2
3	6,009	20	301	1.5
4	25,523	10	2,553	3
5	4,064	10	407	3
6	8,926	20	447	1.5
7	4,707	10	471	3
8	3,028	20	152	1.5
9	2,517	15	168	2
10	26,890	5	5,378	6
11	4,905	15	327	2
12	2,641	20	133	1.5
13	3,042	20	153	1.5
14	3,829	10	383	3
15	4,209	10	421	3
16	8,693	20	435	1.5
17	3,185	5	637	6
18	4,689	30	157	1
19	3,371	20	169	1.5
20	3,217	20	161	1.5
21	22,984	5	4,597	6
22	3,101	20	156	1.5
23	9,799	20	490	1.5
24	3,697	20	185	1.5
25	39,530	15	2,636	2
26	24,482	15	1,633	2
27	4,304	15	287	2
28	8,454	20	445	1.5
29	3,576	5	716	6
30	3,730	20	187	1.5
31	24,193	10	2,420	3
32	4,103	10	411	3
33	3,885	10	389	3
34	4,623	10	463	3
35	38,680	30	1,290	1
36	8,152	20	408	1.5
37	29,068	20	1,454	1.5
38	4,529	10	453	3
39	3,928	5	786	6
40	4,428	10	443	3
41	4,757	10	476	3
42	3,047	20	153	1.5
43	9,040	20	452	1.5
44	3,193	20	160	1.5
45	5,115	30	171	1
46	9,062	20	454	1.5
47	31,080	20	1,554	1.5
48	9,128	20	457	1.5
49	4,608	10	461	3
50	9,528	20	477	1.5

SCENARIO 2 EOQ DATA

COSTS AND DEMANDS							EOQ VALUES		
SKU	Mean Demand (Labels/Year)	Standard Deviation (Labels/Year)	Fixed Cost ($/Setup)	Holding Cost ($/Unit/Year)	Setup Time (Years)	EOQ Processing Time (Years)	EOQ (Labels)	R (Labels)	R+EOQ (Labels)
1	361,831	963	$ 150.00	$0.0221	0.0004	0.0111	70,084	6,091	76,175
2	53,381	940	$ 150.00	$0.0221	0.0004	0.0043	26,919	2,129	29,048
3	71,976	2,135	$ 150.00	$0.0221	0.0004	0.0050	31,258	4,655	35,913
4	297,446	5,228	$ 150.00	$0.0221	0.0004	0.0101	63,544	13,571	77,115
5	53,807	1,308	$ 150.00	$0.0221	0.0004	0.0043	27,027	2,868	29,895
6	107,156	1,806	$ 150.00	$0.0221	0.0004	0.0060	38,140	4,302	42,442
7	54,754	1,755	$ 150.00	$0.0221	0.0004	0.0043	27,263	3,769	31,032
8	35,868	256	$ 150.00	$0.0221	0.0004	0.0035	22,066	652	22,718
9	29,108	963	$ 150.00	$0.0221	0.0004	0.0032	19,878	2,029	21,907
10	273,030	5,162	$ 150.00	$0.0221	0.0004	0.0097	60,880	13,069	73,949
11	54,388	861	$ 150.00	$0.0221	0.0004	0.0043	27,172	1,979	29,151
12	36,296	415	$ 150.00	$0.0221	0.0004	0.0035	22,198	972	23,170
13	39,609	1,034	$ 150.00	$0.0221	0.0004	0.0037	23,188	2,229	25,417
14	54,356	142	$ 150.00	$0.0221	0.0004	0.0043	27,164	539	27,703
15	54,513	861	$ 150.00	$0.0221	0.0004	0.0043	27,203	1,980	29,183
16	107,788	1,171	$ 150.00	$0.0221	0.0004	0.0061	38,252	3,038	41,290
17	45,372	594	$ 150.00	$0.0221	0.0004	0.0039	24,818	1,385	26,203
18	58,600	895	$ 150.00	$0.0221	0.0004	0.0045	28,205	2,076	30,281
19	38,865	1,502	$ 150.00	$0.0221	0.0004	0.0036	22,970	3,161	26,131
20	39,007	1,228	$ 150.00	$0.0221	0.0004	0.0036	23,012	2,615	25,627
21	265,659	6,117	$ 150.00	$0.0221	0.0004	0.0095	60,052	14,869	74,921
22	38,883	831	$ 150.00	$0.0221	0.0004	0.0036	22,975	1,819	24,794
23	107,588	1,439	$ 150.00	$0.0221	0.0004	0.0061	38,217	3,573	41,790
24	39,778	967	$ 150.00	$0.0221	0.0004	0.0037	23,238	2,097	25,335
25	450,054	4,175	$ 150.00	$0.0221	0.0004	0.0124	78,163	14,108	92,271
26	268,322	7,845	$ 150.00	$0.0221	0.0004	0.0096	60,353	18,366	78,719
27	53,101	1,456	$ 150.00	$0.0221	0.0004	0.0043	26,849	3,160	30,009
28	102,576	1,120	$ 150.00	$0.0221	0.0004	0.0059	37,316	2,888	40,204
29	45,164	927	$ 150.00	$0.0221	0.0004	0.0039	24,761	2,049	26,810
30	40,413	1,205	$ 150.00	$0.0221	0.0004	0.0037	23,423	2,576	25,999
31	300,236	3,591	$ 150.00	$0.0221	0.0004	0.0101	63,841	10,341	74,182
32	54,136	279	$ 150.00	$0.0221	0.0004	0.0043	27,109	813	27,922
33	54,324	878	$ 150.00	$0.0221	0.0004	0.0043	27,156	2,012	29,168
34	54,687	716	$ 150.00	$0.0221	0.0004	0.0043	27,247	1,690	28,937
35	468,821	931	$ 150.00	$0.0221	0.0004	0.0126	79,776	7,979	87,755
36	108,826	510	$ 150.00	$0.0221	0.0004	0.0061	38,436	1,726	40,162
37	359,398	5,304	$ 150.00	$0.0221	0.0004	0.0111	69,848	14,731	84,579
38	54,463	1,385	$ 150.00	$0.0221	0.0004	0.0043	27,191	3,026	30,217
39	45,693	748	$ 150.00	$0.0221	0.0004	0.0039	24,906	1,696	26,602
40	54,145	662	$ 150.00	$0.0221	0.0004	0.0043	27,111	1,578	28,689
41	53,254	384	$ 150.00	$0.0221	0.0004	0.0043	26,887	1,015	27,902
42	39,281	810	$ 150.00	$0.0221	0.0004	0.0037	23,092	1,779	24,871
43	107,237	1,592	$ 150.00	$0.0221	0.0004	0.0060	38,154	3,876	42,030
44	38,829	1,073	$ 150.00	$0.0221	0.0004	0.0036	22,959	2,303	25,262
45	58,217	928	$ 150.00	$0.0221	0.0004	0.0045	28,112	2,139	30,251
46	108,016	970	$ 150.00	$0.0221	0.0004	0.0061	38,292	2,639	40,931
47	358,760	3,066	$ 150.00	$0.0221	0.0004	0.0111	69,786	10,245	80,031
48	108,041	1,746	$ 150.00	$0.0221	0.0004	0.0061	38,297	4,192	42,489
49	55,039	1,248	$ 150.00	$0.0221	0.0004	0.0043	27,334	2,757	30,091
50	107,716	1,603	$ 150.00	$0.0221	0.0004	0.0061	38,239	3,902	42,141

Total Yearly Demand 5,867,805 Labels

SCENARIO 2 INVENTORY DATA

SKU	Initial Inventory (Labels)	Big S (Labels)	Little s (Labels)	Unit Holding Cost ($/Unit/Year)	Waiting to Print (Labels)
# of SKUs	50				
1	76,175	76,175	6,091	$0.0221	0
2	29,048	29,048	2,129	$0.0221	0
3	35,913	35,913	4,655	$0.0221	0
4	77,115	77,115	13,571	$0.0221	0
5	29,895	29,895	2,868	$0.0221	0
6	42,442	42,442	4,302	$0.0221	0
7	31,032	31,032	3,769	$0.0221	0
8	22,718	22,718	652	$0.0221	0
9	21,907	21,907	2,029	$0.0221	0
10	73,949	73,949	13,069	$0.0221	0
11	29,151	29,151	1,979	$0.0221	0
12	23,170	23,170	972	$0.0221	0
13	25,417	25,417	2,229	$0.0221	0
14	27,703	27,703	539	$0.0221	0
15	29,183	29,183	1,980	$0.0221	0
16	41,290	41,290	3,038	$0.0221	0
17	26,203	26,203	1,385	$0.0221	0
18	30,281	30,281	2,076	$0.0221	0
19	26,131	26,131	3,161	$0.0221	0
20	25,627	25,627	2,615	$0.0221	0
21	74,921	74,921	14,869	$0.0221	0
22	24,794	24,794	1,819	$0.0221	0
23	41,790	41,790	3,573	$0.0221	0
24	25,335	25,335	2,097	$0.0221	0
25	92,271	92,271	14,108	$0.0221	0
26	78,719	78,719	18,366	$0.0221	0
27	30,009	30,009	3,160	$0.0221	0
28	40,204	40,204	2,888	$0.0221	0
29	26,810	26,810	2,049	$0.0221	0
30	25,999	25,999	2,576	$0.0221	0
31	74,182	74,182	10,341	$0.0221	0
32	27,922	27,922	813	$0.0221	0
33	29,168	29,168	2,012	$0.0221	0
34	28,937	28,937	1,690	$0.0221	0
35	87,755	87,755	7,979	$0.0221	0
36	40,162	40,162	1,726	$0.0221	0
37	84,579	84,579	14,731	$0.0221	0
38	30,217	30,217	3,026	$0.0221	0
39	26,602	26,602	1,696	$0.0221	0
40	28,689	28,689	1,578	$0.0221	0
41	27,902	27,902	1,015	$0.0221	0
42	24,871	24,871	1,779	$0.0221	0
43	42,030	42,030	3,876	$0.0221	0
44	25,262	25,262	2,303	$0.0221	0
45	30,251	30,251	2,139	$0.0221	0
46	40,931	40,931	2,639	$0.0221	0
47	80,031	80,031	10,245	$0.0221	0
48	42,489	42,489	4,192	$0.0221	0
49	30,091	30,091	2,757	$0.0221	0
50	42,141	42,141	3,902	$0.0221	0

APPENDIX IV: INVENTORY DATA FOR SCENARIO 3

DEMAND DATA				
SKU	Mean Monthly Demand (Labels)	Avg # of Orders per Month (Labels)	Mean Order Quantity (Labels)	Interarrival Time (Days)
1	20,082	20	1,005	1.5
2	8,827	15	589	2
3	9,954	20	498	1.5
4	19,134	10	1,914	3
5	7,823	10	783	3
6	20,259	20	1,013	1.5
7	7,821	10	783	3
8	10,387	20	520	1.5
9	8,867	15	592	2
10	21,327	5	4,266	6
11	8,937	15	596	2
12	9,698	20	485	1.5
13	10,170	20	509	1.5
14	18,777	10	1,878	3
15	8,078	10	808	3
16	18,947	20	948	1.5
17	8,681	5	1,737	6
18	9,303	30	311	1
19	19,229	20	962	1.5
20	9,959	20	498	1.5
21	21,488	5	4,298	6
22	9,409	20	471	1.5
23	23,662	20	1,184	1.5
24	10,224	20	512	1.5
25	21,498	15	1,434	2
26	21,912	15	1,461	2
27	8,554	15	571	2
28	10,017	20	501	1.5
29	8,855	5	1,771	6
30	22,123	20	1,107	1.5
31	21,123	10	2,113	3
32	8,170	10	817	3
33	18,862	10	1,887	3
34	7,339	10	734	3
35	8,843	30	295	1
36	9,397	20	470	1.5
37	18,813	20	941	1.5
38	7,880	10	788	3
39	8,618	5	1,724	6
40	8,082	10	809	3
41	21,222	10	2,123	3
42	10,510	20	526	1.5
43	10,674	20	534	1.5
44	19,280	20	964	1.5
45	8,737	30	292	1
46	10,081	20	505	1.5
47	19,320	20	966	1.5
48	10,553	20	528	1.5
49	20,295	10	2,030	3
50	17,759	20	888	1.5

SCENARIO 3 EQO DATA

COSTS AND DEMANDS							EOQ VALUES		
SKU	Mean Demand (Labels/Year)	Standard Deviation (Labels/Year)	Fixed Cost ($/Setup)	Holding Cost ($/Unit/Year)	Setup Time (Years)	EOQ Processing Time (Years)	EOQ (Labels)	R (Labels)	R+EOQ (Labels)
1	227,999	2,301	$ 150.00	$0.0221	0.0004	0.0088	55,633	6,703	62,336
2	108,402	1,147	$ 150.00	$0.0221	0.0004	0.0061	38,361	2,996	41,357
3	119,241	1,845	$ 150.00	$0.0221	0.0004	0.0064	40,233	4,499	44,732
4	240,832	4,470	$ 150.00	$0.0221	0.0004	0.0091	57,178	11,220	68,398
5	96,306	1,780	$ 150.00	$0.0221	0.0004	0.0057	36,157	4,150	40,307
6	226,459	463	$ 150.00	$0.0221	0.0004	0.0088	55,445	3,007	58,452
7	96,629	579	$ 150.00	$0.0221	0.0004	0.0057	36,218	1,752	37,970
8	121,902	1,121	$ 150.00	$0.0221	0.0004	0.0064	40,679	3,077	43,756
9	107,979	1,018	$ 150.00	$0.0221	0.0004	0.0061	38,286	2,734	41,020
10	240,596	2,131	$ 150.00	$0.0221	0.0004	0.0091	57,149	6,538	63,687
11	107,744	1,160	$ 150.00	$0.0221	0.0004	0.0061	38,244	3,016	41,260
12	121,025	2,140	$ 150.00	$0.0221	0.0004	0.0064	40,533	5,106	45,639
13	119,195	766	$ 150.00	$0.0221	0.0004	0.0064	40,225	2,339	42,564
14	239,375	2,597	$ 150.00	$0.0221	0.0004	0.0090	57,004	7,454	64,458
15	95,574	1,402	$ 150.00	$0.0221	0.0004	0.0057	36,020	3,388	39,408
16	227,681	300	$ 150.00	$0.0221	0.0004	0.0088	55,594	2,698	58,292
17	104,694	669	$ 150.00	$0.0221	0.0004	0.0060	37,699	2,006	39,705
18	108,597	1,150	$ 150.00	$0.0221	0.0004	0.0061	38,395	3,005	41,400
19	228,388	2,322	$ 150.00	$0.0221	0.0004	0.0088	55,681	6,751	62,432
20	121,631	1,888	$ 150.00	$0.0221	0.0004	0.0064	40,634	4,607	45,241
21	238,455	2,646	$ 150.00	$0.0221	0.0004	0.0090	56,895	7,539	64,434
22	121,164	1,690	$ 150.00	$0.0221	0.0004	0.0064	40,556	4,208	44,764
23	276,042	4,309	$ 150.00	$0.0221	0.0004	0.0097	61,215	11,407	72,622
24	119,726	1,382	$ 150.00	$0.0221	0.0004	0.0064	40,315	3,578	43,893
25	270,818	3,658	$ 150.00	$0.0221	0.0004	0.0096	60,633	10,027	70,660
26	269,662	2,919	$ 150.00	$0.0221	0.0004	0.0096	60,503	8,533	69,036
27	107,486	370	$ 150.00	$0.0221	0.0004	0.0061	38,198	1,434	39,632
28	121,205	1,178	$ 150.00	$0.0221	0.0004	0.0064	40,563	3,184	43,747
29	104,396	947	$ 150.00	$0.0221	0.0004	0.0060	37,645	2,559	40,204
30	276,695	2,356	$ 150.00	$0.0221	0.0004	0.0097	61,287	7,512	68,799
31	239,601	4,235	$ 150.00	$0.0221	0.0004	0.0090	57,031	10,733	67,764
32	95,568	734	$ 150.00	$0.0221	0.0004	0.0057	36,019	2,052	38,071
33	240,712	2,901	$ 150.00	$0.0221	0.0004	0.0091	57,163	8,080	65,243
34	96,454	934	$ 150.00	$0.0221	0.0004	0.0057	36,185	2,461	38,646
35	107,900	766	$ 150.00	$0.0221	0.0004	0.0061	38,272	2,230	40,502
36	119,875	1,512	$ 150.00	$0.0221	0.0004	0.0064	40,340	3,839	44,179
37	229,751	3,923	$ 150.00	$0.0221	0.0004	0.0089	55,847	9,971	65,818
38	96,308	529	$ 150.00	$0.0221	0.0004	0.0057	36,158	1,649	37,807
39	105,727	1,864	$ 150.00	$0.0221	0.0004	0.0060	37,885	4,405	42,290
40	95,867	1,001	$ 150.00	$0.0221	0.0004	0.0057	36,075	2,589	38,664
41	238,052	2,814	$ 150.00	$0.0221	0.0004	0.0090	56,847	7,868	64,715
42	119,692	2,075	$ 150.00	$0.0221	0.0004	0.0064	40,309	4,963	45,272
43	119,576	2,170	$ 150.00	$0.0221	0.0004	0.0064	40,290	5,151	45,441
44	230,196	2,426	$ 150.00	$0.0221	0.0004	0.0089	55,901	6,984	62,885
45	107,308	1,230	$ 150.00	$0.0221	0.0004	0.0061	38,167	3,153	41,320
46	119,937	1,202	$ 150.00	$0.0221	0.0004	0.0064	40,350	3,219	43,569
47	229,005	1,588	$ 150.00	$0.0221	0.0004	0.0088	55,756	5,292	61,048
48	120,453	1,914	$ 150.00	$0.0221	0.0004	0.0064	40,437	4,648	45,085
49	238,246	3,700	$ 150.00	$0.0221	0.0004	0.0090	56,870	9,643	66,513
50	227,286	1,652	$ 150.00	$0.0221	0.0004	0.0088	55,546	5,396	60,942

Total Yearly Demand 8,143,405 Labels

SCENARIO 3 INVENTORY DATA

SKU	Initial Inventory (Labels)	Big S (Labels)	Little s (Labels)	Unit Holding Cost ($/Unit/Year)	Waiting to Print (Labels)
# of SKUs	50				
1	62,336	62,336	6,703	$0.0221	0
2	41,357	41,357	2,996	$0.0221	0
3	44,732	44,732	4,499	$0.0221	0
4	68,398	68,398	11,220	$0.0221	0
5	40,307	40,307	4,150	$0.0221	0
6	58,452	58,452	3,007	$0.0221	0
7	37,970	37,970	1,752	$0.0221	0
8	43,756	43,756	3,077	$0.0221	0
9	41,020	41,020	2,734	$0.0221	0
10	63,687	63,687	6,538	$0.0221	0
11	41,260	41,260	3,016	$0.0221	0
12	45,639	45,639	5,106	$0.0221	0
13	42,564	42,564	2,339	$0.0221	0
14	64,458	64,458	7,454	$0.0221	0
15	39,408	39,408	3,388	$0.0221	0
16	58,292	58,292	2,698	$0.0221	0
17	39,705	39,705	2,006	$0.0221	0
18	41,400	41,400	3,005	$0.0221	0
19	62,432	62,432	6,751	$0.0221	0
20	45,241	45,241	4,607	$0.0221	0
21	64,434	64,434	7,539	$0.0221	0
22	44,764	44,764	4,208	$0.0221	0
23	72,622	72,622	11,407	$0.0221	0
24	43,893	43,893	3,578	$0.0221	0
25	70,660	70,660	10,027	$0.0221	0
26	69,036	69,036	8,533	$0.0221	0
27	39,632	39,632	1,434	$0.0221	0
28	43,747	43,747	3,184	$0.0221	0
29	40,204	40,204	2,559	$0.0221	0
30	68,799	68,799	7,512	$0.0221	0
31	67,764	67,764	10,733	$0.0221	0
32	38,071	38,071	2,052	$0.0221	0
33	65,243	65,243	8,080	$0.0221	0
34	38,646	38,646	2,461	$0.0221	0
35	40,502	40,502	2,230	$0.0221	0
36	44,179	44,179	3,839	$0.0221	0
37	65,818	65,818	9,971	$0.0221	0
38	37,807	37,807	1,649	$0.0221	0
39	42,290	42,290	4,405	$0.0221	0
40	38,664	38,664	2,589	$0.0221	0
41	64,715	64,715	7,868	$0.0221	0
42	45,272	45,272	4,963	$0.0221	0
43	45,441	45,441	5,151	$0.0221	0
44	62,885	62,885	6,984	$0.0221	0
45	41,320	41,320	3,153	$0.0221	0
46	43,569	43,569	3,219	$0.0221	0
47	61,048	61,048	5,292	$0.0221	0
48	45,085	45,085	4,648	$0.0221	0
49	66,513	66,513	9,643	$0.0221	0
50	60,942	60,942	5,396	$0.0221	0

APPENDIX V: ORDER QUANTITY AND INTERARRIVAL TIME DISTRIBUTIONS FOR SCENARIOS 1, 2, AND 3

ORDER QUANTITY AND INTERARRIVAL TIME DISTRIBUTIONS

		TRIANGULAR DISTRIBUTION DATA								
		SCENARIO 1			SCENARIO 2			SCENARIO 3		
SKU	Interarrival Time	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
1	1.5	100	550	1,000	1,000	1,500	2,000	600	950	1,300
2	2	300	750	1,200	100	300	500	400	600	800
3	1.5	100	550	1,000	100	300	500	300	500	700
4	3	500	1,000	1,500	2,000	2,500	3,000	1,500	2,000	2,500
5	3	500	1,000	1,500	300	450	600	600	800	1,000
6	1.5	100	550	1,000	300	450	600	600	950	1,300
7	3	500	1,000	1,500	300	450	600	600	800	1,000
8	1.5	100	550	1,000	100	150	200	300	500	700
9	2	300	750	1,200	50	163	275	400	600	800
10	6	1,500	1,850	2,200	3,000	4,500	6,000	3,000	4,000	5,000
11	2	300	750	1,200	100	300	500	400	600	800
12	1.5	100	550	1,000	100	150	200	300	500	700
13	1.5	100	550	1,000	50	163	275	300	500	700
14	3	500	1,000	1,500	300	450	600	1,500	2,000	2,500
15	3	500	1,000	1,500	300	450	600	600	800	1,000
16	1.5	100	550	1,000	300	450	600	600	950	1,300
17	6	1,500	1,850	2,200	500	750	1,000	1,500	1,750	2,000
18	1	100	350	600	50	163	275	200	300	400
19	1.5	100	550	1,000	50	163	275	600	950	1,300
20	1.5	100	550	1,000	50	163	275	300	500	700
21	6	1,500	1,850	2,200	3,000	4,500	6,000	3,000	4,000	5,000
22	1.5	100	550	1,000	50	163	275	300	500	700
23	1.5	100	550	1,000	300	450	600	800	1,150	1,500
24	1.5	100	550	1,000	50	163	275	300	500	700
25	2	300	750	1,200	2,000	2,500	3,000	1,000	1,500	2,000
26	2	300	750	1,200	1,000	1,500	2,000	1,000	1,500	2,000
27	2	300	750	1,200	100	300	500	400	600	800
28	1.5	100	550	1,000	300	450	600	300	500	700
29	6	1,500	1,850	2,200	500	750	1,000	1,500	1,750	2,000
30	1.5	100	550	1,000	50	163	275	800	1,150	1,500
31	3	500	1,000	1,500	2,000	2,500	3,000	1,500	2,000	2,500
32	3	500	1,000	1,500	300	450	600	600	800	1,000
33	3	500	1,000	1,500	300	450	600	1,500	2,000	2,500
34	3	500	1,000	1,500	300	450	600	600	800	1,000
35	1	500	1,000	1,500	1,000	1,300	1,600	200	300	400
36	1.5	100	550	1,000	300	450	600	300	500	700
37	1.5	100	550	1,000	1,000	1,500	2,000	600	950	1,300
38	3	500	1,000	1,500	300	450	600	600	800	1,000
39	6	1,500	1,850	2,200	500	750	1,000	1,500	1,750	2,000
40	3	500	1,000	1,500	300	450	600	600	800	1,000
41	3	500	1,000	1,500	300	450	600	1,500	2,000	2,500
42	1.5	100	550	1,000	50	163	275	300	500	700
43	1.5	100	550	1,000	300	450	600	300	500	700
44	1.5	100	550	1,000	50	163	275	600	950	1,300
45	1	100	350	600	50	163	275	200	300	400
46	1.5	100	550	1,000	300	450	600	300	500	700
47	1.5	100	550	1,000	1,000	1,500	2,000	600	950	1,300
48	1.5	100	550	1,000	300	450	600	300	500	700
49	3	500	1,000	1,500	300	450	600	1,500	2,000	2,500
50	1.5	100	550	1,000	300	450	600	600	950	1,300

VITA

Dustin Allen Fackler was born on October 29, 1980 to Stephen and Marcia Fackler. Raised in Louisville, Kentucky, he attended grade school at Our Lady of Lourdes and Holy Trinity. He graduated high school in May 1999 from Trinity High School. He fulfilled his co-operative internships at United Parcel Service in the Aircraft Maintenance Industrial Engineering department and received his Bachelor of Science in Industrial Engineering in May 2006 from the University of Louisville J.B. Speed School of Engineering. Dustin is currently pursuing his Masters degree in Industrial Engineering at the University of Louisville.