COMPARISON OF CONNECTED VS DISCONNECTED CELLULAR SYSTEMS USING SIMULATION

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COMPARISON OF CONNECTED VS DISCONNECTED CELLULAR SYSTEMS USING SIMULATION (196 pp.)

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A comparison between two cellular manufacturing systems namely; connected and disconnected systems have been studied in order to evaluate the performance of each system with respect to certain performance criteria. Two cases have been considered namely: Make to Order and Make to Stock environment. In the make to order case, a sub case with different process routings for each family has been considered. Simulation models for each of the systems and each of the cases were developed in ARENA 7.0 simulation software. The data used to model each of these systems were obtained from a medical products manufacturer for a maximum period of nineteen months. The models were run 24 hours a day which basically represented 3 shifts round the clock. It was expected that the disconnected system which had a higher flexibility would perform better in both cases. The results obtained indicate that for case 1, connected system performed better than disconnected system in most of the comparisons made. Also, an increase in routing flexibility resulted in lower flowtimes and work in process depending on the cellular design of the system. In case 2 for the make to stock environment, the disconnected system performed better than the connected system with lower finished goods inventory and lower overall inventory.

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1 Introduction

This chapter gives an overview of the thesis by discussing and outlining in brief some of the topics that would aid in better understanding the rest of this document. The topics in this chapter give an introduction of some of the manufacturing approaches that are widely used in the industry today.

1.1 Group Technology

The Group Technology (GT) philosophy believes in identifying similarities in objects or things and grouping them together to obtain certain benefits. For example, car pooling is a GT phenomenon observed in daily life, where the similarity in people going to the same company or area for work is taken advantage of to reduce cost of transportation. Applications of GT can be found in all walks of life from our house to our workplace to everywhere we go. This philosophy is widely used in all types of industries and on a wide scale in the area of manufacturing. GT as applied to manufacturing takes advantage of parts and processes by treating them in a similar manner. Similar parts are usually grouped into part families based on either their manufacturing process or design features. For example, if parts needed to be drilled as per certain diameters or if they needed certain similar attributes then these parts could be grouped together. Some of the basic methods used for the formation of part families are visual search, math modeling, genetic algorithms, production flow of the parts and classification and coding systems [1]. Application of GT in the manufacturing industry can lead to benefits like reduced cost in production, lower set up times, reduced material handling for moving batches of parts etc.

1.2 Cellular Manufacturing

Cellular manufacturing is a well known application of Group Technology. It involves determining appropriate machine cells and part families. This can be done either by grouping parts into families and then forming machine cells based on the part families or machine cells are determined first and based on these machine cells the part families may be formed or lastly both these formations can take place simultaneously. There can be a machine cell for each part family or some of the machine cells can process more than one part family based on the flexibility of the layout. The factors affecting the formation of machine cells can differ under various circumstances, some of them being: volume of work to be performed by the machine cell, variations in routing sequences of the part families, processing times etc. Some of the types of cellular manufacturing layouts are discussed below.

1.2.1 Connected Cells

Connected cells represent a continuous flow wherein the products enter the cells in the manufacturing area, complete the machining sequence and exit through the corresponding assembly and packaging area after completion of the assembly and packaging sequence. In other words, the output of a cell in the manufacturing area becomes the input to the corresponding cell in the assembly and packaging area. This represents the current manufacturing system in the company that this thesis pertains to. The products essentially follow a unidirectional flow as shown in figure 1.1. There are three cells in the manufacturing area and three cells in the assembly and packaging area.

In these cells, M1 through M3 represent the machines in the manufacturing area, A1, A2 and P1 through P3 represent the machines in the assembly and packaging area.

The three manufacturing cells are similar since they have similar machines and all the products can be manufactured in any of the cells. In the assembly and packaging area this is not the case; the three cells have restrictions in terms of the products that can be processed. Figure 1.1 represents the actual manufacturing system to be studied in this thesis. The constraint for manufacturing the products in the manufacturing area lies in the manner that the products are assembled and packaged. The manufacturing area consists of similar machines and can process parts belonging to any family but this is not possible in the assembly and packaging area because of differences in production rates of machines and the type of machines available in each of the cells. The parts flow through the manufacturing area either through Cells 1, 2 or 3 and then have to go to the respective packaging Cells 1, 2 or 3 because of the packaging constraints. This constraint makes the manufacturing system rigid or less flexible. Hence, the evaluation of alternate cell designs is to be considered in the scope of this thesis. The system considered for this thesis has well defined families which are based on their packaging and hence the formation of cells for this problem was relatively simple.

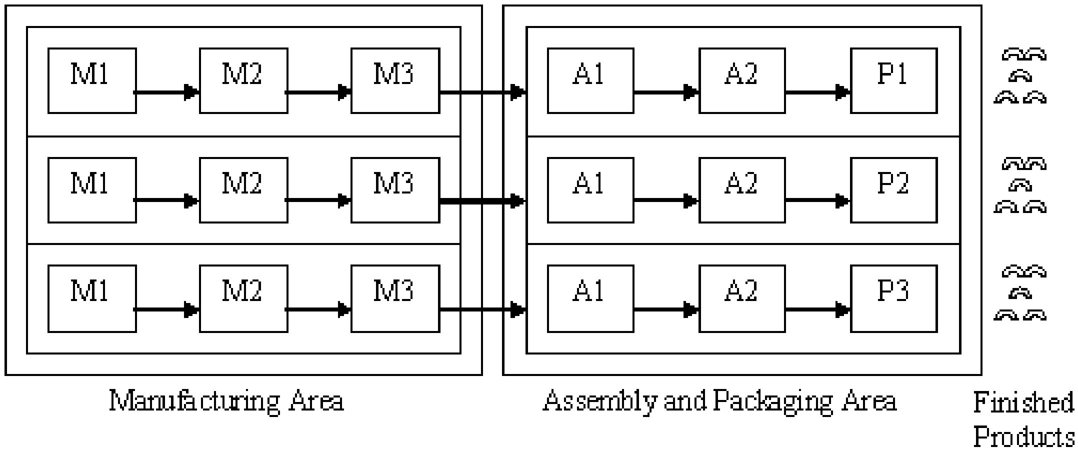


Figure 1.1 Connected cells

1.2.2 Disconnected Cells

In the disconnected cell type of layout, two alternatives may be considered partially flexible cells and completely flexible cells.

1.2.2.1 Partially Flexible Disconnected Cells

This type of disconnected cells represent a disconnected flow wherein the products enter the manufacturing area, complete the machining sequence and exit this area. On exiting the manufacturing area, the products can go to more than one of the assembly and packaging cells and is shown in fig 1.2. In other words, the output from the cells in the manufacturing area can become an input for only some of the cells in the assembly and packaging area. Here, the parts from cell 1 in the manufacturing area can go to any of the cells in the assembly and packaging area. Parts from cell 2 can go to only cell 2, and cell 3 of the assembly and packaging area. Parts from cell 3 of the manufacturing area can go to only cell 3 of the assembly and packaging area.

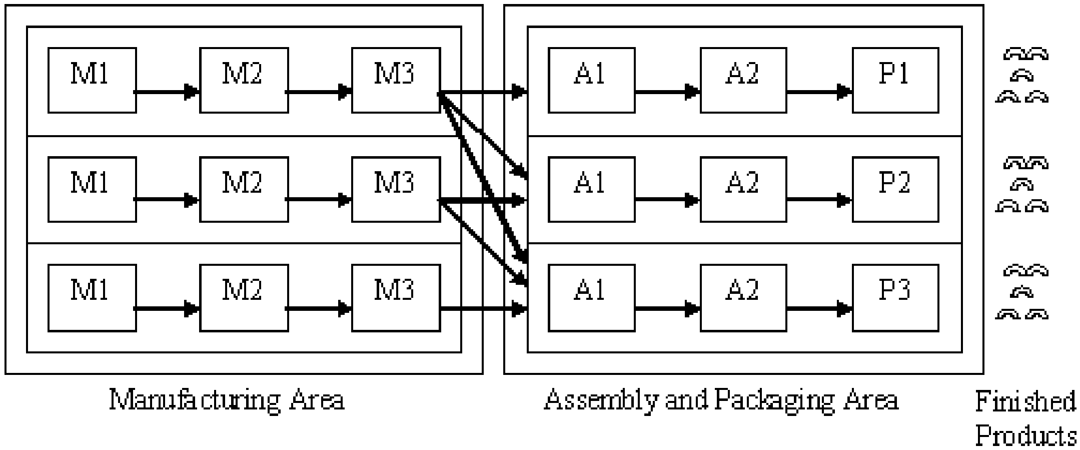


Figure 1.2 Disconnected cells with partial flexibility

1.2.2.2 Completely Flexible Disconnected Cells

This type of Disconnected cells also represent a disconnected flow wherein the products enter the manufacturing area, complete the machining sequence and exit this area. On exiting the manufacturing area, the products can go to any of the assembly and packaging cells, and this is depicted in fig 1.3. In other words, the output from the cells in the manufacturing area can become an input for any of the cells in the assembly and packaging area. This system is one of the alternatives considered in the scope of this thesis.

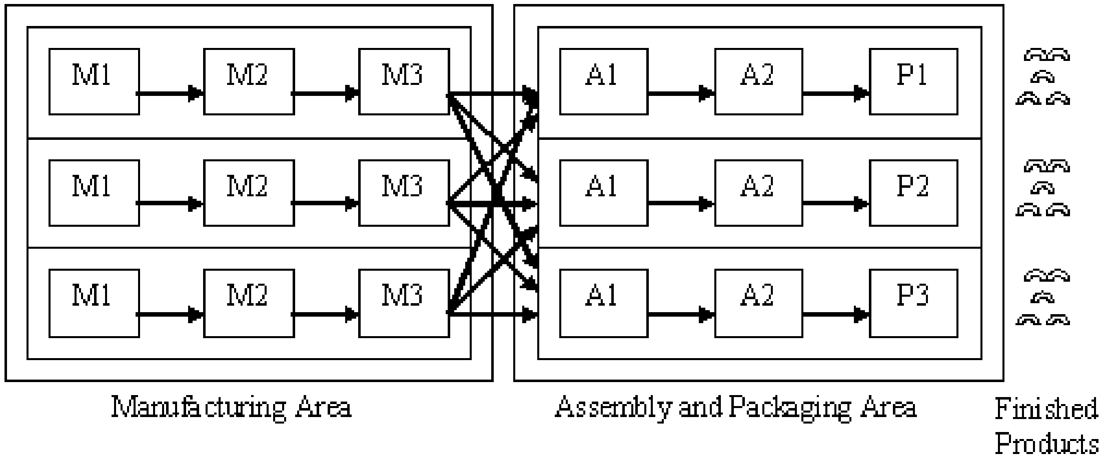


Figure 1.3 Disconnected cells with complete flexibility

1.3 Simulation

The design of an efficient cellular manufacturing system can be extremely complex especially when a greater flexibility is required, resources are limited, etc. In such circumstances it is difficult to visualize the hurdles that could arise which may hinder the prospects for further growth in the organization. Improving systems that are currently used in an organization can also be a challenging task due various restrictions that may exist. To tackle such issues various methodologies and techniques like Mathematical Modeling, Simulation, etc. have been used in the past. A mathematical model does not incorporate for many of the real world situations like machine breakdown, probabilistic order sizes, inter-arrival times of products, probabilistic processing times, etc. in addition to not providing a visual impact of the situation. In order to foresee and identify such unexpected issues a simulation approach could be used. Simulation as a stochastic tool has been around for a while and is popular in the industry due to the insight it provides in understanding and making a manufacturing system robust. It is a faster and cost effective approach to model dynamic systems which is the need of the hour. Simulation can be used as a reliable decision support tool in considering alternate cell designs by developing and running simulation models that give a complete picture of the system even before their implementation. The analysis of the results provided by a simulation run can help identify important performance measures for the system [1]. It provides a cheaper alternative to determine how the addition or deletion of certain resources in a cell or system would affect its performance. Most simulation software provide animation of the events that are being simulated which further helps people to better understand the logic of the system. Various steps like collection and validation of data, assumptions made in the model etc. need to be adopted whilst using simulation as a tool [1].

1.4 Make To Order And Make To Stock

A manufacturing system in which the goods or products are manufactured only after customer orders are received is called a make to order system. This type of system helps reduce inventory levels since no inventory is kept on hand. A manufacturing system in which the goods or products are manufactured and stocked as inventory is called a make to stock system. In this type of system, the finished goods are depleted from the inventory on receiving customer orders. This reduces the delivery time of goods to the customer.

1.5 Objectives

This scope of this thesis is to simulate and compare the behavior of Connected and Disconnected systems under 1) a make to order environment for the as-is scenario and under different routing flexibilities, 2) a make to stock environment. It is desired to compare the Connected and Disconnected cellular systems with respect to various performance measures such as flow times, inventory levels of finished goods, and, work in process inventory. The models for each type of layout is developed using Simulation software Arena 7.0.The warm up times for the simulations were after a steady state for each system had been reached and was decided based on the plots obtained for average work in process and average flowtimes. Thereafter, the system was simulated for a fixed duration and the results obtained were analyzed and conclusions were made.

1.6 Justification

The behavior and comparison of Connected and Disconnected systems are important in order to study dynamics of the systems under different inventory control policies. It is also important to research the impact of flexibility within each system for different combinations of family routings to each of the manufacturing and packaging cells. The company under consideration is a medical device manufacturing company called Lifescan. A similar set up of a connected-disconnected system has been observed at B-Way Corporation, a can manufacturing company. This type of study can be used to study similar set ups and also develop what-if scenarios with modifications in input data, customer orders, family routings, etc.

1.7 Organization Of The Work

This thesis begins with an Introduction Chapter which provides an insight into the rest of the document. It briefly explains the Group Technology philosophy and its application of Cellular Manufacturing in the industry along with outlining some of the advantages of using a tool like Simulation which could be used as a decision making tool. Chapter 2 covers previous work and relevant literature that has been established in the area of cellular manufacturing pertaining to connected and disconnected cells. Chapter 3 explains the actual system that is in practice in the real world along with considering certain alternate systems that could be used. Chapter 4 basically presents the methodology used in evaluating the current system and its alternatives. In Chapter 5 the results of the system studied are presented in detail. In the final Chapter 6, conclusions from the results obtained are made along with suggesting the scope for future work.

2 Literature Review

This chapter reviews various research papers or journal articles pertaining to the scope of this thesis that have been published in the past. A brief explanation of each paper/journal article is attempted in this section.

2.1 Simulation

Flynn and Jacobs [2] developed a simulation model using SLAM for an actual shop to compare its performance with a group technology layout against a process layout. Each type of layout was modeled based on the physical arrangement of the machines and the dedication of the machines to a group of parts. CRAFT was used to model the four types of layouts that were examined in their study. Four demand distributions were used to compare the layouts. Another feature of the simulation was the re-routing of parts to other machines when the queue lengths were too long. Each model was run for a simulated period of 20 years with a start up period of seven years. They concluded that dedicating machines to a cell reduces the average set up time. Also, GT reduces the distance traveled by a batch of parts by arranging the machines that are most frequently used in a sequence. There was no difference observed in the average machine utilization between the layouts. It was also observed that even though the set up and transfer times were high, the flexibility of machines gave overall advantages. Another conclusion stated was that not all GT models necessarily perform well and their performance depends on the layout.

Morris and Tersine [3] developed simulation models for a process layout and a cellular layout using SIMAN. MICROCROFT was used to position the cells and machines for the sake of consistency. Four experiments were conducted involving four variables namely ratio of setup to process time, material transfer time, demand stability and the flow of work within cells. The two performance measures used were throughput time and work in process inventory (WIP). A statistical analysis of the two layouts was performed using a weighted two stage sample mean as a performance measure. They concluded that cellular layouts are likely to offer an operating advantage under certain conditions such as long set up times, predictable demand, considerable move times etc. They also mentioned batch sizes, labor constraints and machine breakdowns as some of the performance measures that could be used in evaluating the two layouts.

Selen and Ashayeri [4] used a simulation approach to identify improvements in the average daily output through management of buffer sizes, reduced repair time, and cycle time in an automotive company. A total of nine buffers were defined in the cell layout. The mean time failure for each operation was calculated independently according to a negative exponential distribution. For repair times an empirically derived frequency table was used for most of the operation, while a Erlang distribution was used for the rest. The output parameter was defined as the number of finished products. Two cycle time settings, four buffer sizes, and two mean times to repair (MTR) lead to a total of 16 combinations to be tested. A statistical analysis using a three factor ANOVA model was conducted. Results showed that cycle times and mean time for repair had significant impact on the output. The standard deviation of the data decreased as the buffer size increased. They also found that one buffer setting of the four gave the best results though they were not significantly differently from each other.

Bertolini and Rizzi [5] designed and developed a simulation model to optimize the management of an integrated finished goods inventory system which can also be adopted in a wide range of make to stock systems. The model was developed to operate in a mixed push-pull environment wherein the Master Production Schedule (MPS) is set at the beginning of each month based on forecast and then adjusted on a daily basis according to the demand. The objective of their model was to minimize inventory holding cost through the assessment of optimal inventory management coefficients and to adjust to the MPS in order to prevent stock outs. The input variables for the simulated system were safety stock levels and stochastic distributions for the demand of products. The simulation model was applied to test a case study in a zootechnical feeds production industry. The authors concluded that firms characterized by high flexibility could alter their MPS without incurring substantial costs. The opposite holds true for firms with low flexibility in addition to the annual overall inventory management cost being higher. For both types of firms the holding cost is the key and the optimal configuration has to be determined by minimizing safety stock levels.

Yazici [6] designed and developed a simulation model using Promodel based on data collected from a screen-printing company to ascertain the influence of volume, product mix, routing and labor flexibilities in the presence of fluctuating demand. A comparison between a one cell and two cell configurations versus a job shop is made to determine the shortest delivery and highest utilization. An infinite supply of raw material is maintained through an initial buffer and a high inter-arrival frequency and customer orders are stochastically generated based on data collected. A fixed order release rule is adopted which accepts a maximum of seven orders by rejecting the rest till a previous order is completed and leaves the system. A one piece flow of parts of each order is adopted in the system for the cellular environment and a batch flow is adopted for the job shop. Impact of labor flexibility on the system is studied under low, medium and high flexibility levels. The system was simulated for 5000 hours and 10 replications were performed. The author concluded that effect of volume flexibility decreases as routing flexibility increases in the presence of cellular manufacturing. Also, with an increase in volume quantity and frequency for a 2 cell configuration a significant increase in labor utilization was observed due to sharing of workers within and across cells.

Albino and Garavelli [7] simulated a cellular manufacturing system using Matlab to study the effects of resource dependability and routing flexibilities on the performance of the system. The authors investigate three cases namely: a) balance between routing flexibility and the cost arising from providing alternate routes for part families, b) cell loading rule to be used, c) effect of the distributions used in modeling the capacities of the cells in a given period on system performance. Based on the simulation results, the authors concluded that as resource dependability decreases, flexible routings for part families can increase productivity. On the contrary, from an economic standpoint they concluded that benefits will greatly reduce from an increase routing flexibility cost and resource dependability. Lastly, they pointed out that the efficiency of dedicated cells for parts can be reduced by high lost sales and proposed a condition to recognize the trade off between cost of lost sales and cost of processing part families in non dedicated cells.

Caprihan and Wadhwa [8] studied the impact of fluctuating levels of routing flexibility on the performance of a Flexible Manufacturing System (FMS). A hypothetical FMS comprising of six machines is considered, each capable of producing up to six different part types. Makespan is used as a performance measure for the study. The system is simulated using SIMAN IV and only one replication was performed for each experiment. Some of the assumptions made were: machines never break down, pre-emption is not allowed, and, operation times are deterministic etc. The methodology for the study is based on the Taguchi experimental design to conduct an analysis of means and variances from the simulation results obtained. Based on results obtained, the authors concluded that there is an optimal flexibility level beyond which the system performance tends to decline. Also, increase in routing flexibility when made available with an associated cost seldom tends to be beneficial.

2.2 Group Technology

Hamid et al. [9] used an Analytic Hierarchy Process (AHP) methodology to evaluate layouts. Three layouts namely process layout, cellular layout and flow lines were considered. The main objectives considered for selection of layouts were increasing flexibility, increasing production volume and reducing manufacturing costs. AHP can be used to hierarchically structure a complex problem consisting of multiple attributes while incorporating the inconsistencies that may arise on the decision maker's side. The hierarchy as explained by the authors consists of different elements at each level. A likewise comparison of the elements at each level is then done using a scale giving an indication of the strength by which one element dominates another with respect to a higher element. This scaling process can be transformed into weights or scores and the layout with the highest score results in being the best alternative that can be chosen.

2.3 Make To Order Versus Make To Stock

Arreola-Risa and DeCroix [10] studied the optimality of a Make to Order (MTO) versus a Make to Stock (MTS) policy for a manufacturing set up producing various heterogeneous products facing random demands. These optimality decisions were derived for two back-order cost cases namely: $ per unit and $ per unit per unit time. The authors build a cost model to come across some of the basic properties that can be used for optimization purposes. They concluded that in the first back order cost case the optimality conditions were independent of manufacturing times. In the second case where the optimality conditions were dependent on manufacturing times, the authors identified scenarios where the MTO vs. MTS decision can be made entirely on the first moments of the manufacturing time distributions.

Federgruen and Katalan [11] investigated a hybrid system comprising of Make to Order (MTO) and a Make to Stock (MTS) systems and presented a host of alternatives to prioritize the production of the MTO and MTS items. In their study a single MTO item was considered which was primarily distinguished by the type of priority it was given in the overall production strategy. It was also assumed that a MTO would have zero inventory. The authors state that a production/inventory strategy consists of an appropriate interruption discipline that determines the switch from MTS items to MTO items and, a schedule that determines the type and quantity of MTS items to produce in the absence of interruptions for MTO items. The authors also discuss several interruption disciplines that could be considered. The authors evaluated the various alternatives under different performance measures like inventory and waiting time distributions, average setup cost, average holding cost, average backlogging costs etc. They also deduced stability conditions and expressions for the effective utilization rate for the different options presented. The authors in particular compared absolute priority and postponable priority schemes to evaluate the best one and also to identify the circumstances under which it would excel. Absolute priority rules were given to MTO items and were either preemptive or non-preepmtive. Postponable priority rules allow the insertion of MTO items in the MTS production item schedule only in the event that the facility would switch between MTS items. Among other conclusions, the authors concluded that absolute priority rules tend to dominate when setup times are low, the demand rate for the MTO items was small and a high service level was required.

Liberopoulos and Dallery [12] investigated a single stage production inventory system of a manufacturing facility that operated in a make to stock mode consisting of parts either in work in process (WIP) or finished goods (FG). Some of the assumptions made by the authors were: there is an infinite supply of raw material and a single type of part being produced, demand for FG inventory arrives randomly, demands that are not satisfied by the FG inventory are backordered etc. The authors focused on a two parameter replenishment policy called a base stock with WIP cap policy. The policy dictates that whenever the difference in the sum of the WIP and FG inventory and the backordered goods fall below a specified level an order for the release of a new part in system is issued. If the WIP inventory falls below another specified level called the WIP cap then the order goes through and the part is released into the system. The authors concluded that for the system studied, the optimal base stock is a non increasing function of the WIP cap. They also concluded that the optimal base stock and WIP cap are in a region where there is a trade off between the both. In addition, they related the optimal parameters of a system operating under a base stock with WIP cap policy and a system operating under a make to stock CONWIP policy.

Van Donk [13] used the concept of decoupling point (DP) developed by two other authors to develop a frame in order to help managers in the food processing industries to decide which of their products should be made-to-order (MTO) and which ones should be make-to-stock (MTS). The authors stresses that the concept of decoupling point is important in the food processing sector due to the manufacture of a variety of products to meet high logistical demands at low costs. A case study was performed by the author using the frame for a food manufacturer to study the alternate DP's available and locate the best one. The frame also helped decide which products were to be MTO and which ones were to be MTS. The author noted that the customer service improved with respect to speed of delivery and dependability which in turn reduced inventory cost. The author also mentioned that decisions to be made with respect to the DP compels the company to gather information regarding patterns in demand, orders, and lead time which may not be available in the company.

2.4 Delayed Product Differentiation

Gupta and Benjaafar [10] presented a delayed product differentiation methodology; a hybrid strategy which is a combination of Make to Order (MTO) and Make to Stock (MTS) modes of production. This strategy is applied in two stages. The first stage takes advantage of the similarities between the products being manufactured by building the common product platform in a make to stock mode of production. In the second stage, the products are built according to specific customer demands. In this manner semi finished goods are maintained in stock which relatively reduces the lead time when compared to a pure MTO system. Semi finished goods are maintained in inventory which is relatively cheaper as compared to maintaining finished goods in inventory. The authors build three models to realize the benefits and costs in implementing this strategy in a series production type of system where in the order lead times were load dependent. The first model compares the MTS and the Delayed Differentiation (DD) strategies under different situations namely: the effect of loading, the effect of the number of products, and the effect of the service level. The second model studies the feasibility involved in identifying the optimal Point of Differentiation (PoD) which corresponds to the point at which the buffer is placed and divided into MTO and MTS stages of production. The third model studies the effect of partial DD in which multiple partially differentiated parts are produced and stocked in separate buffers. The authors concluded that a tighter capacity reduces the desirability of a DD and favors a MTS mode of production and that flexibility in choosing PoD favors a later differentiation in the case of higher loading.

Hsu and Wang [15] constructed a dynamic programming model using an AND/OR graph to establish points in the manufacturing process where the product can be differentiated. The costs and the benefits associated with the decisions of determining differentiation points at each design stage were taken into account. A work in process (WIP) inventory is held in store after each stage of manufacturing. The inventory levels are maintained by each of the stock points using a periodic review policy and it is also assumed that each of the stock points have the same review period. The authors concluded that product deferment leads to lower inventory levels to achieve the required service level. They expect the model developed to play a major role in solving the problem of establishing points for product differentiation deferment.

He et al. [16] developed a methodology for implementing the delayed product differentiation strategy in a manufacturing environment. The manufacturing environment for the study was an assembly line with no buffers between stations. Three design rules are suggested along with quantifying and incorporating the impact of this strategy in product design. In addition, the problem of selecting product designs to minimize the number of parts and cycle time in manufacturing was formulated and solved using an integer programming model. The authors provided guidelines to implement the methodology which suggest that first alternate differential designs should be developed. Secondly, the design rules should be applied to eliminate undesirable designs, and lastly the equations developed to optimize the designs should be solved.

Garg and Tang [17] developed two models in order to study products involving two point of differentiation. In each of the models, the advantages of delayed differentiation at each of the points are studied and conditions are derived when one type of delayed differentiation is superior to the other. The difference between the two models is that the first one is based on a centralized policy which means that only finished goods inventories are maintained. The second model is based on a decentralized policy which means that inventory is maintained after each stage of the production process. Three special examples for the centralized policy were investigated in order to study the optimal points of delayed differentiation which would best reduce the finished goods inventory. The authors discussed the limitations of the study, some of them are: demands of the retailers were normally distributed but in reality they could be correlated over time, ample production capacity was assumed at each stage but in reality the capacity needs to be evaluated for systems with high utilization. Also, the costs associated with the delay strategy need to be incorporated and studied.

2.5 Order Review And Release Strategy

Nandi and Rogers [18] simulated a manufacturing system to study its behavior in a make to order environment under a control policy involving an order release component and an order acceptance/rejection component. The order arrival times are sampled from a Gamma distribution which are either accepted or rejected based on an acceptance/rejection rule. The accepted orders are held in a pre-shop pool known as the Order Release Pool (ORP) before they are released to the shop floor which is again based on an order release rule. The jobs that enter the shop floor are prioritized on the machines based on the First in First out (FIFO) rule. The primary performance measure used is the sum of the percentage of orders rejected by the acceptance/rejection rule and the percentage of orders that are accepted but are not completed on time. In addition average tardiness, average overall flow time, average overall lead time, average overall waiting time, work in process, and average machine utilization are the other performance measures used. The authors concluded that releasing orders to the shop floor as soon as they were accepted appeared to minimize the rejection and tardiness losses. However they argued that it would not necessarily always be the case and it required further experimentation in order to find out combinations of experimental factors that would lead to an overall increase in performance by using a delayed release policy.

2.6 Re-order Point

Grubbström and Wikner [19] modeled standard inventory ordering rules in terms of controls systems theory by designing a differential equation. The equation developed for the system represents a reorder point which is triggered when a certain predefined inventory level is reached. The authors considered a one product system and the task of optimizing the system was not taken into consideration. The two inventory control policies considered were periodic review and continuous review. The authors concluded that the typical inventory processes can be expressed as differential equations involving Heaviside and Dirac impulse functions. Also, the equations developed corresponded to order policies that generate saw tooth like patterns

Ward [20] developed a simple regression model to determine reorder points for items having a fluctuating demand pattern based on the knowledge of demand parameters and the required service level. The lead time was assumed to be known and constant. A continuous review type of inventory policy was used with an order quantity, order point (Q, R) approach. A joint optimization of Q and R has not been addressed by the author but instead is based on an independently calculated order quantity. The author concluded that the applicability of the model in the real world depends on how similar the demand distribution is to the stuttering Poisson model which is the basis of the regression model.

Braglia and Gabbrielli [21] used a genetic algorithm approach to calculate the EOQ and reorder points for products in a machine manufacturing company. The goodness of the solutions obtained from the GA was evaluated by using them in a deterministic simulation. A comparison between EOQ, MRP and GA approaches were made in terms of number of orders and annual average inventory level. The authors concluded that there was no significant difference between the three approaches, especially between the EOQ and GA approaches. A lower average inventory level and number of orders with the GA approach was observed to be lower as compared with the EOQ approach.

Yang [22] tested the Kanban and reorder point policies for managing the production of a set of different parts on a single machine using a simulation model built using SLAM II. The policies were tested for different levels of demand variability, set up time requirement, and machine utilization. The demand for the parts fluctuated but was not lumpy. Based on the experimentation conducted, the author concluded that the Kanban policy consistently required lower average inventory as compared to reorder point to achieve a 90% customer satisfaction level. The results also showed that the advantage of using Kanban diminishes as the demand variability, set up time or machine utilization is reduced. The experimentation conducted also showed that the kanban approach is easier to implement as compared to reorder point to achieve varying levels of customer service.

3 System Description And Alternate Designs

This chapter describes a medical device manufacturing company operating in a clean room environment mainly divided into two areas, namely Fabrication and Packaging. Each area consists of three cells. The differences between the three cells along with the quantities and types of machines available in each cell are presented. A connected system and disconnected system are the cellular designs considered for the manufacturing system in question. Various performance measures are used to compare their performance under different configurations.

3.1 System Description

3.1.1 Part Families

The products are categorized under three families: Family 1, Family 2, and Family 3. The products for this system are vials consisting of blood sugar strips and each vial essentially contains 25 strips. Table 3.1 shows the number of products belonging to each family. Tables showing the inter-arrival time distributions and the order size distributions for each product and family are present in Chapter 4.

Table 3.1 Product-family matrix

Family type	Products
Family 1	P1 to P11
Family 2	P12 to P32
Family 3	P34 to P36

The product structures of each family are shown in fig 3.1. Families that are described were already formed by the manufacturer based on type of product. Family 1 (F1) requires only one subassembly (S), one box (B1), one Label (L), and one Insert for instructions (I), Family 2 (F2) requires 2 subassemblies, one box (B2), one label and one insert, and Family 3 (F3) requires 4 subassemblies, one box (B3), one label and one insert to become finished products.

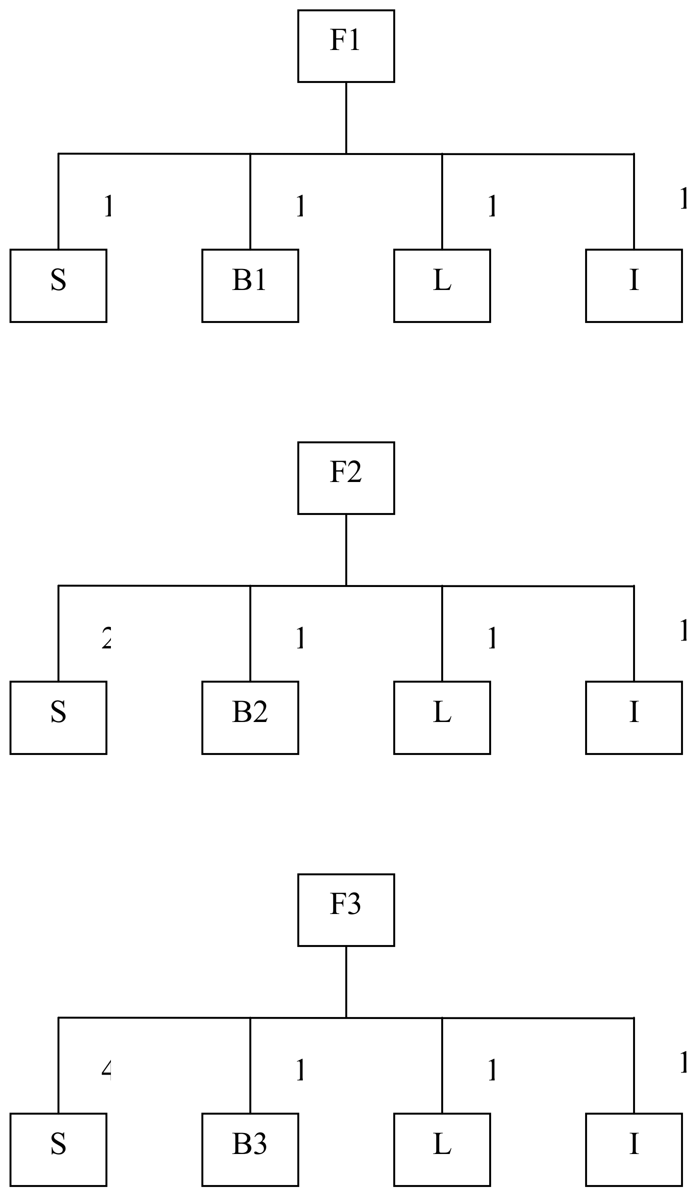


Figure 3.1 Product structures of families

3.1.2 Fabrication

The Fabrication area is where the subassemblies used for the finished products are manufactured. This area contains three cells which fabricate a single common subassembly and hence all three families can be manufactured in any of the three cells. Table 3.2 shows the family types that can be processed in each fabrication cell. The fabrication area has a conveyor system which transfers the products from one machine to another based on a one piece flow principle.

Table 3.2 Fabrication matrix of families and cells

	Fabrication Cell 1	Fabrication Cell 2	Fabrication Cell 3
Family 1	●	●	●
Family 2	●	●	●
Family 3	●	●	●

3.1.3 Operations In Fabrication

There are three operations associated with the Fabrication area:

Operation 1 (Lamination): This operation involves attaching a thin paper film of plasma, whole blood, or hospital material to a harder surface which provides the necessary firmness. It is then converted to a long roll of plastic film.

Operation 2 (Slicing and Bottling): This operation involves the slicing and bottling of the roll of plastic film of either plasma, whole blood, or hospital material assembled in the previous operation. The slicing of the film converts it into small strips.

Operation 3 (Capping): Here, the strips are enclosed in vials and closed with a cap.

The machines used for Operation 1 in all three cells are similar and work under the same velocities (120 vials/min) but the number of machines within each cell varies. Operation 2 has machines that process 17 vials/min and 40 vials/min. Similarly, Operation 3 has machines that process 78 vials/min and 123 vials/min. Table 3.3 shows the distribution of machines and velocities among the three cells.

Table 3.3 Machines and their production rates for the system

	Operation 1	Operation 2		Operation 3		Output of Bottleneck (vials/min)
		Type I	Type II	Type I	Type II	
Production Rate (vials/min)	120	17	40	78	123	
Cell 1	1	2	2	0	1	114
Cell 2	1	4	0	1	0	68
Cell 3	2	3	2	0	2	131

3.1.4 Packaging

The packaging area also has a conveyor system similar to the fabrication area which transfers products within packaging cells and also from the fabrication cells to the packaging cells. In the Packaging area, the subassemblies produced in the Fabrication area are used to produce the various finished products. Packaging Cell 1 is semiautomatic while Cells 2 and 3 are automatic. This difference in the types of machines results in constraints that do not allow the packaging of certain products in certain cells. There are total of 38 finished products which differ in: the quantity of vials they contain, the type of raw material the vials are made of, and the destination of the country to where they will be shipped. The finished products in Family 1, Family 2, and Family 3 consist of 1, 2, and 4 vials or subassemblies, respectively. The families are constructed based on the number of vials or subassemblies due to the constraint in the packaging of the vials as shown in table 3.4.

Table 3.4 Packaging matrix of families and cells

	Packaging Cell 1	Packaging Cell 2	Packaging Cell 3
Family 1	●	●	
Family 2	●	●	●
Family 3	●		●

3.1.5 Operations In Packaging

The packaging area comprises six operations with each operation using only one machine. The operations are described as follows:

Operation 4 (Feeding): In this operation, the subassemblies from Operation 3 in the Fabrication area are supplied to the cell in the packaging area. This operation is only performed in the case of disconnected cells.

Operation 5 (Labeling): Here, labels are placed on the bottles describing specific details of the product.

Operation 6 (Assembling): The difference in packaging among the three cells lies in this operation. The assembly operation is performed by a single machine in Cells 2 and 3, whereas in Cell 1, two machines and three operators are required for the same.

Cell 2 and Cell 3: In these cells all the tasks are performed by a single machine namely: assembly of the box, insertion of subassemblies or vials into the box, insertion of instructions for usage into the box, and box closure.

Cell 1: This operation is divided into four operations: two carried out manually by operators and two by machines. The four operations are as follows:

Operation 6a (Assembly and Bar Coding): A machine assembles and bar codes the boxes to enclose the vials.

Operation 6b (Vial Insertion): An operator manually inserts vials into the box assembled in the previous operation.

Operation 6c (Instruction insertion): An operator manually inserts the instructions for product usage into the box.

Operation 6d (Box Closure): Here the machine closes the box containing the vials.

Operation 7 (Sealing): This operation is common to all cells. Here, the boxes are sealed by a machine.

Operation 8 (Bar Coding): In Cells 2 and 3 this operation is performed by a machine whereas in Cell 1, Operation 6a assembles and bar codes.

There are three operators assigned to operations 3b and 3c. One operator each is permanently assigned to Operation 3b and 3c. The third operator is normally is assigned to operation 3b but may alternate between Operations 3b and 3c. The third operator assists in reducing work in progress that may accumulate at either of the operations by shifting from one operation to another. The operator also provides an immediate substitution for any of the two operators who may leave their station for any reason.

The production rates for the three families for each operation are constant except for Operation 6. Table 3.5 shows the production rates of the machines in all cells.

Table 3.5 Production rates for packaging machines in vials/minute

		Operation				
		4	5	6	7	8
Cell 1	Family 1	160	135	**80	150	150
	Family 2	160	135	**80	150	150
	Family 3	160	135	**80	150	150
Cell 2	Family 1	160	135	100	150	150
	Family 2	160	135	180	150	150
	Family 3	NA	NA	NA	NA	NA
Cell 3	Family 1	NA	NA	NA	NA	NA
	Family 2	160	135	150	150	150
	Family 3	160	135	280	150	150

NA indicates that the combination of the particular cell and family does not exist.

**The production rates for the packaging Operation 6 in Cell 1 is shown in table 3.6 of which 80 vials/min is the bottleneck production rate.

Table 3.6 Production rate for operation 6 in cell 1 in vials/minute

	Operation			
	6a	6b	6c	6d
Family 1	160	80	152	120
Family 2	160	80	152	120
Family 3	160	80	152	120

3.2 Alternate Designs

3.2.1 Connected System

The current manufacturing system is set up such that the packaging cells form an extension or continuation of the respective fabrication cells. In other words, the output of a cell in fabrication area becomes the input for the corresponding packaging cell. Hence, it is referred to as a connected system. A connected system is shown in fig 1.1. The cell routing for each family is shown in fig 3.2. The output of Family 1, Family 2, and Family 3 is essentially based on the bottleneck or the slowest machine in each cell of the fabrication or the packaging area and is shown in table 3.7.

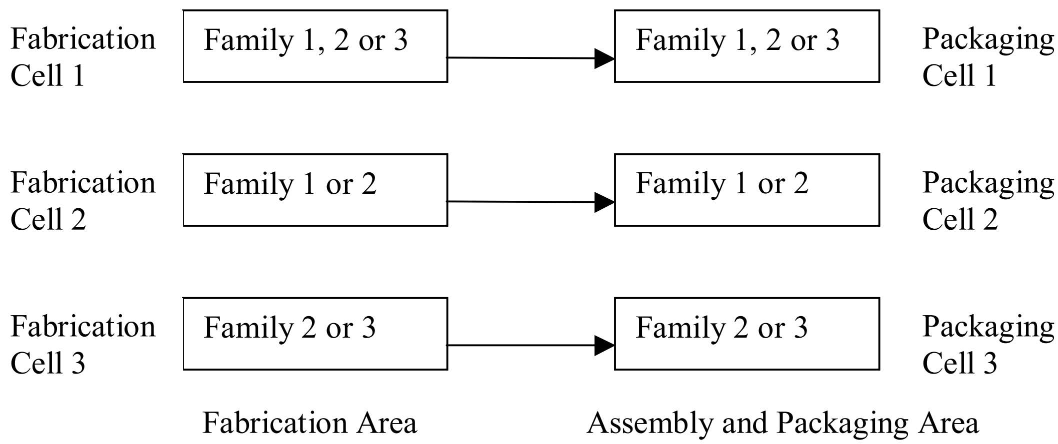


Figure 3.2 Cell routing of families for connected system

Table 3.7 Output rate of each cell for the connected system

Cell #	Family #	Output rate of bottleneck machine in Fabrication area (vials/min)	Output rate of bottleneck machine/operator in Packaging area (vials/min)	Output rate (vials/min)
Cell 1	Family 1	114	80	80
	Family 2		80	80
	Family 3		80	80
Cell 2	Family 1	68	100	68
	Family 2		135	
Cell 3	Family 2	131	135	131
	Family 3		135	

3.2.2 Disconnected System

The disconnected system is an alternate design developed, considered and compared with respect to the connected system for the medical company. In this system, the output of a cell in the fabrication area can become an input for more than one cell in the packaging area depending upon the constraints in the packaging area. This can be considered to be a partially flexible disconnected cells type of system as discussed in section 1.2.2.1. The cell routing for each family is shown in fig 3.3. This provides a greater amount of flexibility with respect to routing the parts in the system. The part families, production rates for machines in the fabrication and the packaging area, and the overall fabrication and packaging process remain unchanged. The output rates of Family 1, Family 2, and Family 3 is essentially based on the sum of the output rate of the bottleneck or the slowest machine in each cell of the fabrication or the packaging area and is shown in table 3.8.

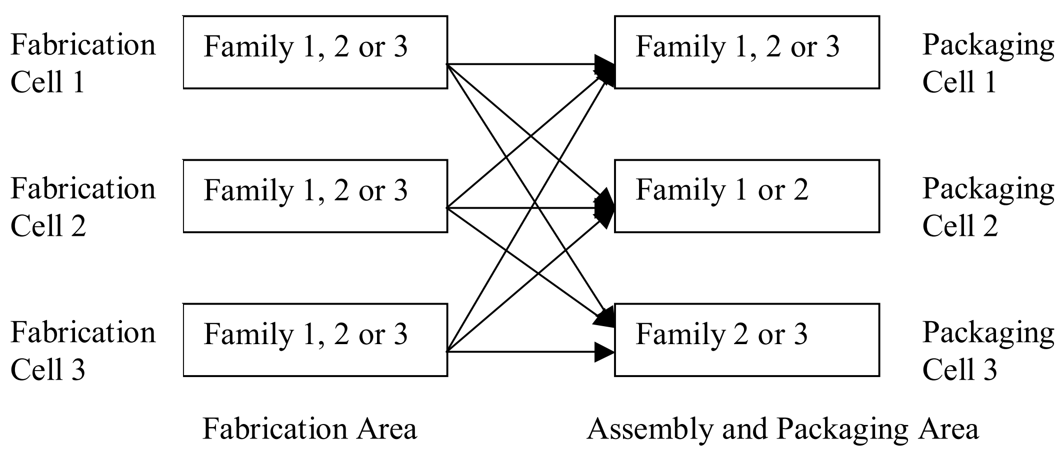


Figure 3.3 Cell routing of families for disconnected system

Table 3.8 Output rate of each routing combination for the disconnected system

Family #	Fabrication area cell (Output of bottleneck machine in vials/min)	Packaging area cell (Output of bottleneck machine in vials/min)	Output rate of routing combination (vials/min)
Family 1	Cell1 (114)	Cell1 (80)	80
	Cell1 (114)	Cell2 (100)	100
	Cell2 (68)	Cell1 (80)	68
	Cell2 (68)	Cell2 (100)	68
	Cell3 (131)	Cell1 (80)	80
	Cell3 (131)	Cell2 (100)	100
Family2	Cell1 (114)	Cell1 (80)	80
	Cell1 (114)	Cell2 (135)	114
	Cell1 (114)	Cell3 (135)	114
	Cell2 (68)	Cell1 (80)	68
	Cell2 (68)	Cell2 (135)	68
	Cell2 (68)	Cell3 (135)	68
	Cell3 (131)	Cell1 (80)	80
	Cell3 (131)	Cell2 (135)	131

Table 3.8 Output rate of each routing combination for the disconnected system (continued)

Family #	Fabrication area cell (Output of bottleneck machine in vials/min)	Packaging area cell (Output of bottleneck machine in vials/min)	Output rate of routing combination (vials/min)
Family 3	Cell1 (114)	Cell1 (80)	80
	Cell1 (114)	Cell3 (135)	114
	Cell2 (68)	Cell1 (80)	68
	Cell2 (68)	Cell3 (135)	68
	Cell3 (131)	Cell1 (80)	80
	Cell3 (131)	Cell3 (135)	131

4 Methodology

This chapter describes the methodology used to develop the different simulation models for the current manufacturing system in Arena 7.0 for analysis. A flow chart representing the simulation logic is shown to provide a better understanding of the system.

4.1 Cases Considered

1 a. Make to Order – Existing System: This case studies the as-is behavior of the manufacturing facility for a connected as well as a disconnected type of manufacturing system in a make to order type of environment.

1 b. Make to Order – Different Scenarios: This case studies the behavior of connected and disconnected systems developed in Case 1A for different combinations of family routings.

2 a. Make to Stock – Existing System: Similar to Case 1A, this case studies the as-is behavior of the manufacturing facility in a make to stock type of environment.

The results and comparisons between the connected and disconnected systems are presented in chapter 5.

4.2 Overview Of Simulation Methodology

4.2.1 Assumptions

A few assumptions were made while developing and experimenting with the simulation models. No set up times were used in the simulations for processing different families on machines. Machines were assumed to run without any breakdowns. For case 2, there would be a lost sale in the event that there would be insufficient finished goods inventory to satisfy the customer order. Some other constraints that existed in the company that were implemented in the models were: no preemption allowed, unit transfer size of material in vials, and, no material handing time.

4.2.2 Input Data Analysis

Every simulation model has an input or more than one input, based on which the output or outputs are obtained. Some of the inputs to build simulation models with reference to this thesis are production orders, their respective inter-arrival times, processing times, routings etc. The production orders can either be constant or be randomly generated or follow a particular distribution based on the input requirements. The inter-arrival times can also be constant or be randomly generated or they could follow a particular distribution based on the requirements of the system being modeled. Processing times, routings for families are generally obtained from the company or manufacturer that the simulation is being modeled to study or it could be based on experimental data developed for certain hypothetical case studies.

4.2.3 Validation And Verification

Validation and verification are an inherent part of any computer simulation or computer program. It is important that the model developer has sufficient confidence that the program or simulation is valid for the proposed task. Verification is the process of checking whether the model is working as intended. Flow charts are convenient way of depicting the logic or system behavior and should be used in building the model to help the verification process. Validation is the process in which the simulation or program developed accurately reflects the actual system it is being modeled after and is providing expected results. Pilot runs are generally performed to validate and interpret the results against the actual system.

4.2.4 Flowchart Of Simulation Model

A general flowchart explaining the routing of different families based on bottleneck machines and minimum queue sizes is shown in figure 4.1. Entities entering the system are routed to the cells in the fabrication area based on packaging constraints and minimum queue sizes. The entities are processed on each machine in the fabrication area following which they enter the packaging area. After getting processed in the packaging area the entities are batched as per the production order sizes and the leave the system.

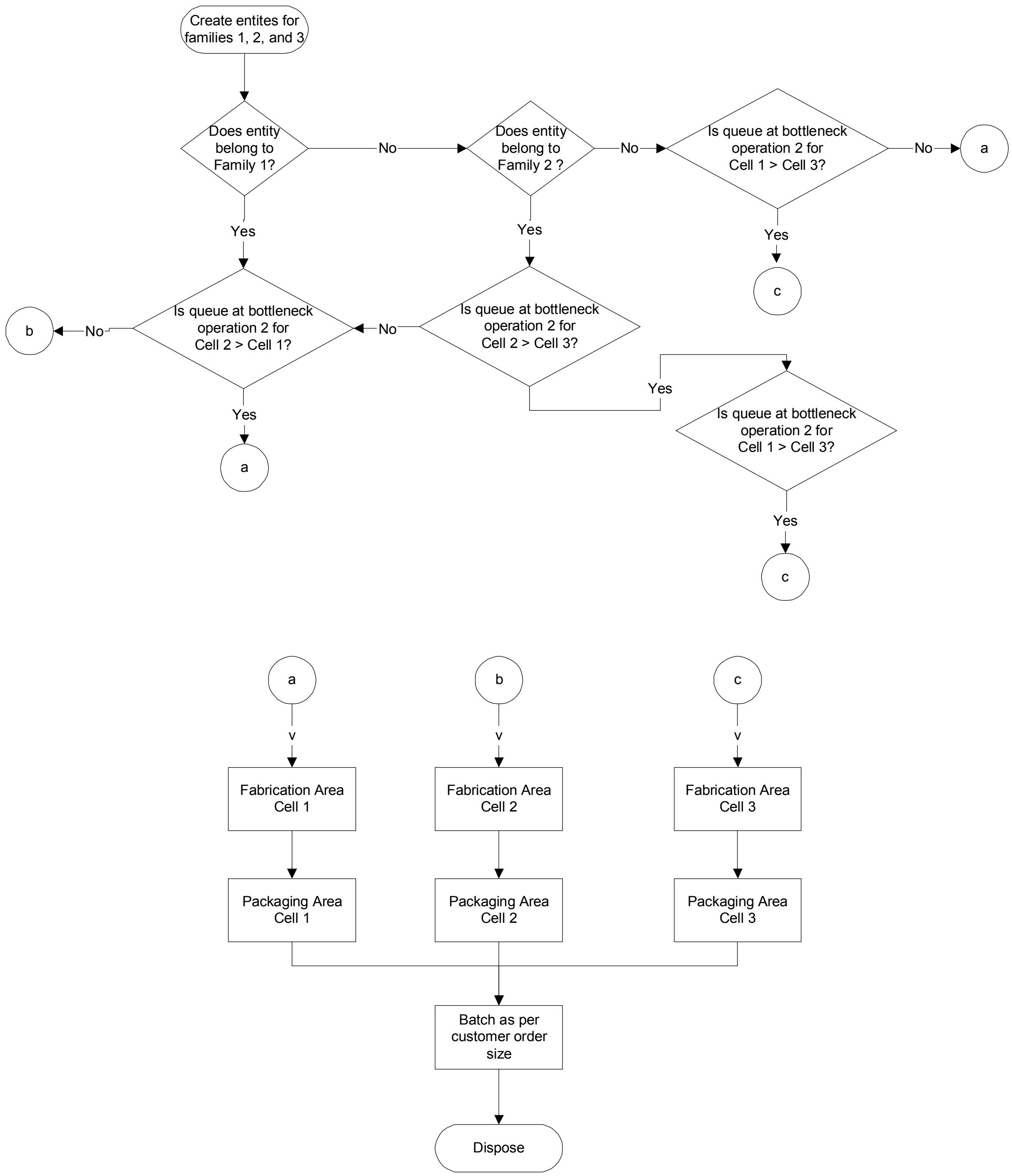


Figure 4.1 General flowchart of simulation model for cases 1 and 2

4.3 Methodology For Case 1A

This depicts the as-is scenario of the manufacturing system prevailing in the company. A direct comparison is made between the Connected and Disconnected systems.

4.3.1 Connected System

4.3.1.1 Input Data Analysis

In this case, some of the inputs were customer order sizes of the products, their respective inter-arrival times, processing time for each of the families, and family routings. The customer order sizes for each product per day in the model are based on a distribution which was determined based on the information obtained from the company. It was calculated as follows. The data provided was basically the total sales volume in vials for each part belonging to one of the three families for a period of nineteen months. The order sizes per day were calculated from this data by dividing the sales figure of a product for a particular month by the number of days there were sales for the respective product. For example, if product 1 had a total sales of 4466 units for a particular month and the number of days the product was sold was 22 then the order size for that product per day in that month was 4466/22 = 203 units. Due to the constraint of having a limited number of entities in Arena, the order sizes per day were divided by 100 and hence each entity represented 100 entities of the same. These order sizes were used to determine a distribution which would best represent the order sizes for that product. This task was accomplished using the Input Analyzer in Arena which takes the data as input and provides the distribution with the best fit. In this way, the order size and hence a distribution for each product was calculated for a maximum period of nineteen months.

The inter-arrival times (days) for each product in the model are based on a distribution. The inter-arrival time for each product in days was calculated for each month for a maximum period of nineteen months. This was calculated by dividing the number of days there were sales for the respective product in that month by the highest sales days for any product in that month. For example, if product 1 was sold for 22 days in a particular month and product 5 was sold for 23 days which was the highest compared to any another product in that month then, the inter-arrival time for product 1 would be 23/22 = 1.04 days. These inter-arrival times were used to determine a distribution which would best represent the inter-arrival times for that product. This task was also accomplished using the Input Analyzer in Arena.

4.3.1.2 Creation Of Entities In Arena

Entity creation in Arena was based upon the order sizes and the frequency of arrival of the different products and was determined as explained in the previous section in this chapter. The products are categorized under three families or entity types: Family 1, Family 2, and Family 3. Each product is assigned 2 attributes after creation in order to route the products through the system appropriately and to batch the products before disposal as per their input batch sizes. Table 4.1, Table 4.2 and Table 4.3 show the customer order sizes and the inter-arrival time distributions for each product belonging to Family 1, Family 2, and Family 3, respectively.

Table 4.1 Inter-arrival time and customer order size distributions for Family 1

Family #	Product #	Inter-arrival time distribution	Customer order size distribution
Family 1	1	0.999 + WEIB(0.115, 0.54)	1.09 + LOGN(1.56, 1.06)
	2	0.999 + WEIB(0.0448, 0.512)	TRIA(18, 23.7, 52)
	3	1.11 + EXPO(1.87)	9 + WEIB(7.66, 1.27)
	4	2 + LOGN(3.19, 3.68)	2 + 17 * BETA(0.387, 0.651)
	5	4 + LOGN(5.05, 14)	207 + LOGN(86.5, 139)
	6	UNIF(0, 26)	TRIA(6, 12.5, 71)
	7	-0.001 + 26 * BETA(0.564, 0.304)	UNIF(9, 80)
	8	TRIA(0, 6.9, 23)	EXPO(25.3)
	9	NORM(13.7, 7.49)	NORM(108, 30.8)
	10	6 + WEIB(3.78, 0.738)	TRIA(98, 120, 187)
	11	UNIF(0, 26)	UNIF(14, 34)

Table 4.2 Inter-arrival time and customer order size distributions for Family 2

Family #	Product #	Inter-arrival time distribution	Customer order size distribution
Family 2	12	0.999 + WEIB(0.0126, 0.405)	5 + WEIB(7.51, 0.678)
	13	1 + LOGN(0.99, 2.62)	2 + 11 * BETA(0.412, 0.527)
	14	1.24 + EXPO(1.46)	30 + 26 * BETA(0.643, 1.08)
	15	EXPO(7.06)	2 + 34 * BETA(0.321, 0.519)
	16	0.999 + WEIB(0.0313, 0.503)	NORM(149, 57.1)
	17	0.999 + WEIB(0.195, 1.12)	NORM(23, 14.2)
	18	TRIA(0, 11.2, 25)	101 * BETA(0.822, 0.714)
	19	26 * BETA(0.649, 0.42)	EXPO(154)
	20	EXPO(7.4)	UNIF(0, 90)
	21	UNIF(0, 26)	TRIA(0, 231, 330)
	22	28 * BETA(1.11, 0.547)	TRIA(0, 224, 325)
	23	27 * BETA(0.679, 0.429)	EXPO(119)
	24	28 * BETA(0.468, 0.255)	TRIA(425, 1.05e+003, 2.5e+003)
	25	1.16 + LOGN(2.48, 1.76)	NORM(867, 534)
	26	EXPO(7.03)	NORM(68, 32.8)
	27	TRIA(0, 4.44, 25)	EXPO(13.8)
	28	9 + 17 * BETA(0.559, 0.0833)	24 * BETA(0.67, 0.969)
	29	28 * BETA(0.466, 0.301)	NORM(420, 168)
	30	28 * BETA(0.932, 0.479)	NORM(267, 110)
	31	2 + 26 * BETA(0.314, 0.458)	TRIA(0, 274, 381)
	32	UNIF(0, 26)	TRIA(0, 297, 368)

Table 4.3 Inter-arrival time and customer order size distributions for Family 3

	Product #	Inter-arrival time distribution	Customer order size distribution
Family 3	33	0.999 + WEIB(0.0117, 0.424)	TRIA(843, 1.19e+003, 2e+003)
	34	1.33 + 1.96 * BETA(0.3, 0.636)	WEIB(6.83, 0.613)
	35	1 + LOGN(5.23, 7.03)	37 + LOGN(147, 1.51e+003)
	36	4 + 22 * BETA(0.305, 0.197)	TRIA(0, 543, 591)

4.3.1.3 Simulation Of The Fabrication Area In Arena

After the entities are created as explained in section 3.1.1, they are routed to Cells 1, 2 or 3 based on the type of family they belong to. The entities enter the fabrication area as a batch equivalent to the customer order size. Once a batch of entities enters the cell they are split and there is a one piece flow in the cell. Entities belonging to Family 1 go to Cell 1 or Cell 2 only based on the shorter queue length between operation 2 of the two cells. This is done because the second operation in each cell has been identified as the bottleneck operation based on trial runs conducted. Entities belonging to Family 2 are routed to Cell 1, Cell 2 or Cell 3 again based on the shorter queue length among the second operation of the three cells. Also, entities belonging to Family 3 go to Cell 1 or Cell 3 based on the shorter queue length between the second operations of the two cells. In Cell 1 and Cell 3, the entities undergo Operation 1 and go to Operation 2 where there are two types of machines namely the slow (Type I) and fast (Type II) machines available for processing. The entities are routed to either type of machine based on a percentage which was decided after a number of simulation runs in order to minimize the queue lengths and hence the waiting time. In cell 1, 30% of the entities were routed to the Type I machine and the rest were routed to the Type II machine. In cell 3, 40% of the entities were routed to the Type I machine and the rest were routed to the Type II machine. The entities then go to Operation 3 from where they move on to the Packaging area. In Cell 2, only one type of machine is available for operation 2 and the entities undergo processing in all the operations and move on to the packaging area. The processing time for each machine is converted from vials/minute to seconds/vial. The base time of the simulation run is in hours.

4.3.1.4 Simulation Of The Packaging Area In Arena

Each of the entities leaving the fabrication cells enters the corresponding packaging cells. For example, entities from cell 1 in the fabrication area will enter cell 1 of the packaging area. The Entities entering the packaging area undergo processing through Operation 4. In the fifth operation, the vials are grouped based on the type of family they belong to. Family 1 consists of only 1 vial or subassembly, Family 2 consists of 2 vials or subassemblies and Family 3 consists of 4 vials or subassemblies. Thus, the vials that are batched in Arena after Operation 5 are processed in Operations 6, 7 and 8 where they are boxed, sealed and coded. In the final batching, the vials are batched together in a box based on the final customer order sizes. The final batch sizes are the same as the input batch sizes and are batched accordingly. The boxes then leave the system through the dispose module of Arena. No processing time is associated for the entities being batched and disposed however, there is a waiting time associated since the entities might have to wait till the required batch size is reached and only then get disposed.

4.3.1.5 Validation And Verification

The model was simulated using animation in order to verify and validate the model. The entities were followed during the simulation to ensure that the entities belonging to different families were routed to the appropriate cells in the fabrication and packaging area. The queues for batching were also checked to make sure there was no mix up in the entities being batched. The model was run for 24 hours a day for a total of 5000 hours in order validate the model. The average flowtimes and the work in process for each family were plotted using the Arena Output Analyzer. It was realized that capacity problems existed in the model. In order to tackle this problem, a capacity evaluation was done for the manufacturing system and the batch sizes and hence the input for products 33 and 36 of family 3 were reduced to 40% and 50% of the original batch sizes, respectively. The warm up time for the model was decided as 2000 hours as shown in the figures 4.1 and 4.2 which display the average flowtimes and work in process for each family, respectively. The simulation was a run for 2500 hours after the end of the warm up period. The peak in the graph in figure 4.2 at the beginning of the simulation run is due to the fact that all entities enter the system at time, t=0. Also, the peaks observed in the graph in figure 4.3 could be due to the fact that the entities are held in the system after the packaging area till the customer order size is reached following which they are batched and they exit the system.

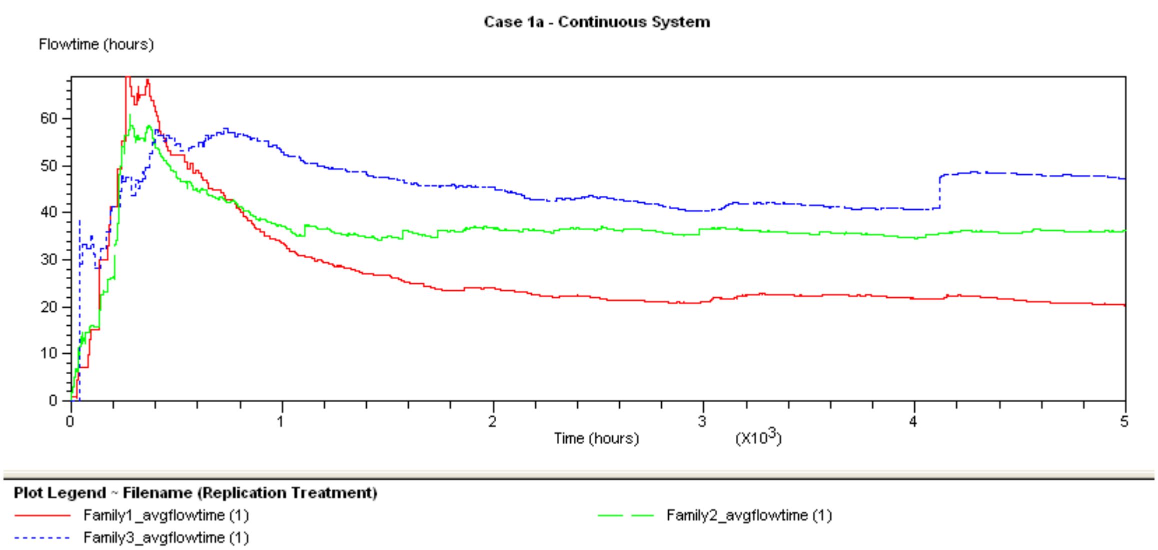


Figure 4.2 Average flowtimes for Family 1, Family 2, and Family 3 for connected system

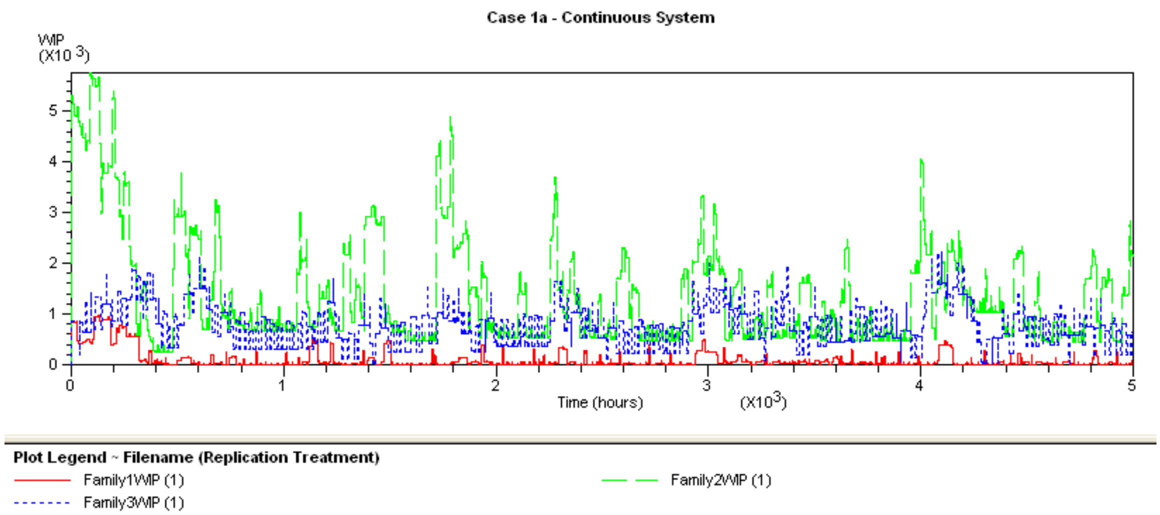


Figure 4.3 Average work in process for Family 1, Family 2, and Family 3 for connected system

4.3.2 Disconnected System

4.3.2.1 Input Data Analysis

The input data for disconnected system is the same as the connected system and hence the analysis for the customer order sizes and inter-arrival times for each of the parts remain unchanged.

4.3.2.2 Creation Of Entities In Arena

The creation of entities for the disconnected system remain as in the connected system as explained in section 4.3.1.2. Table 4.1, Table 4.2 and Table 4.3 show the customer order size and the inter-arrival time distributions for each product belonging to Family 1, Family 2, and Family 3, respectively.

4.3.2.3 Simulation Of The Fabrication Area In Arena

The entities enter the fabrication area in batches as explained for the connected system. The batches of entities in disconnected system are routed differently as compared to the connected system. Here, the batches of entities are routed to cell 1, cell 2, or cell 3 of the fabrication area based on the shortest queue length of the bottleneck operation which is operation 2 as explained earlier. The flexibility of routing the families to any of the cells in this type of system is the only major difference between the connected and disconnected systems in the fabrication area. The processing times of the machines and the sequence of operations for the entities for both systems are the same. Since the flow is disconnected in this system, the entities are batched again to the same customer order sizes at the end of the fabrication area.

4.3.2.4 Simulation Of The Packaging Area In Arena

The batches of entities entering the packaging area are routed to specific packaging cells based on shortest queue length as shown earlier in table 3.4. These batches are then split and the entities follow a one piece flow. Also, there is an extra feeding operation at the start of the packaging cells in order to accommodate the transfer of entities from fabrication to packaging. The method in which the entities are transferred from fabrication to packaging and the extra feeding operation is the only major difference between the connected and disconnected systems in the packaging area. The processing times of the machines and the sequence of operations for the entities for both systems are the same.

4.3.2.5 Validation And Verification

The model was validated and verified similar to the connected system. It was realized that capacity problems also existed in this model. A capacity evaluation similar to the connected system was done for the manufacturing system and the batch sizes following which the input for products 33 and 36 of family 3 were reduced to 40% and

50% of the original batch sizes, respectively. The warm up time for the model was decided as 2000 hours as shown in the figures 4.3 and 4.4 which display the average flowtimes and work in process for each family, respectively. The system was run for a total time of 4500 hours including warm up time.

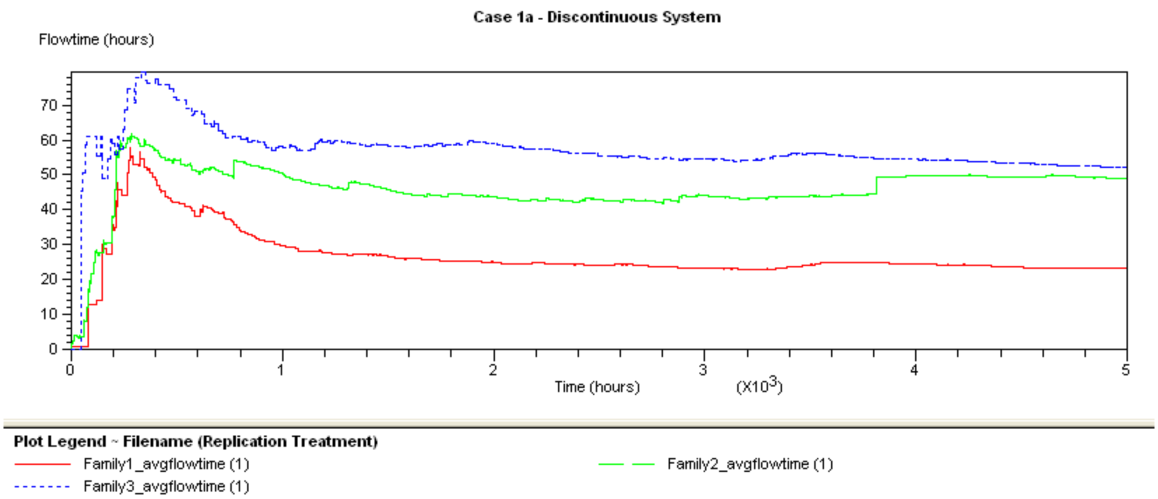


Figure 4.4 Average flowtimes for Family 1, Family 2 and Family 3 for disconnected system

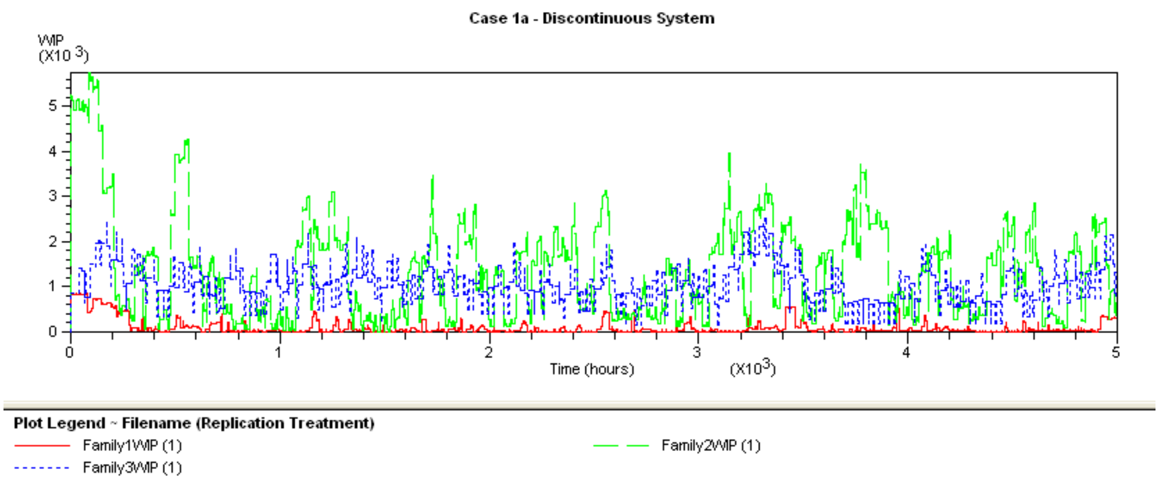


Figure 4.5 Average work in process for Family 1, Family 2, Family 3 for disconnected system

4.4 Methodology For Case 1B

This case compares the Connected and Disconnected systems based on different cell routings of the parts. A total of four models for the connected system and seven models for the disconnected systems are developed for this purpose. A couple of the models developed for the connected system are repeated in four of the comparisons against the disconnected system and are explained later.

4.4.1 Connected And Disconnected Systems

4.4.1.1 Input Data Analysis

The input data analysis performed in Case 1A for both the connected and disconnected systems was also used for Case 1B as the only difference between them was the routing of parts to the cells in the fabrication and packaging areas. The results of the capacity analysis conducted in Case 1A were also applied to each of the models developed in this case.

4.4.1.2 Creation Of Entities In Arena

The creation of entities for the disconnected system remains the same as those for the connected system as explained in section 4.3.1.2. Table 4.1, Table 4.2 and Table 4.3 show the customer order size and the inter-arrival time distributions for each product belonging to Family 1, Family 2, and Family 3, respectively.

4.4.1.3 Simulation Of The Fabrication And Packaging Areas In Arena

The different comparison studies conducted between the connected and disconnected systems are shown below in figure 4.5. The figure shows the different routings for the families through the fabrication and the packaging areas which were used for the comparison of the two systems. In the figure, F1, F2, and F3 denote family 1, family 2, and family 3, respectively. The processing times of products on each of the machines and the number of operations for each family remain the same as in Case 1A. Models 1, 2, 3, and 4 basically depict a comparison between the connected and the disconnected system wherein the parts that enter the fabrication area in both the systems follow the same routing as shown in the figure 4.5 below. The difference however lies in the packaging area of both the systems. In the connected system, as per the family routing, parts that enter the any of the cells in the fabrication area enter the corresponding cell in the packaging area whereas in the disconnected system these parts are completely flexible to go to any of the cells in the packaging area. For models 5 and 6 in figure 4.5, the same holds good for the connected system but for the disconnected system the parts are completely flexible to enter any of the cells in the fabrication area but follow the same routing in the packaging area as the connected system. For model 7, as shown in figure

4.5, routing for each family through the fabrication and the packaging area remain the same.

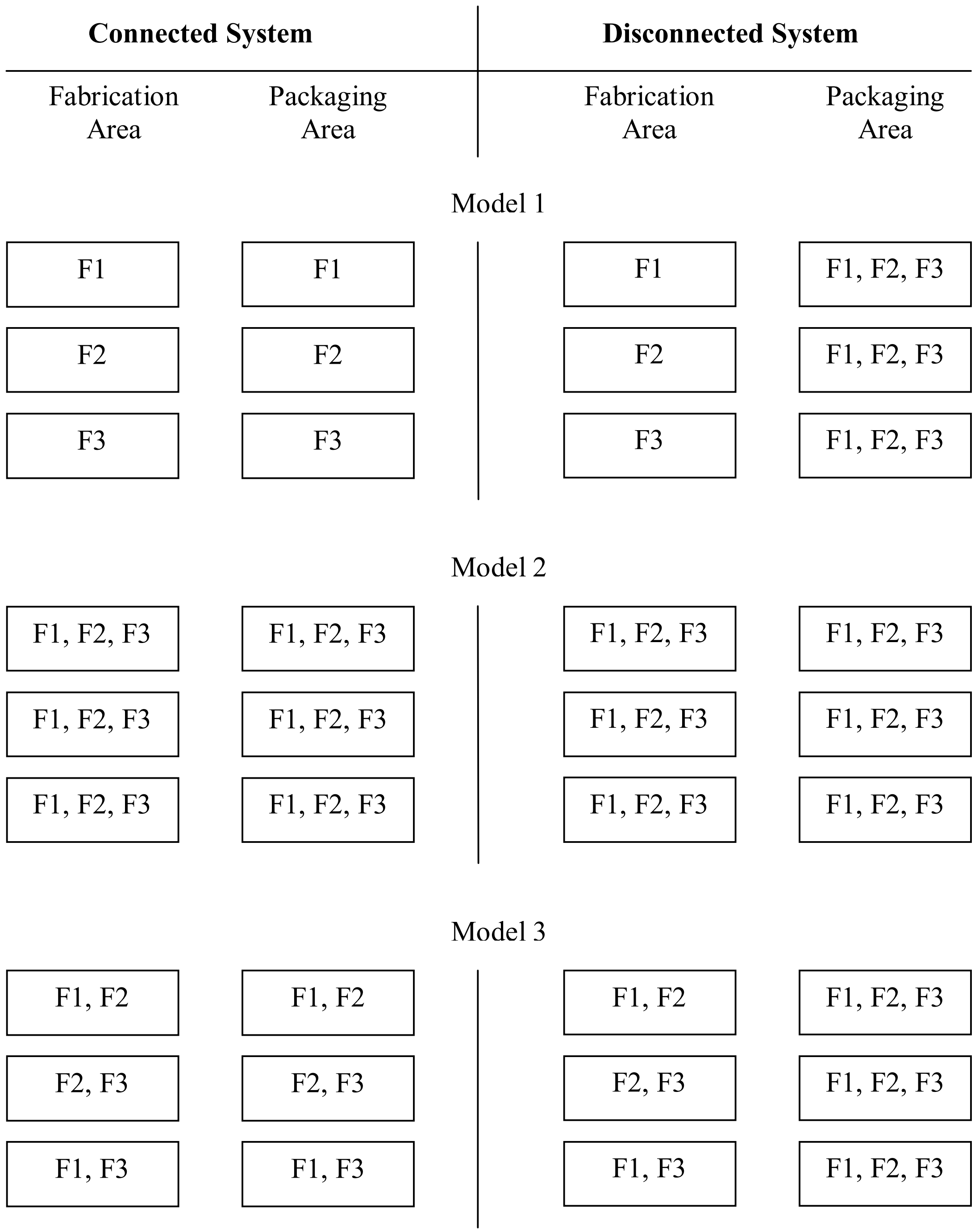


Figure 4.6 Various cell routings used for comparison

Connected System		Disconnected System	
Fabrication Area	Packaging Area	Fabrication Area	Packaging Area
Model 4			
F1, F2, F3	F1, F2, F3	F1, F2, F3	F1, F2, F3
F1, F2	F1, F2	F1, F2	F1, F2, F3
F2, F3	F2, F3	F2, F3	F1, F2, F3
Model 5			
F1	F1	F1, F2, F3	F1
F2	F2	F1, F2, F3	F2
F3	F3	F1, F2, F3	F3
Model 6			
F1, F2	F1, F2	F1, F2, F3	F1, F2
F2, F3	F2, F3	F1, F2, F3	F2, F3
F1, F3	F1, F3	F1, F2, F3	F1, F3

Figure 4.6 Various cell routings used for comparison (continued)

Connected System		Disconnected System	
Fabrication Area	Packaging Area	Fabrication Area	Packaging Area
Model 7			
F1, F2	F1, F2	F1, F2	F1, F2
F2, F3	F2, F3	F2, F3	F2, F3
F1, F3	F1, F3	F1, F3	F1, F3

Figure 4.6 Various cell routings used for comparison (continued)

4.4.1.4 Validation And Verification

The model was validated and verified similar to Case 1A. The capacity evaluation done for Case 1A was applied to this case. The warm up time for the model was decided as 2000 hours based on the average flowtimes and work in process for each family, respectively. The warm up graphs for the models are displayed in appendix A. The total runtime for the models was 4500 hours including the warm up time. As observed in figures 4.6, 4.7, 4.8, and 4.9, the warm up time for model 1 could not be decided as the system did not tend to stabilize and hence model was not used in the comparison of the two systems. Also, model 5 is the same as model 1 for the connected system as shown in figure 4.3 and was not used for comparison.

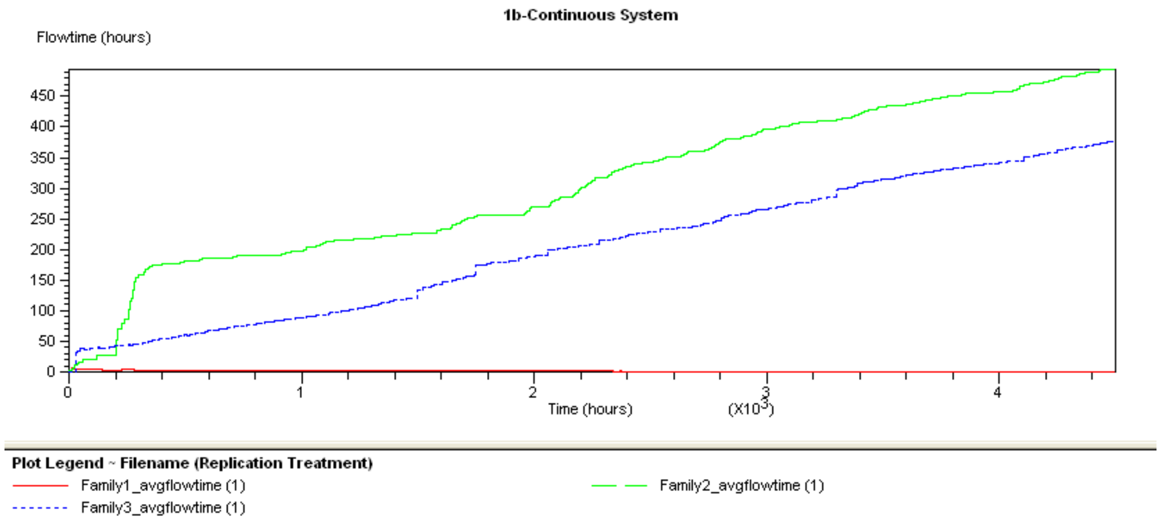


Figure 4.7 Model 1, Model 5 - Average flowtimes for Family 1, Family 2 and Family 3 for connected system

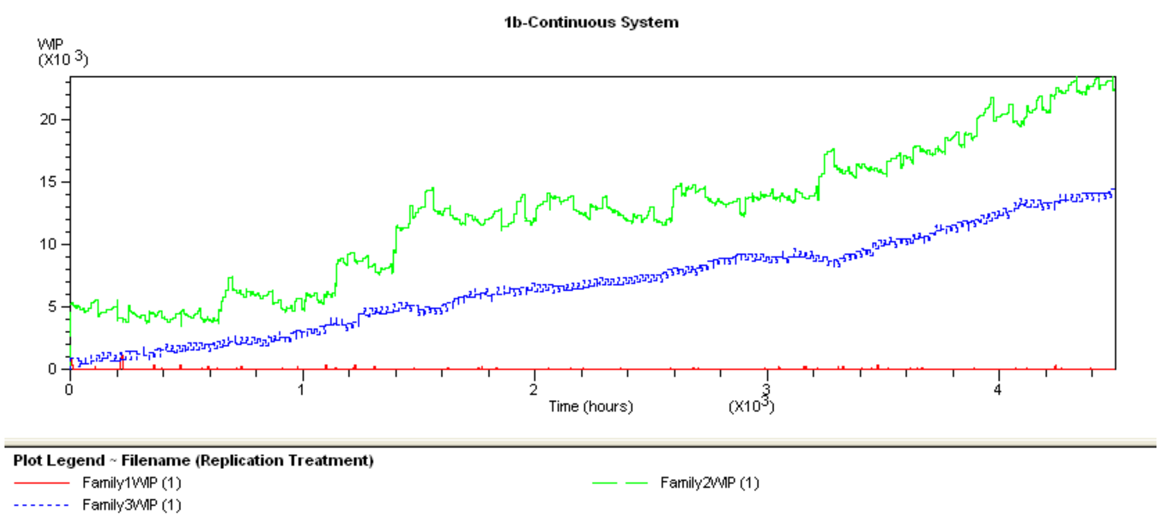


Figure 4.8 Model 1, Model 5 - Average work in process for Family 1, Family 2, and Family 3 for connected system

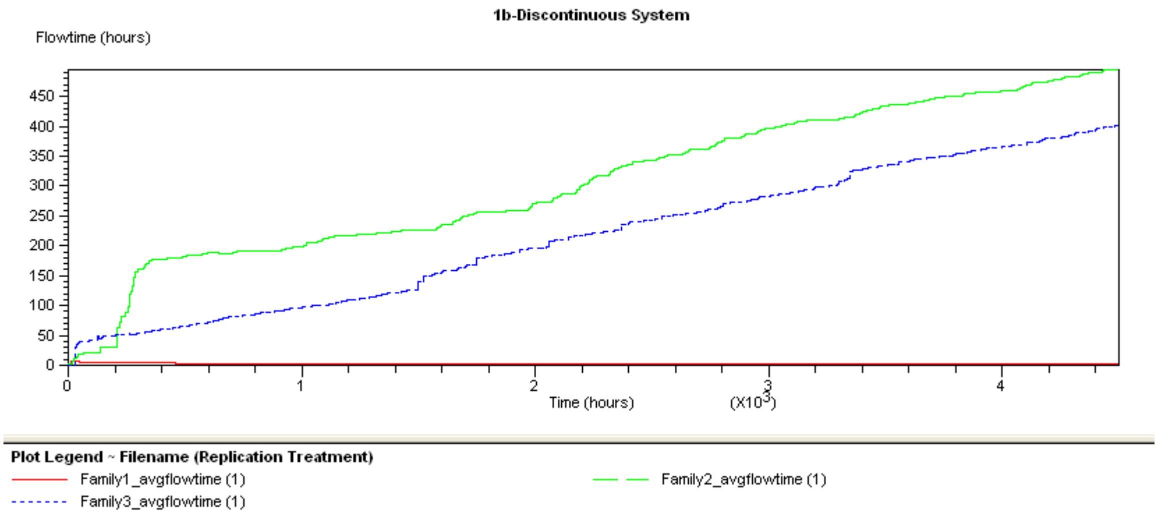


Figure 4.9 Model 1 - Average flowtimes for Family 1, Family 2 and Family 3 for disconnected system

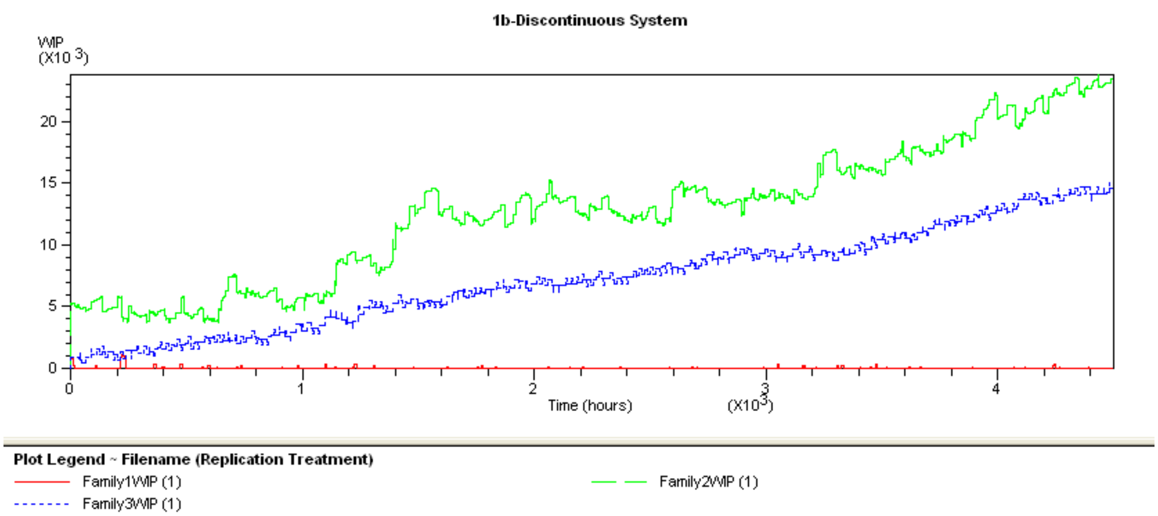


Figure 4.10 Model 1 - Average work in process for Family 1, Family 2, and Family 3 for disconnected system

4.5 Methodology For Case 2

This case compares the Connected and Disconnected systems in a make to stock environment. In this system, finished products are made and stored in inventory till an order is placed for them. For this case, the criteria for comparison are the finished goods inventory and the work in process, the argument being that finished goods inventory are more expensive to carry than work in process inventory. Three of the products namely: 5, 13, and 14 of family 2 were not included in this case due to limitations in the number of entities in the student version of Arena 9.0 used. The system performances were optimized by minimizing the number of lost sales orders. It was important that the number of lost sales orders for the two systems were in the same range so that a like comparison could be made. A t-test of the lost sales comparison in both the systems was conducted and the difference in means was not significant. On an average, 20% of the products only lost 1 order during the entire simulation period. These results are based on 100 replication runs.

4.5.1 Connected System

4.5.1.1 Input Data Analysis

In the make to stock system, the frequency and the order sizes of the parts from case 1 were used to generate customer orders to deplete goods in the inventory. This in turn was used to analyze and predict the input data required in order to have sufficient inventory so that none of the customer orders generated were lost. This is different from case 1 in which parts were made on the basis of customers order received. In this case, the order size and the frequency of arrival for each part are constant. Parts that were fast moving and had large order sizes were scheduled so that they would arrive everyday or every week, the parts which were slow moving and had small order sizes were scheduled so that they would arrive either every 2 or 3 weeks. These decisions were made based after generating hundred data points from the order size and inter-arrival time distributions from case 1 and then sorting them based on average order size and frequency of arrival.

4.5.1.2 Creation Of Entities In Arena

As explained in Case 1A and Case 1B the entities arrive based on their order sizes and frequency of arrivals. The products are categorized under three families or entity types: Family 1, Family 2, and Family 3. Each product is assigned two attributes after creation in order to route the products through the system appropriately and to ensure that the processing times for each family were appropriately assigned at each machine. Table 4.4, Table 4.5 and Table 4.6 show the batch or order size and frequency of arrival for each product belonging to Family 1, Family 2, and Family 3, respectively

Table 4.4 Inter-arrival times and production order sizes for Family 1

Family #	Product #	Inter-arrival Time (days)	Production Order Size
Family 1	1	15	30
	2	10	380
	3	15	70
	4	15	30
	5	5	190
	6	10	40
	7	10	25
	8	10	50
	9	5	40
	10	5	55
	11	10	30

Table 4.5 Inter-arrival times and production order sizes for Family 2

Family #	Product #	Inter-arrival Time (days)	Production Order Size
Family 2	12	15	155
	13	15	50
	14	15	180
	15	15	30
	16	1	105
	17	15	255
	18	15	65
	19	10	235
	20	15	103
	21	10	145
	22	10	160
	23	10	100
	24	5	350
	25	1	177
	26	15	400
	27	15	20
	28	15	12
	29	5	100
	30	5	80
	31	5	75
	32	5	110

Table 4.6 Inter-arrival times and production order sizes for Family 3

	Product #	Inter-arrival Time (days)	Production Order Size
Family 3	33	1	505
	34	15	100
	35	10	295
	36	10	290

4.5.1.3 Simulation Of The Fabrication Area In Arena

The simulation of the fabrication area in this case is exactly the same as that of the connected system in Case 1A. The entities go through each of the operations in the fabrication area based on their routings.

4.5.1.4 Simulation Of The Packaging Area In Arena

The entities from each of the cells in the fabrication area enter the corresponding cell in the packaging area as explained in section 4.3.1.4. The difference between the two cases lies in the way the orders leave the system. For this case, customer order sizes and their respective inter-arrival times are based on the input data analysis done for Case 1A. In other words, the distributions used to decide the order sizes and inter-arrival times for entity arrivals are used to generate the order sizes and inter-arrival times for the customer orders. The products after completion of packaging are held back as finished goods using a hold module in Arena till the customer order is generated through the distributions used that were explained above. The products are then batched according to this order size distribution and also leave the system based on the inter-arrival time distribution for the customer orders.

4.5.1.5 Validation And Verification

The model was validated and verified similar to Case 1A. The capacity evaluation done for Case 1A was applied to this case. There was no warm up time for this case but instead there was an inventory accumulation of the finished goods for 8 weeks or 40 days. In other words, the first customer order was generated on the 40th day so that there were sufficient finished goods made to stock. The system was tracked for lost orders using a record module. The customers were lost because there were insufficient finished goods in inventory. The number of orders lost was minimized by increasing the order size in the creation module of arena and also by delaying the first customer order in the system. In other words, the order sizes were increased till the numbers shown in tables 4.5, 4.6 and 4.7 were reached and the first customer was pushed back to the 8th week.

4.5.2 Disconnected System

4.5.2.1 Input Data Analysis

The input data analysis for the disconnected system was the same as the connected system as the input parameters were kept identical as observed in cases 1a and 1b in order to facilitate a like comparison.

4.5.2.2 Creation Of Entities In Arena

Entities arrive into the system based on constant production order sizes and inter-arrival times. Tables 4.7 give the production order sizes and the inter-arrival times for the disconnected system. Instead of creating the separate entities for each product in each family, entities for each product in a family were created in common and build as a common subassembly till the end of the fabrication area.

Table 4.7 Inter-arrival times and production order sizes release for Family 1, Family 2, and Family 3

	Inter-arrival time (hours)	Production Order Size
Family 1	1	7
Family 2	1	16
Family 3	1	26

4.5.2.3 Simulation Of The Fabrication Area In Arena

The simulation of the fabrication area in this case is exactly the same as that of the disconnected system in Case 1A. The entities go through each of the operations in the fabrication area based on their routings.

4.5.2.4 Simulation Of The Packaging Area In Arena

The entities from each of the cells in the fabrication area enter a work in progress area where they are held in an inventory buffer. There are three buffers for each of the three families and they are released when any of the finished goods inventories for any of the products for a specific family fall below a certain predefined level as explained earlier. Every 5 minutes the parts held by the buffer are released and they check the finished goods inventories for each of the part types. If any of the inventories are lower than those shown in the tables 4.8, 4.9, and 4.10 for family 1, family 3, and family 2, respectively, then the parts are assigned attributes and they are now identified as a specific part within the family. The basic idea is to build the parts to an intermediate stage which is common to all finished products within a family and then differentiate them into specific part types based on the inventory levels of the finished goods. The advantage of holding the goods in a work in progress inventory is that cost of carrying such an inventory is less than carrying finished goods inventory as done in the connected system. This is the major difference between the connected and disconnected system. For this case, customer order sizes and their respective inter-arrival times are based on the input data analysis similar to the connected system. In other words, the distributions used to decide the order sizes and inter-arrival times for entity arrivals are used to generate the order sizes and inter-arrival times for the customer orders. The products after completion of packaging are held back as finished goods using a hold module in Arena till the customer order is generated through the distributions used that were explained above. The products are then batched according to this order size distribution and also leave the system based on the inter-arrival time distribution for the customer orders.

Table 4.8 Minimum finished goods inventory levels for Family 1

Family #	Product #	Reorder levels
Family 1	1	70
	2	140
	3	80
	4	50
	5	440
	6	70
	7	80
	8	70
	9	150
	10	180
	11	60

Table 4.9 Minimum finished goods inventory levels for Family 3

	Product #	Reorder levels
Family 3	33	1400
	34	100
	35	250
	36	230

Table 4.10 Minimum finished goods inventory levels for Family 2

Family #	Product #	Reorder levels
Family 2	12	60
	13	20
	14	60
	15	40
	17	50
	18	90
	19	250
	20	120
	21	300
	22	300
	23	360
	26	480
	27	90
	28	100
	29	610
	30	370
	31	400
	32	350

4.5.2.5 Validation And Verification

The model was validated and verified similar to Case 1A.The capacity evaluation done for Case 1A was applied to this case. There was no warm up time for this case but instead there was an inventory accumulation of the finished goods for 6 weeks or 30 days. In other words, the first customer order was generated on the 30th day so that there were sufficient finished goods made to stock. Similar to the connected system, the order size and the first customer order was reached by minimizing the number of customer orders lost.

5 RESULTS AND DISCUSSION

In this chapter, a summary of the results obtained from simulation runs as well as statistical analysis for each of the cases discussed in chapter 4 are presented. The results of 100 replications as well as statistical analysis in detail can be referred to in appendix B and C, respectively. A comparison between the connected and disconnected systems is made with respect to the results obtained and analyzed. The system with a better performance is ascertained based on the statistical analysis performed for the output rates, average work in process, and average flowtimes.

5.1 Case 1A and Case 1B – Connected Vs. Disconnected Systems

5.1.1 Statistical Results

The statistical analysis was conducted using the statistical functions available in Excel. A t-test assuming unequal variances for two samples was conducted for a 95% confidence interval for each family under each system. Based on the analysis conducted, summary tables 5.1, 5.2, and 5.3 are presented below. Table 5.1 displays comparisons for the families with respect to flowtimes and work in process between connected and disconnected systems. Table 5.2 displays comparisons for the families for the same performance measures but the comparisons are made between the different connected systems from Case 1A and Case 1B. Table 5.3 also displays comparisons for the families for the same performance measures but the comparisons are made between the different disconnected systems from Case 1A and Case 1B. Results are denoted as significant (S) or not significant (NS) based on analysis conducted. Also, wherever significant, the connected system (C), disconnected system (D) for table 5.1 and model (M) or connected/disconnected system (1a) as applicable for tables 5.2 and 5.3 being compared are denoted in parenthesis which indicates which system or case was better. The significance of the results was based on the p-value obtained from the T-test conducted for an alpha level of 0.05. As mentioned in chapter 4, no results for models 1 and 6 were obtained as the system did not stabilize. As observed in table 5.1, for case 1A, the flowtimes and work in process were observed to be significantly different and the disconnected system had lower flowtimes and work in process as compared to the connected system for family 1. Similarly, the WIP for the connected system was better than the disconnected system for the family 2. The rest of the comparisons for this case did not yield any significant results. For model 2, the flowtime for family 2 and the WIP for all three families for the connected system were significantly lower than the disconnected system. For models 3, 6, and 7 which were the same for the connected system, the flowtimes and WIP for families 1 and 2 were significantly lower than the disconnected system. For model 4, the WIP for family 2 in the connected system was the only significant result. From table 5.2 it can be observed that model 2 (M2) provided the best results when compared to rest of the model within the connected system with lower overall flowtimes and WIP followed by model 3 (M3). Comparison of models 1A and 4 did not yield any significant results. From table 5.3, it can be observed that the flowtimes and WIP for models 3 and 7 (M3, M7) were consistently significant and better when compared to the rest of the models. Also, when compared against each other there was no significant difference observed for any of the families and performance measures. A comparison between models 1A and 2 did not yield any significant results either and were definitely less superior in performance compared to the rest of the models.

Table 5.1 Summary table of results for connected vs. disconnected systems – cases 1A and 1B

	FLOWTIME			WIP		
	FAMILY1	**FAMILY2**	**FAMILY3**	**FAMILY1**	**FAMILY2**	**FAMILY3**
1A	S (D)	NS	NS	S (D)	S (C)	NS
M2	NS	S (C)	NS	S (C)	S (C)	S (C)
M3	S (C)	S (C)	S (C)	S (C)	S (C)	NS
M4	NS	NS	NS	NS	S (C)	NS
M6	S (C)	S (C)	NS	S (C)	S (C)	NS
M7	S (C)	S (C)	NS	S (C)	S (C)	NS

Table 5.2 Summary table of results for connected system – cases 1A and 1B

	FLOWTIME			WIP		
	FAMILY 1	**FAMILY 2**	**FAMILY 3**	**FAMILY 1**	**FAMILY 2**	**FAMILY 3**
M2 VS M3	S (M2)	S (M2)	NS	S (M2)	S (M2)	NS
M2 VS M4	S (M2)	NS	NS	S (M2)	S (M2)	NS
M3 VS M4	S (M3)	S (M3)	NS	S (M3)	S (M3)	NS
1A VS M2	S (M2)	NS	NS	S (M2)	S (M2)	NS
1A VS M3, M6,M7	S (M3)	S (M3)	NS	S (M3)	S (M3)	NS
1A VS M4	NS	NS	NS	NS	NS	NS

Table 5.3 Summary table of results for disconnected system – cases 1A and 1B

	FLOWTIME			WIP		
	FAMILY 1	**FAMILY 2**	**FAMILY 3**	**FAMILY 1**	**FAMILY 2**	**FAMILY 3**
M2 VS M3	S (M3)	S (M3)	NS	S (M3)	S (M3)	NS
M2 VS M4	S (M4)	S (M4)	NS	S (M4)	S (M4)	NS
M2 VS M6	S (M6)	S (M6)	NS	S (M6)	S (M6)	NS
M2 VS M7	S (M7)	S (M7)	NS	S (M7)	S (M7)	NS
M3 VS M4	S (M3)	NS	NS	S (M3)	S (M3)	NS
M3 VS M6	S (M3)	S (M3)	NS	S (M3)	S (M3)	NS
M3 VS M7	NS	NS	NS	NS	NS	NS
M4 VS M6	NS	NS	NS	S (M6)	NS	NS
M4 VS M7	S (M7)	S (M7)	NS	S (M7)	S (M7)	NS
1A VS M2	NS	NS	NS	NS	NS	NS
1A VS M3	S (M3)	S (M3)	NS	S (M3)	S (M3)	S (1a)
1A VS M4	NS	NS	NS	NS	NS	NS
1A VS M6	NS	NS	NS	NS	NS	NS
1A VS M7	S (M7)	S (M7)	NS	S (M7)	S (M7)	NS

5.2 Case 2 – Connected Vs. Disconnected Systems

5.2.1 Statistical Results

A statistical analysis was conducted similar to Cases 1A and 1B and the results of the analysis are shown in table 5.4. Results are denoted as significant (S) or not significant (NS) based on the analysis conducted. Also, wherever significant, the connected system (C) and disconnected system (D) being compared are denoted in parenthesis which indicates which system was better. The performance measures used for this case were finished goods inventory (FG) and work in process (WIP). A comparison between each of the families against the mentioned performance measures yielded significant results as observed in table 5.4. For families 1 and 3, the FG was lower for the disconnected system as compared to the connected system. In contrast, the WIP was higher for families 1 and 3 in the disconnected system. Also for family 2, the FG and WIP were significantly lower for the connected system. An overall comparison was also made by adding up the FG and WIP of all families for each replication. The statistical analysis of the overall results shows that the overall FG is lower and the overall WIP is higher for the disconnected system as compared to the connected system. But, an analysis of the FG and WIP as a total showed that the disconnected system had a significantly lower level of total inventory.

Table 5.4 Summary table of results for connected vs. disconnected systems – case 2

	FAMILY1		FAMILY2		FAMILY3	
	FG	**WIP**	**FG**	**WIP**	**FG**	**WIP**
C VS D	S (D)	S (C)	S (C)	S (C)	S (D)	S (C)

Table 5.5 Summary table of results for connected vs. disconnected Systems – overall and total inventory - case 2

	OVERALL		TOTAL
	FG	**WIP**	**FG + WIP**
C VS D	S (D)	S (C)	S (D)

6 CONCLUSIONS AND FUTURE RESEARCH

In this chapter, conclusions and future work based on the experimentation and research conducted are discussed.

The scope of this thesis was to develop and study the behavior of connected and disconnected cellular systems using simulation software Arena 7.0. A total of three performance measures namely: flowtimes, work in process inventory, and finished goods inventory were used. Simulation models were developed to study the systems in a make to order and a make to stock environment. Further, simulation models were developed to study the impact of routing flexibilities of part families as a sub case in the make to order environment. The simulation runs provided results which were statistically analyzed to evaluate and compare the performance of the two systems.

6.1 Conclusions

Two cases were considered in order to study the performance of the connected and disconnected cellular systems. From an overall perspective it can be concluded that if the aim of the organization is to have minimum finished goods inventory and work in process inventory then the make to order system could be implemented. For a MTO approach, the manufacturing system needs to be flexible to demand fluctuations and possess the ability to deliver customer orders on time. If the aim is to reduce the response time for delivery of goods to the customer then a make to stock approach could be implemented. The drawback of the MTS approach is the cost of carrying higher inventory but the time for customer delivery can be much lower due to the fact that finished goods are stocked resulting in a higher service level. In Case 1A, it was observed that the difference in cellular manufacturing design had very little impact on the flowtimes and work in process inventories for the part families. The flowtimes and work in process for family 1 for the disconnected system were lower and hence better as compared to the same in the connected system. In addition, the WIP for family 2 in the connected system was lower and hence better as compared to the same in the connected system. The majority of the comparisons did not yield any significant results and hence it cannot be necessarily concluded that either one of the systems would be a better choice for a make to order strategy. In other words, the delivery of products and the cost of carrying work in process inventory would not significantly vary between the two systems. In Case 1B, which is basically an extension of case 1A, extensively studies the impact of considering alternate cell routings for each part family. For model 2, the WIP for all families in the connected system was significantly lower compared to the disconnected system. Also, the flowtime for family 2 in the connected system was better. From these results it can be concluded that a connected system would definitely yield lower WIP inventories and hence prove to be more effective in reducing costs. A conclusion similar to case 1A can be made for model 4, the results from which were not sufficient to determine whether the connected or disconnected system was better. For model 3, the connected system had significantly lower flowtimes and WIP for families 1 and 2, whereas the results for family 3 were not significant. This leads to the conclusion that the connected system is the better system in this situation since family 1 and family 2 make up for 32 of the 36 products and comprise of about 85% by volume of the production orders in the system. Models 3, 6, and 7 for the connected system used for the comparison were the same. The statistical analysis conducted amongst all models developed for the connected system indicated that model 2 had significantly lower flowtimes and WIP. This is because model

2 had the highest flexibility of all as each of the families could be routed to any of the fabrication and packaging cells. Models 3, 4 and the model from case 1A followed in the order of performance leading to the conclusion that increase in routing flexibility of the families resulted in significantly lower flowtimes and WIP. A similar comparison between all models developed for the disconnected system showed that models 3 and 7 which did not yield any significant results when compared and performed better than the rest of the models. Model 3 had complete flexibility in the packaging area but limited flexibility in the fabrication area and model 7 had limited flexibilities in both the areas. Limited flexibility as applicable to these two models means that each family could go to at least two specified cells as shown in fig 4.5. Model 6 followed next in performance with complete flexibility in fabrication and limited flexibility in packaging. Model 2 was worst performing system among the models for case 1b even though it had the highest flexibility. This can be attributed to the fact that routing decisions are made based on queue sizes with family 3 having the highest processing times on a machine, followed by family 2 and, family1. Thus, it is possible that products could be routed to queues in all cells with queue having products belonging to family 3. Hence, even though there may be a smaller queue size there is a possibility that majority of the queue comprises of family 3 products leading to higher lead times for the parts that join that queue. For case 1a and model 2 from case 1b, the disconnected system was modified to delete the extra feeding operation and the batching at the end of the fabrication area. This was done in order to determine the reason for the connected system performing better than the disconnected system for most of the comparisons made. The two modified simulation models were run and the results were statistically analyzed. In case 1a, the flowtime for family 1 and the

WIP for family 2 was significantly better for disconnected system. In the original comparison, WIP and flowtime for family 1 in the disconnected system was better and the WIP for family 2 in the connected system was significantly better. The rest of the comparisons did not yield any significant results. For model 2, none of the comparisons yielded significant results as opposed to the original comparison when the connected system clearly performed better than the disconnected system. From these results it can be concluded that the extra operation and the extra batching increases the average WIP and flowtimes for each of the families and could be responsible for the disconnected system not performing better than the connected system. For case 2, it was observed that holding finished goods inventory can be minimized to a great extent by only marginally increasing work in process inventory resulting in an overall reduction in inventory. One drawback of implementing a disconnected system would be that, the paperwork required for traceability requirements for each vial would be more than that required for a connected system. The benefits obtained from implementing a disconnected system would have to be weighed against the increase in labor costs needed to perform the extra paperwork.

6.2 Future Research

The scope of this thesis can be expanded in one of the following areas:

Pull/Re-order based on trigger – The simulation models from case 2 can be modified to implement a system wherein reorder points for work in process inventory and creation of production orders to enter the system could be based on a trigger system from finished goods inventory and work in process inventory, respectively. This system would be more dynamic in nature and could respond better to high demand fluctuations. This can be implemented by establishing optimal reorder levels for finished goods and reorder levels for work in process inventory. When the FG and WIP levels fall below the levels specified the production orders will be released to become WIP and parts in the WIP buffer will be released to become FG.

Impact of increased processing times – The systems in case 1b were studied under various cell routing flexibilities for each family. From the output rate analysis shown in tables 3.7 and 3.8 it can be observed that there is higher flexibility and output rate possible with some of the routings especially in the packaging area which was not taken advantage of since there were no long queues observed. However from the simulation results it was noted that queue sizes were high especially for operations 1 and 2 in the fabrication area.. Thus, it would be worthwhile to study the system performance when the processing times in the packaging areas are increased with a decrease in the processing times in the fabrication areas so as to keep the output rate the same, forcing the flexibility of the systems in the packaging area to come into play.

Impact of machine breakdowns – The models could be incorporated to include machine breakdown with minor modifications in the resource module in Arena. The machine breakdowns could follow a distribution for downtime and uptime. Also, the machine breakdowns could occur after a predefined level of entities are processed, which, could also follow a distribution. The machine breakdowns will then force the entities to follow alternate routes thus making the routing flexibility an important issue in the performance of the systems.

Hybrid MTO and MTS environment – A system incorporating a mix of make to order and make to stock environments would be worthwhile to investigate. The key factor in such a system would be to decide which of the products would be MTO and which products would be MTS. A combination of MTO and MTS would probably yield some advantages which are important to investigate. Parts that have large order sizes and have a high frequency could probably be made to stock and parts with small order sizes and low frequency could be made to order.

REFERENCES

[1] Kamrani, Hubbard, Parsaei, and Leep (1998) Simulation Based Methodology for Machine Cell Design. *Computers and Industrial Engineering* Vol.34, No.1, pp. 173-188.

[2] Flynn, B. B. and Jacobs, F. R. (1987) A comparison of group technology and process layout using a model of an actual shop. *Decision Science* Vol. 18, 289-293

[3] Morris, S. J. and Tersine, J. R. (1990) A simulation analysis of factors influencing the attractiveness of group technology cellular layouts. *Management Science* Vol. 36, No 12, 1567-1578.

[4] Selen, J. W. and Ashayeri, J. (2001) Manufacturing cell performance improvement: a simulation study. *Robotics and Computer Integrated Manufacturing* 17, 169-176.

[5] Bertolini, M. and Rizzi, A. (2002) A simulation approach to manage finished goods inventory replenishment economically in a mixed push/pull environment. *Logistics Information Management,* Vol. 15, No.4, 281-293.

[6] Yazici, J. H. (2005) Influence of flexibilities on manufacturing cells for faster delivery using simulation. *Journal of Manufacturing Technology* Vol. 16, No 8, 825-841.

[7] Albino, V. and Garavelli, C. A. (1998) Some effects of flexibility and dependability on cellular manufacturing system performance. *Computers and Industrial Engineering,* Vol. 35, Nos. 3-4, 491-494.

[8] Caprihan, R. and Wadhwa, S. (1997) Impact of routing flexibility on the performance of an FMS – A simulation study. *The International Journal of Flexible Manufacturing Systems,* 9, 273-278.

[9] Abdul-Hamid, T. Y., Kochhar, K. A. and Khan. K. M. (1999) An analytic hierarchy process approach to the choice of manufacturing plant layout.

[10] DeCroix, G. A. and Arreola-Risa, A. (1998) Make-to-order versus make-to-stock in a production inventory system with general production times. *IIE transactions* (1998) 30, 705-713.

[11] Federgruen, A. and Katalan, Z. (1999) The impact of adding a Make-to-order item to a Make-to-order production system. *Management Science*, Vol. 45, No.7, 980-994.

[12] Liberopoulos, G. and Dallery, Y. (2002) Base stock versus WIP cap in single-stage make-to-stock production-inventory systems. *IIE transactions* 34, 627-636.

[13] Van Donk. D. P. (2000) Make to stock or make to order: The decoupling point in the food processing industries. *International Journal of Production Economics* 69, 297-306.

[14] Gupta, D. and Benjaafar, S. (2004) Make-to-order, make-to-stock, or delay product differentiation? A common framework for modeling and analysis. *IIE transactions,* 36, 529-546.

[15] Hsu, H. and Wang, W. (2004) Dynamic programming for delayed product differentiation. *European Journal of Operation Research,* Vol. 156, Nos. 183-193.

[16] He, D., Kusiak, A. and Tseng, T. (1998) Delayed product differentiation: a design and manufacturing perspective. *Computer-Aided Design,* Vol.30, No. 2, Nos.105-113.

[17] Garg, A. and Tang, S. C. (1997) On postponement strategies for product families with multiple points of differentiation. *IIE Transactions* 29, 641-650.

[18] Nandi, A. and Rogers, P. (2003) Behavior of an order release mechanism in a make-to-order manufacturing system with selected order acceptance. *Proceedings of the 2003 Winter Simulation Conference*.

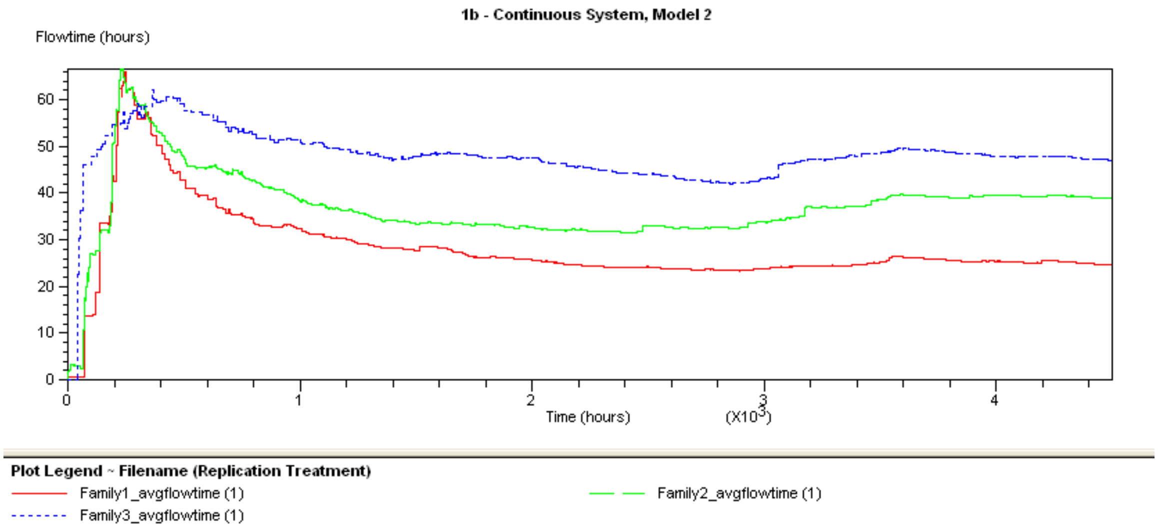
[19] Grubbstörm, W. R. and Wikner, J. (1996) Inventory trigger control policies developed in terms of control theory. *International Journal of Production Economics,* Vol. 45, Nos. 397-406.

[20] Ward, B. J. (1978) Determining reorder points when demand is lumpy. *Management Science,* Vol.24, No.6.

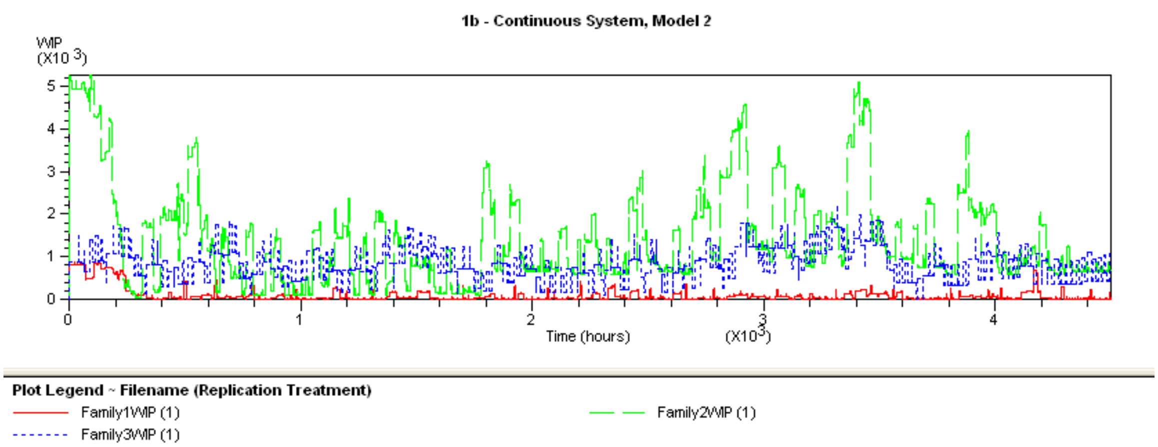
[21] Braglia, M. and Gabbrielli, R. (2001) A genetic approach for setting parameters of reorder point systems. *International Journal of Logistics: Research and Applications,* Vol.4, No.3.

[22] Yang, K. K. (1998) A comparison of reorder point and kanban policies for a single machine production system. *Production Planning & Control,* Vol.9, No.4, 385-390.

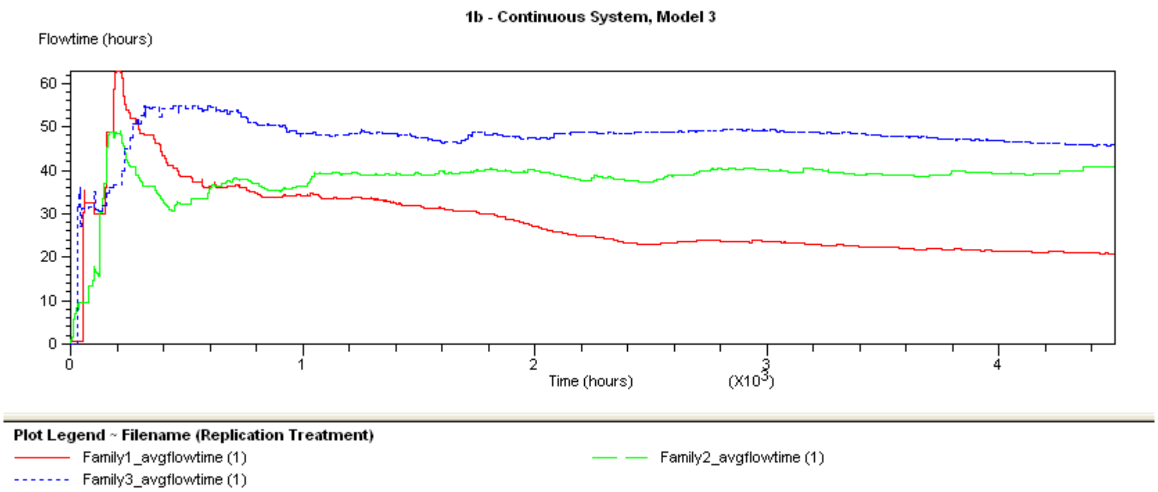
APPENDIX A – WARM UP TIME GRAPHS



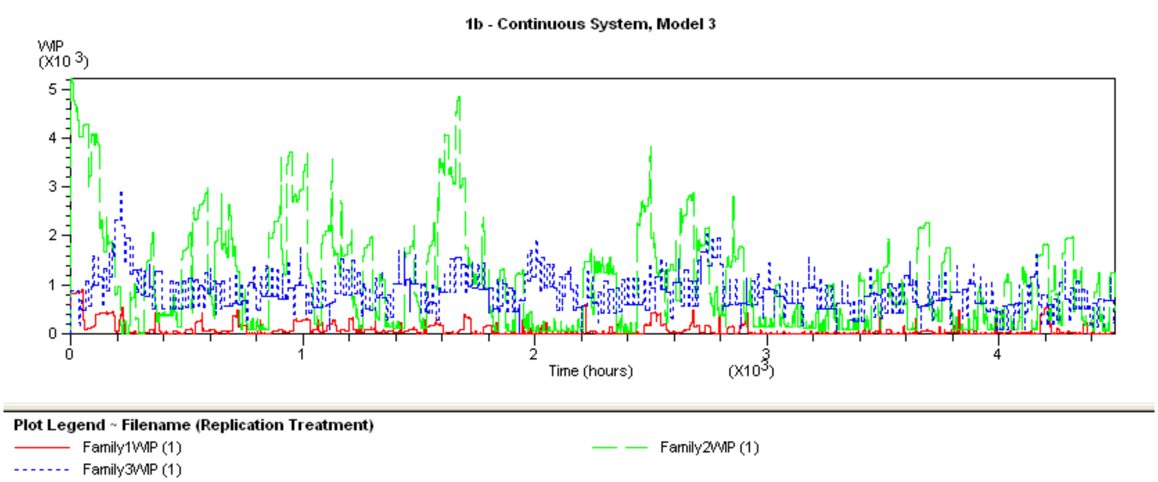
Model 2 - Average flowtimes for Family 1, Family 2, and Family 3 for connected system



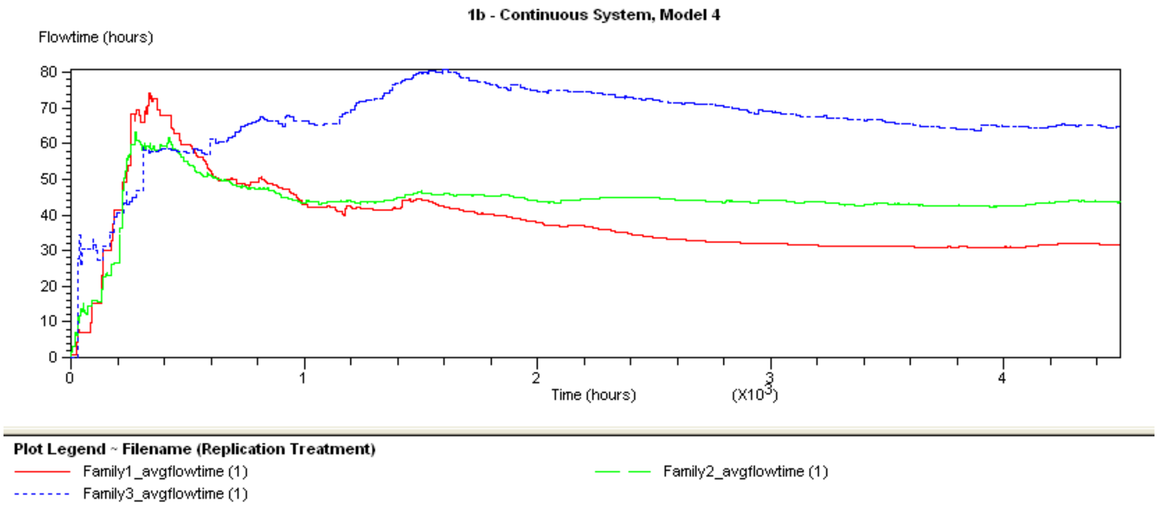
Model 2 - Average work in process for Family 1, Family 2, and Family 3 for connected system



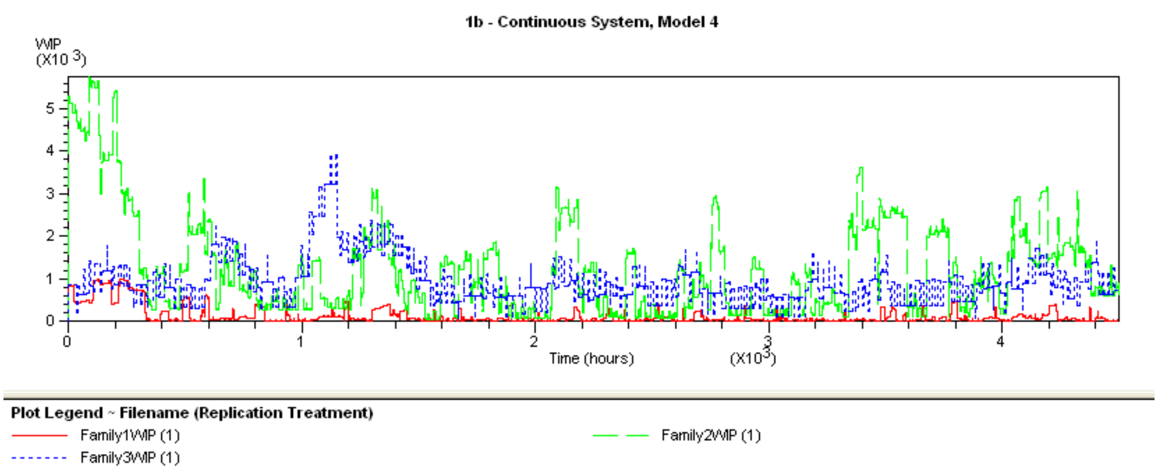
Model 3, Model 6, Model 7 - Average flowtimes for Family 1, Family 2, and Family 3 for connected system



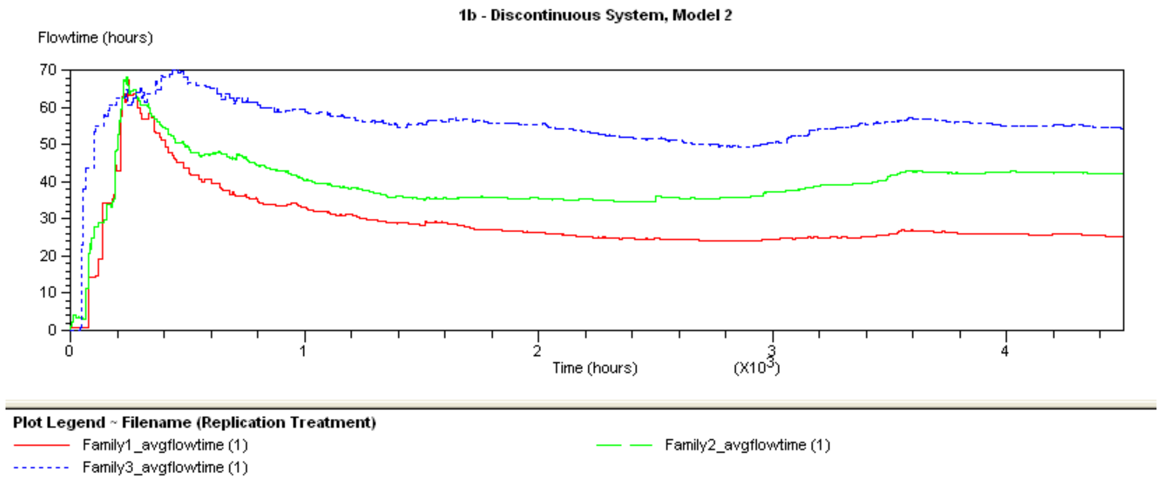
Model 3, Model 6, Model 7 - Average work in process for Family 1, Family 2, and Family 3 for connected system



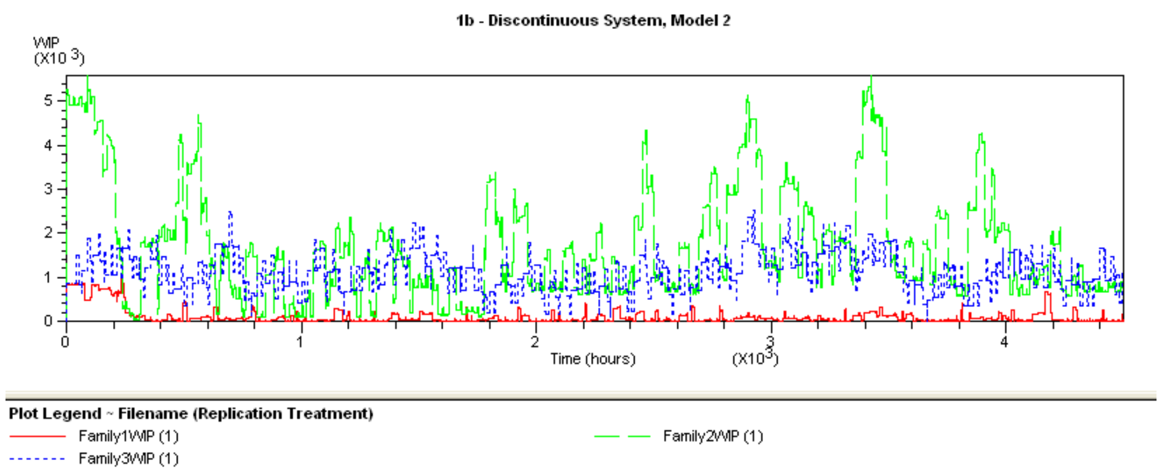
Model 4 - Average flowtimes for Family 1, Family 2, and Family 3 for connected system



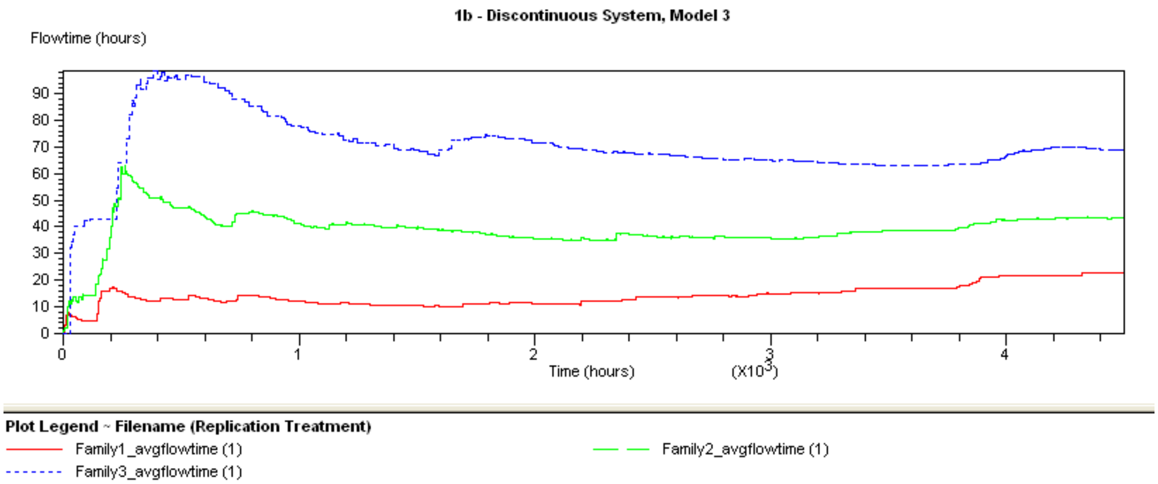
Model 4 – Average work in process for Family 1, Family 2, and Family 3 for connected system



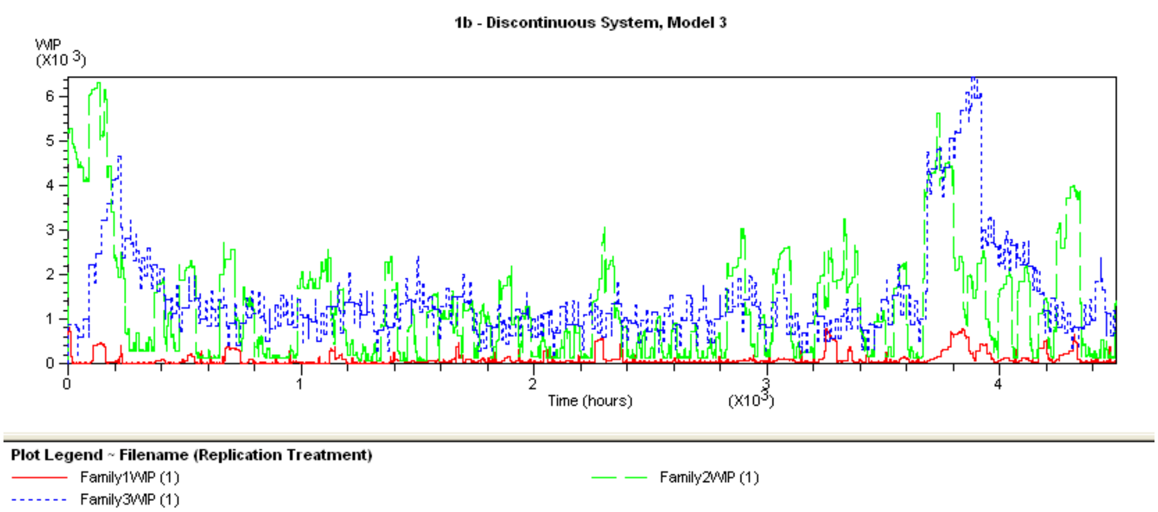
Model 2 - Average flowtimes for Family 1, Family 2, and Family 3 for disconnected system



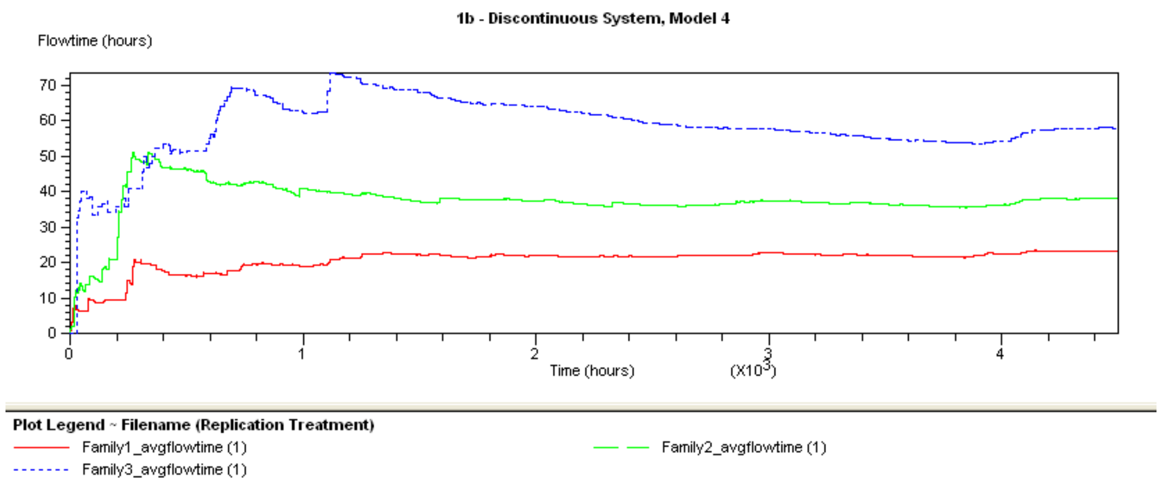
Model 2 - Average work in process for Family 1, Family 2, and Family 3 for disconnected system



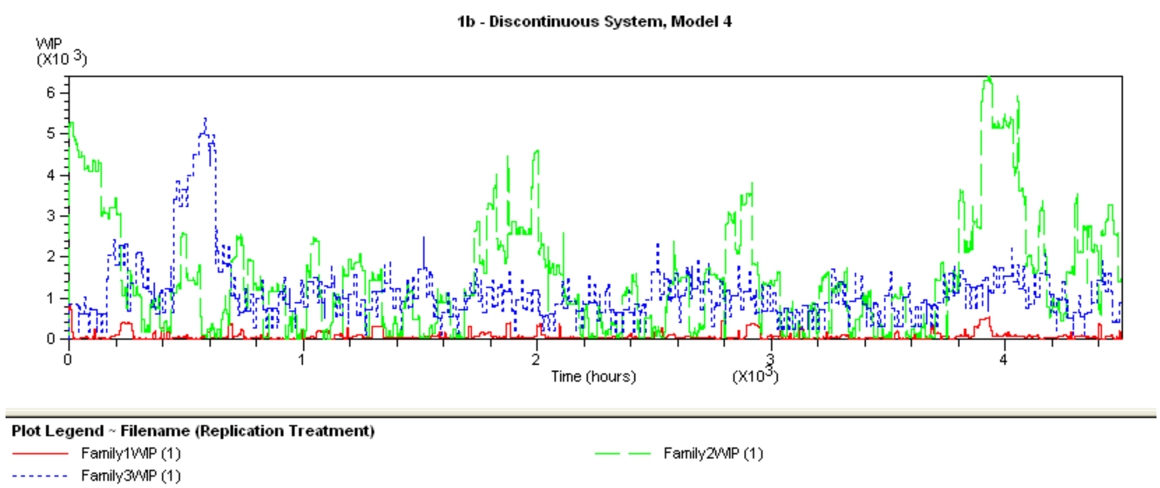
Model 3 - Average flowtimes for Family 1, Family 2, and Family 3 for disconnected system



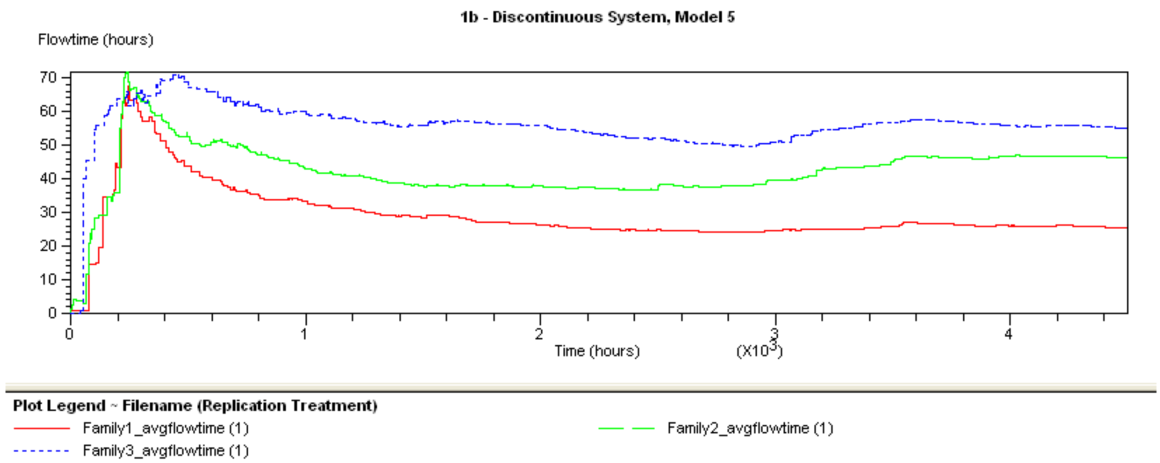
Model 3 - Average work in process for Family 1, Family 2, and Family 3 for disconnected system



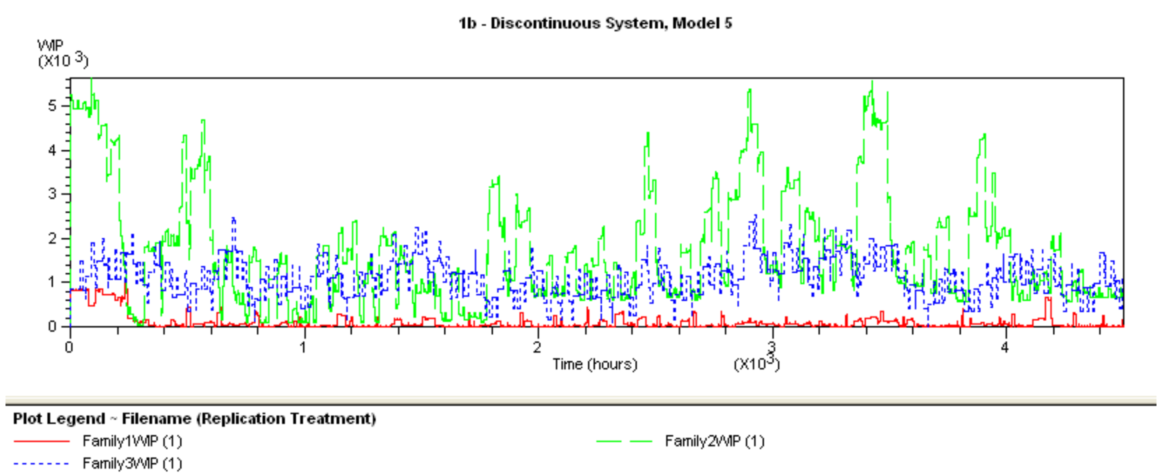
Model 4 - Average flowtimes for Family 1, Family 2, and Family 3 for disconnected system



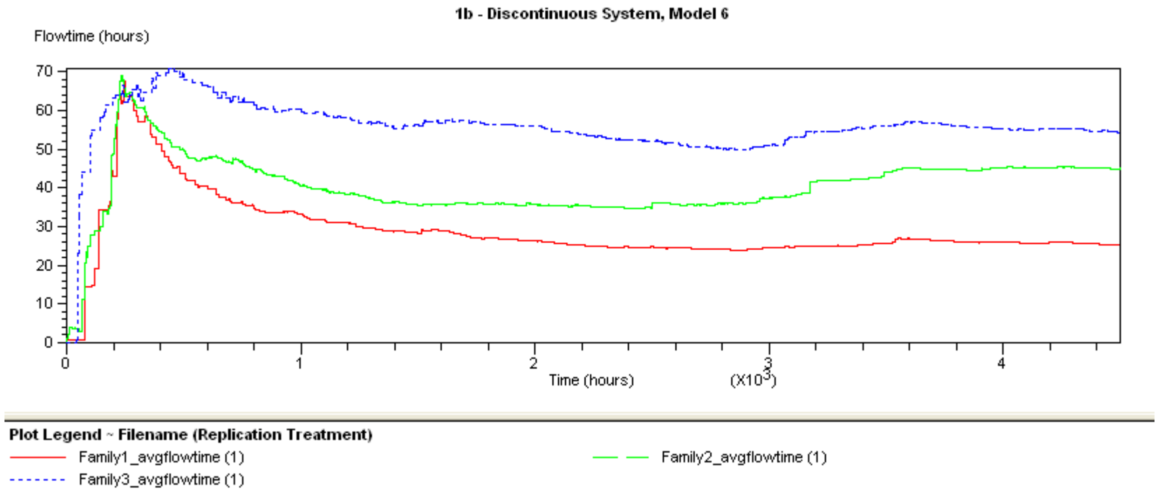
Model 4 - Average work in process for Family 1, Family 2, and Family 3 for disconnected system



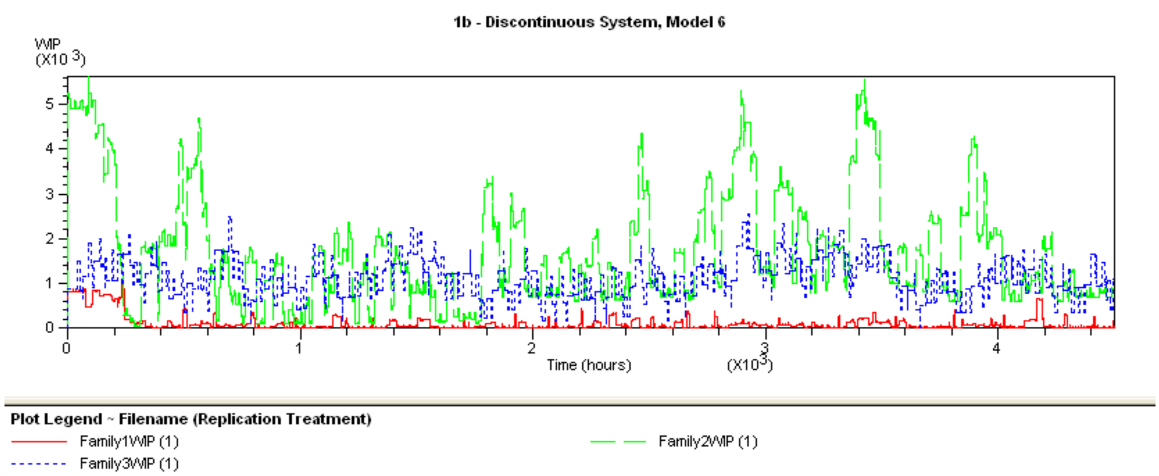
Model 5 - Average flowtimes for Family 1, Family 2, and Family 3 for disconnected system



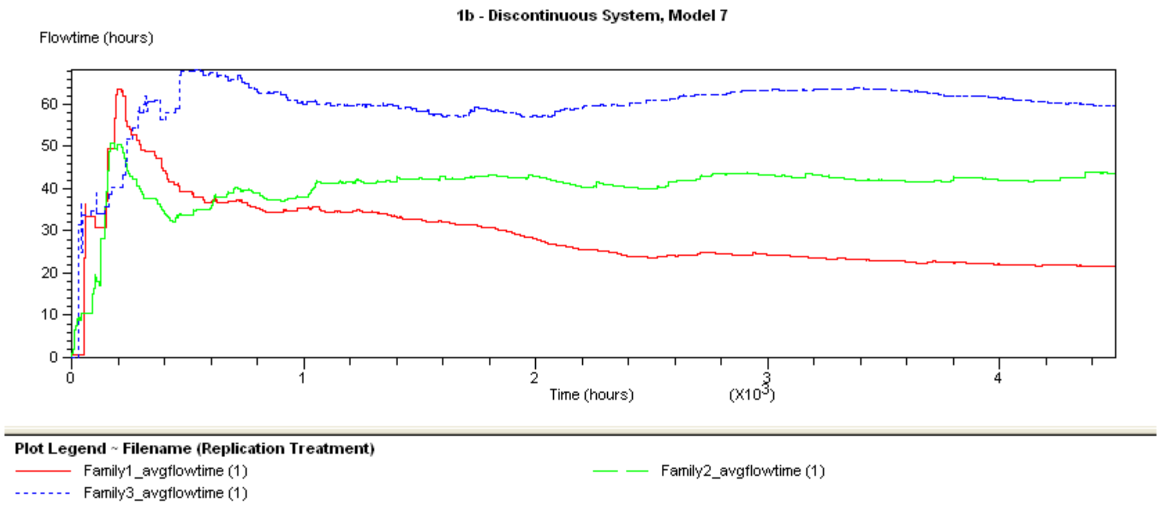
Model 5 - Average work in process for Family 1, Family 2, and Family 3 for disconnected system



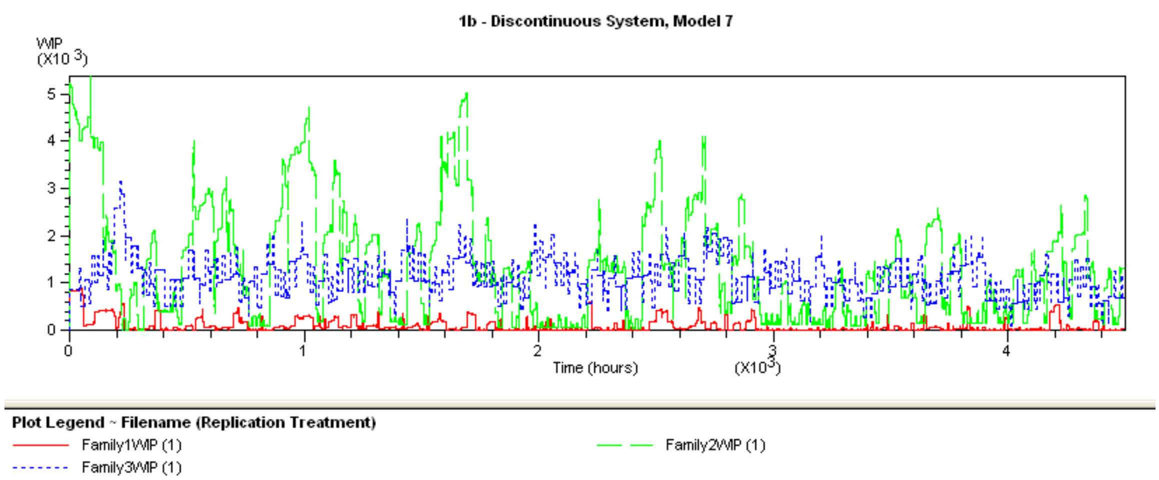
Model 6 – Average flowtimes for Family 1, Family 2, and Family 3 for disconnected system



Model 6 – Average work in process for Family 1, Family 2, and Family 3 for disconnected system



Model 7 - Average flowtimes for Family 1, Family 2, and Family 3 for disconnected system



Model 7 - Average work in process for Family 1, Family 2, and Family 3 for disconnected system

APPENDIX B – FLOWTIMES AND WORK IN PROCESS INVENTORY FOR CONNECTED AND DISCONNECTED SYSTEMS

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1A

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	19.2	34.631	49.878	22.437	53.52	48.029
2	31.302	31.555	57.609	22.168	39.263	79.611
3	28.229	40.846	65.955	25.326	65.41	69.894
4	27.176	41.232	38.187	24.619	66.748	68.649
5	30.887	43.73	64.055	29.213	41.687	54.042
6	23.341	33.852	42.038	23.637	36.213	52.097
7	25.95	38.463	282.23	28.013	48.227	64.681
8	39.613	26.523	49.785	26.644	65.227	55.592
9	26.009	34.243	62.028	29.634	46.876	56.496
10	18.653	35.583	59.092	24.821	46.09	47.36
11	46.562	40.869	61.386	31.241	48.58	67.651
12	27.116	36.356	40.054	25.137	38.086	48.751
13	38.169	36.031	61.758	27.704	59.375	54.937
14	18.692	35.49	41.539	29.274	56.678	65.075
15	18.637	25.078	38.569	25.434	53.92	67.007
16	22.871	42.009	40.851	51.003	65.743	139.04
17	34.243	40.126	52.803	39.736	63.168	81.004
18	24.349	27.32	39.512	47.776	46.258	65.535
19	261.36	251.01	753.29	33.596	53.497	47.221
20	124.74	80.629	609.95	39.888	64.177	323.66
21	23.963	45.994	46.193	22.284	39.936	77.051
22	19.367	50.728	42.778	28.079	59.783	61.979
23	18.495	33.309	53.324	37.973	47.519	47.361
24	30.002	35.532	38.754	26.96	59.285	57.381
25	40.841	44.842	65.89	32.08	58.93	67.309
26	26.211	36.362	42.3	17.816	35.974	47.838
27	27.34	27.904	46.467	19.616	40.25	45.757
28	21.969	46.712	104.88	25.46	53.631	90.107
29	30.114	37.226	48.177	26.984	47.689	70.655
30	46.146	48.568	40.048	30.623	45.744	80.534
31	34.335	41.905	60.837	20.909	38.444	68.508

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1A (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
32	35.044	42.905	54.221	21.101	43.783	52.539
33	27.385	46.717	49.016	21.984	32.322	47.785
34	29.684	42.489	48.2	31.708	56.748	57.402
35	33.258	38.474	73.793	16.844	45.883	44.108
36	25.578	37.925	36.928	28.497	52.634	73.012
37	27.856	36.491	38.496	22.067	49.361	69.739
38	23.246	38.481	38.789	21.28	38.229	46.759
39	37.204	35.028	63.199	30.032	28.362	57.132
40	18.732	27.92	40.127	25.479	44.905	54.944
41	30.65	37.998	64.001	29.836	49.72	73.87
42	34.079	53.264	38.102	23.78	55.59	49.504
43	25.866	36.543	41.123	26.973	51.451	48.989
44	27.024	46.138	62.405	36.841	49.392	74.799
45	29.834	40.359	48.688	24.987	34.92	47.148
46	55.195	51.75	291.15	42.449	66.91	68.055
47	24.848	43.349	44.497	33.459	65.001	60.43
48	31.633	29.204	40.026	21.939	42.977	50.701
49	35.349	31.479	57.352	22.148	45.11	53.875
50	21.942	36.438	53.252	20.199	46.809	57.224
51	22.776	46.352	61.62	30.429	51.518	60.427
52	33.274	40.789	58.149	38.293	50.133	64.863
53	18.924	30.078	42.209	35.484	82.01	50.873
54	263.55	237.66	392.62	27.661	59.273	84.593
55	38.833	37.355	41.401	36.238	61.895	56.061
56	74.55	74.55	74.55	28.958	56.093	52.699
57	28.373	46.398	56.32	34.901	71.222	59.746
58	396.18	305	637.47	115.15	166.24	324.07
59	38.953	30.96	43.475	18.598	63.571	63.477
60	26.335	43.639	61.754	49.324	48.623	73.798
61	32.745	42.7	58.042	34.38	58.854	69.178
62	39.61	49.77	45.828	20.613	45.207	53.199
63	23.393	45.793	40.195	22.327	45.689	59.449
64	30.516	35.197	62.339	31.467	59.991	49.699
65	41.445	38.673	60.024	22.233	61.952	49.318
66	70.693	63.565	133.7	28.106	44.255	49.523
67	34.497	47.391	45.768	24.666	43.901	51.002

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1A (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
68	34.146	45.618	68.136	28.941	40.441	54.944
69	20.791	32.665	43.637	22.437	48.477	46.85
70	28.45	47.952	45.562	37.572	50.009	68.701
71	22.346	34.259	41.949	47.653	71.983	92.316
72	28.963	38.507	55.479	16.753	34.823	45.782
73	34.799	38.618	49.071	45.475	67.959	62.474
74	205.96	293.8	397.46	27.822	55.992	74.419
75	23.115	35.558	43.585	30.23	52.339	83.567
76	23.45	35.619	44.614	35.843	49.696	50.437
77	40.967	64.387	70.147	47.961	55.819	65.433
78	21.234	33.09	37.658	54.804	99.736	123.85
79	30.855	46.429	62.245	93.62	154.42	444.48
80	115.59	96.642	505.97	41.311	48.805	53.847
81	35.763	54.3	117.62	36.019	43.795	47.289
82	35.248	45.985	42.331	29.707	47.937	49.082
83	35.019	39.812	51.739	28.784	59.557	55.188
84	34.964	39.388	44.674	20.358	60.125	58.401
85	45.594	41.035	52.408	28.79	39.725	47.418
86	31.783	36.809	40.559	37.007	63.305	72.36
87	23.601	33.697	42.192	30.018	62.61	69.364
88	36.47	49.1	61.252	23.957	31.694	96.777
89	29.133	43.289	56.985	49.432	55.197	52.837
90	38.909	27.705	40.223	20.113	43.409	63.116
91	29.552	42.735	53.11	20.9	62.095	66.676
92	32.423	50.725	45.833	21.467	48.571	51.107
93	33.822	30.797	43.319	43.019	52.47	54.054
94	13.439	33.418	59.602	29.289	48.262	73.618
95	38.843	40.446	66.98	35.604	49.377	67.905
96	27.429	23.495	33.093	21.103	54.899	53.386
97	26.482	49.347	39.379	23.682	59.489	63.449
98	23.24	38.36	52.22	17.851	65.194	77.852
99	30.44	38.554	42.256	39.083	57.586	63.401
100	39.036	56.774	103.1	35.985	47.415	80.122

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1A

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	62.931	1142.5	808.22	66.56	1334.9	1002.4
2	75.648	926.76	738.4	52.985	1282.5	1150.8
3	104.52	1196.3	838.74	93.982	1790	1051.5
4	71.894	893.01	770.13	102.76	1683.7	1167.6
5	97.314	1308.3	900.37	82.12	1798.8	1053.6
6	60.804	1085.7	784.62	90.395	1272.2	1222.3
7	151.52	2072.7	7570.2	68.726	1401.2	1070.7
8	97.313	824.99	830.2	79.547	2104.3	1179.8
9	91	1106.6	818.35	92.733	1621.3	996.61
10	76.5	1090.7	772.28	55.105	1794.9	984.83
11	160.38	1956.1	872.12	238.62	1718.7	1109.8
12	57.331	1177.9	711.61	53.958	1345.1	979.18
13	83.369	1872.8	852.05	92.038	1850	1222.5
14	76.895	1073.4	756.84	74.912	1288.7	1066.2
15	63.388	835.43	740.8	73.56	1668.5	1104.5
16	68.068	838.72	787.98	179.68	1421.7	2332.5
17	74.046	1265.8	928.28	118.45	2616.3	1246.5
18	79.852	1342.4	760.24	145.61	1346.9	1149.7
19	867.26	4374.1	12964	83.82	1196.9	1122.3
20	467.18	2878	11956	74.381	1450.5	2281.9
21	82.414	1264.2	761.44	70.007	946.32	1069.7
22	42.121	904.79	729.42	97.709	1696.7	1092.3
23	77.76	998.45	764.27	64.923	1990.5	971.69
24	69.06	1492.4	700.15	74.645	1440.1	1158.7
25	193.43	1057	939.08	100.24	2129.8	1147.8
26	76.85	1165.4	796.41	64.877	945.82	989.51
27	79.338	1247.3	874.36	78.188	978.04	1023.5
28	70.6	1544.7	1212.8	131.89	1892.2	1358.7
29	99.745	1218	921.38	89.004	1833.7	1112.6
30	153.35	1241.4	708.51	56.014	1203.1	940.04
31	91.865	1007.2	907.07	66.218	1935.4	1030.7
32	130.45	1156.7	933.17	82.157	1119.9	1072.9
33	78.088	1505.1	819.38	76.703	913.55	1064
34	85.664	1198.3	960.35	117.42	1284.9	1102.9
35	104.68	1100.7	1173.2	44.137	836.03	892.23
36	87.611	987.97	676.72	91.529	2138.6	1235.5

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1A (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
37	87.625	1261.1	754.85	60.901	1523.5	1191
38	53.311	1479.2	710.98	53.284	928.43	975.9
39	120.32	1314.6	830.14	66.43	881.35	1080.5
40	52.517	1096.7	715.28	63.743	1192.8	1149.8
41	85.427	1161.9	931.18	100.74	1591.8	1189.2
42	81.903	1531.3	689.05	96.623	2468.6	1046.3
43	73.037	1042.3	770.41	68.8	1046.3	1060.2
44	73.739	1529.1	866.62	104.4	1477.9	1223.4
45	97.511	1295.4	808.15	85.022	1259.1	915.12
46	128.3	1331.4	2290.6	133.58	2131	1899.9
47	130.56	1738.5	873.82	125.18	2450.1	1197
48	73.622	628	745.5	93.107	1448	1131.4
49	192.71	999.84	747.77	101.06	1235.4	1188.9
50	77.961	1311	715.84	101.92	1629.9	1078.5
51	79.554	1276.9	895.01	94.967	1386.3	1191.1
52	101.72	1288.9	837.76	124.44	1772	1112.9
53	54.396	961.83	788.26	99.159	1567.3	1114.9
54	559.15	3821	3659.1	98.234	1771.2	1108
55	74.55	1158	754.05	66.834	2480	1326.3
56	152.11	1342	982.46	119.36	1483.4	1057.6
57	100.65	1322.9	776.45	147.97	2457.6	1178.9
58	1017.3	4064	4563.8	443.96	3904.9	2245
59	85.358	918.29	800.35	83.809	1609	1064.1
60	83.138	1716.5	820.59	157.07	1866.8	1237.9
61	78.986	1131.9	829.39	139.72	2213.1	1151
62	125.95	1188.1	815.93	59.492	1081.8	1079.1
63	71.043	1402.9	741.16	55.757	1620.5	1000.8
64	84.894	1133.4	1055.8	126.94	2118.5	1032
65	204.32	1507.2	957.47	89.802	2327.3	1045.4
66	189.03	1674	1342.1	89.983	1192.6	993.36
67	119.18	1598.2	830.35	69.478	1084	1061.1
68	77.217	1242	845.86	52.784	1411	1133.3
69	73.754	849.81	761.87	67.355	1224.6	1001.9
70	79.453	1424.9	865.02	150.89	1829.7	1274.6
71	80.192	1060.5	774.07	112.03	2257.8	1405.3
72	122.59	1250.8	812.14	59.853	958.03	1001

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1A (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
73	103.79	936.64	907.42	99.29	1756.1	1330.5
74	623.84	4184.3	8065.4	72.203	1150.3	1076.4
75	81.784	1210.2	781.76	96.776	1649.4	1251.4
76	69.608	889.86	850.26	64.016	1302.9	1080.7
77	181.97	1767.5	1184.6	178.03	1836.4	1258
78	54.27	1643.8	756.11	159.42	1894.7	1728.5
79	91.776	1851.8	948.18	358.8	3164.2	2871.4
80	425.26	3759.6	8841.3	124.74	1502.9	1004.5
81	115.61	1621.9	1422.6	88.593	1554.6	1023.6
82	113.68	1459.7	774.88	59.579	1134.6	1034.2
83	92.541	865.37	953.61	64.58	2002.1	1148.6
84	94.369	1850.6	866.23	106.64	2138.8	1008
85	105.8	1122.7	978.34	61.566	1584.9	1014.7
86	93.752	1093.3	847.4	130.05	2127.2	1235.5
87	67.543	1108.7	772.61	72.863	2003.1	1181.5
88	95.612	1189.2	938.07	46.593	1309.8	1263.4
89	75.257	2215.3	791.7	255.11	1603.1	978.45
90	100.08	814.36	716.35	65.968	1146.8	1081.1
91	152.96	1257.2	780.99	74.534	1802.3	1101.7
92	90.864	1164.1	869.42	89.758	1294.8	1093.2
93	121.73	939.53	785.76	157.87	1487.5	1192.1
94	54.478	1181.9	882.09	107.98	1600.7	1184.6
95	78.921	1338.8	945.13	69.542	1744.7	1103.3
96	70.667	838.22	637.07	74.043	1208.6	1160.7
97	67.775	1036	695.56	81.728	1586.6	1256
98	72.263	909.33	770.07	70.615	1474.9	1268.4
99	98.32	1386.6	799.46	89.62	1343.2	1163.4
100	111.34	1334.3	1578.8	104.83	1693.7	1234.5

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 2

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	23.854	43.816	46.633	24.432	47.267	53.607
2	19.222	35.469	40.299	20.093	46.566	47.311
3	28.439	46.145	43.068	35.144	55.748	50.663
4	33.949	35.786	49.763	35.116	46.282	57.375
5	40.994	37.34	44.394	41.92	41.943	52.453
6	23.371	40.5	44.917	28.455	45.274	52.232
7	38.915	55.122	60.167	39.266	62.021	127.46
8	33.063	53.26	60.884	49.237	59.523	80.912
9	19.267	33.633	55.195	19.843	35.154	82.069
10	21.91	34.71	79.637	22.511	41.574	84.81
11	58.353	55.882	67.491	60.215	59.639	75.376
12	32.827	44.651	55.643	33.515	52.299	63.24
13	32.329	45.049	190.71	33.117	48.465	192.79
14	31.248	32.294	53.281	32.225	39.268	61.262
15	28.249	46.357	42.008	29.503	62.961	49.421
16	34.701	43.66	50.478	35.968	49.508	58.449
17	33.168	36.981	45.782	41.547	38.663	53.691
18	33.659	52.9	110	36.435	61.638	98.041
19	33.527	32.035	40.353	39.181	41.278	50.503
20	27.016	40.159	38.083	27.484	46.909	45.416
21	22.101	27.672	45.869	32.549	36.408	54.832
22	52.53	45.684	62.234	53.618	51.844	71.615
23	46.982	51.222	183.09	51.494	57.208	203.47
24	19.976	39.008	47.804	20.636	45.035	54.939
25	33.086	54.569	50.418	33.607	64.593	62.604
26	25.453	31.761	47.349	26.149	37.309	56.79
27	49.259	60.211	109.68	54.353	66.4	110.5
28	25.182	45.811	39.513	26.251	51.94	51.346
29	48.115	78.464	101.43	48.779	91.338	204.16
30	30.737	46.454	73.339	32.668	60.501	93.719
31	29.074	42.919	43.233	30.828	52.482	50.543
32	38.936	38.274	40.699	39.852	41.599	48.005
33	24.325	45.524	42.672	31.972	50.766	51.481
34	19.553	47.4	42.267	20.125	54.388	50.165
35	26.911	38.927	57.123	30.307	42.665	64.447
36	24.989	42.32	65.262	27.096	56.356	69.959

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 2 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
37	29.413	36.027	56.774	30.306	39.417	64.031
38	33.42	41.427	40.674	34.298	62.636	50.255
39	18.817	34.798	56.019	19.485	39.025	63.881
40	22.128	38.474	43.723	22.749	46.184	50.716
41	22.564	34.164	46.304	24.301	36.434	55.078
42	20.344	42.242	47.993	22.441	45	52.673
43	23.152	45.656	60.548	31.398	54.145	79.69
44	24.372	39.953	59.198	25.079	44.879	79.901
45	21.819	36.594	41.578	22.452	42.442	48.654
46	29.227	46.687	54.031	31.522	53.411	61.222
47	35.738	52.511	46.875	36.514	62.484	54.432
48	139.98	166.76	474.16	29.043	51.468	86.638
49	39.049	46.077	68.608	39.553	52.978	88.022
50	29.454	41.624	86.134	34.26	43.906	120.4
51	38.122	63.294	213.16	39.438	65.989	229.24
52	29.287	42.734	46.54	30.05	49.016	54.538
53	15.584	38.407	43.777	34.655	62.5	72.372
54	17.104	44.659	46.376	20.786	52.115	55.248
55	25.313	36.336	50.998	26.162	37.86	56.824
56	22.309	40.965	46.204	23.012	44.528	54.651
57	21.635	46.622	64.227	22.389	49.586	71.586
58	26.982	40.744	43.792	27.717	47.611	51.851
59	27.916	51.335	65.633	41.72	58.532	74.352
60	20.168	45.448	59.969	25.488	45.98	67.584
61	31.451	34.972	47.807	32.266	46.425	56.946
62	26.044	37.831	41.091	29.476	43.41	48.617
63	27.955	50.823	58.045	28.789	61.607	65.366
64	40.078	34.768	38.676	42.656	38.237	44.947
65	27.144	42.465	40.799	23.487	38.735	48.134
66	25.272	38.391	40.532	25.938	39.586	49.206
67	49.055	66.541	83.542	53.311	71.35	102.79
68	23.364	45.295	39.929	23.87	51.86	47.698
69	19.713	41.273	39.954	20.395	44.36	62.445
70	26.894	38.706	57.358	40.862	43.499	64.1
71	28.21	44.656	51.448	30.272	47.493	58.949
72	42.787	48.599	60.945	45.04	51.335	80.197

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 2 (continued)

73	30.162	49.193	105.19	32.623	62.979	138.25
74	26.102	37.498	48.747	27.328	45.104	56.189
75	19.775	32.619	42.049	20.437	35.502	50.126
76	28.235	39.892	45.914	29.213	48.052	53.81
77	29.136	47.694	48.412	29.607	54.865	54.565
78	23.712	43.822	100.26	24.724	51.121	82.121
79	35.002	38.35	57.606	42.31	47.219	51.505
80	43.162	90.101	204.1	44.004	95.062	213.1
81	23.595	40.665	52.815	24.275	49.656	60.203
82	29.827	47.666	44.093	38.587	52.574	52.099
83	33.461	56.948	70.772	44.91	60.74	87.922
84	28.49	47.93	65.83	30.793	54.058	72.663
85	39.476	48.242	41.591	40.203	59.514	49.06
86	21.626	42.836	40.82	22.253	52.272	47.723
87	58.354	64.809	105.66	59.653	74.835	137.72
88	25.296	38.155	44.17	30.271	41.013	52.817
89	39.797	50.3	122.58	42.608	58.71	103.88
90	12.277	39.265	56.716	13.521	62.833	65.431
91	26.154	44.206	55.762	26.775	54.175	88.203
92	41.309	53.711	144.75	42.535	63.44	150.96
93	43.042	51.202	60.044	47.495	61.787	68.161
94	33.014	47.086	48.779	33.739	55.063	54.636
95	42.019	48.616	89.959	43.057	51.383	97.552
96	34.921	46.561	46.57	35.545	55.221	53.073
97	31.922	53.717	53.814	27.226	53.324	61.967
98	20.436	34.975	47.177	21.077	40.593	54.773
99	19.379	59.341	40.747	20.135	61.999	47.024
100	22.021	43.743	42.047	23.612	50.179	65.115

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 2

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	62.787	1518	866.4	71.998	1795.4	1109.3
2	92.634	1002.3	750.72	120.21	1286.9	992.26
3	100.13	1341.6	819.04	113.06	1762.9	1080.1
4	106	1040.8	863.51	115.5	1363.2	1112.6
5	60.216	1263.9	798.96	69.008	1571.3	1056.8
6	82.061	1619.8	830.05	94.58	1938	1092.2
7	116.35	1454.9	1276.5	128.93	1927.5	1672.3
8	103.78	1122.7	893.66	140.47	1417.8	1186.4
9	56.736	671.41	845.66	66.018	792.82	1444.8
10	49.483	1347.2	945.7	60.195	1884.4	1235.8
11	117.92	1267.5	866.16	139.13	1576.1	1123.6
12	71.487	1137.8	836.69	80.933	1396.4	1103.3
13	129.94	1124.1	3408	141.15	1362.2	3724.9
14	69.776	799.5	762.23	81.954	1138.6	1037.4
15	102.57	1018.1	834.6	118.44	1325.9	1114.6
16	87.699	1157.1	937.25	96.989	1533	1229.3
17	116.4	1144.8	804.55	158.28	1390	1059.3
18	134.2	942.23	1151.6	147.51	1336.3	1474
19	75.207	903.51	788.71	77.182	1166.1	1045.9
20	53.071	1225.7	737.47	58.485	1491.4	982.88
21	86.876	964.49	834.65	99.972	1259.3	1124.7
22	93.999	1401.2	960.05	98.416	1779.6	1259.2
23	116.68	1354.2	1901.8	131.36	1763.3	2242.9
24	43.833	1007.5	786.58	50.639	1271.8	1038.9
25	94.772	1716.3	880.95	108.7	2198.6	1173
26	60.013	764.73	770.79	72.45	951.51	1095.8
27	148.33	1410.5	1435.5	172.02	1768.2	1744.8
28	66.76	1284	732.8	78.094	1501.9	1103.9
29	191.08	1668.7	1897	202.81	2401.9	2306.8
30	84.81	924.37	970.35	98.51	1242.9	1357.2
31	59.941	1051.2	856.01	69.352	1532.5	1107.3
32	114.37	1356.2	765.68	127.43	1631.4	1022.8
33	64.317	1046.8	801.76	73.273	1345.7	1034.8
34	60.98	804.52	826.36	69.146	1136.8	1085.9
35	74.817	948.84	843.65	91.19	1591.3	1082.7
36	88.417	1366	945.13	112.15	2034.6	1231.8

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 2 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
37	117.02	1088.8	783.7	139.33	1339.1	1040
38	145.77	847.62	772.74	162.37	1109.3	1079.5
39	63.45	931.9	776.95	76.719	1159.9	1022.7
40	61.9	1236.1	780.55	71.319	1604	1012.9
41	65.249	1016.2	808.43	76.618	1318.2	1095.4
42	35.35	609.58	915.38	38.408	779.45	1153.1
43	61.1	1517.7	800.51	68.593	3020.5	1177.3
44	53.138	1106.7	857.03	62.092	2122.2	1171.1
45	67.781	931.73	751.85	78.378	1188.1	968.97
46	72.059	1354.4	813.18	78.033	1660.6	1070.2
47	109.57	1447.4	900.11	120.45	2329.2	1163.1
48	429.27	3058.2	8243.1	113.28	1125.1	1258
49	73.368	1570.8	976.28	77.643	1832	1343.8
50	102.86	1090.1	1000.9	120.16	1436	1287.9
51	119.64	1620.8	2090.9	132.53	1866.2	2441.8
52	120.98	1149.7	729.34	141.35	2176.2	951.55
53	40.637	742.55	722.85	92.986	2260.7	1173.1
54	48.137	878.99	815.38	53.931	1121.3	1058.3
55	97.767	947.6	872.94	118.28	1145.8	1149.6
56	69.78	867.72	856.94	78.59	1113.7	1143.2
57	69.984	1318.3	884.35	79.928	1719.3	1126.2
58	79.05	1043	844.27	90.895	1469.8	1127.2
59	74.642	1204.5	892.39	92.332	2196.9	1196.2
60	59.249	1056.2	861.79	73.271	1236.3	1136.8
61	70.217	944.24	833.79	77.471	1289.5	1086.9
62	45.611	946.66	1123.1	51.225	1726.7	1362.3
63	69.076	1486.7	816.38	77.759	2104.2	1066.2
64	99.422	866.87	742.55	109.46	1125.6	958.64
65	65.163	941.97	799.58	73.769	1594.6	1043.3
66	69.24	992.93	742.91	76.521	1250.8	1015
67	164.14	2048	1369.5	190.31	2428.3	1727.2
68	44.67	839.75	739.2	49.228	1090.4	982.49
69	64.532	804.69	729.61	77.172	1016.3	1015.6
70	68.664	1341.2	878.23	91.18	1761.8	1121.6
71	78.446	1672.8	926.58	88.239	2006.1	1173.6
72	175.55	1132.8	926.89	195.26	1325.6	1197.4

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 2 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
73	103.57	982.4	1565.3	112.13	1323.8	1886.7
74	84.409	1149.8	890.65	85.428	1937.8	1157.6
75	59.641	1241.4	805.41	67.604	1505.9	1080.3
76	74.888	1118.2	810.35	90.075	1507.1	1078.7
77	50.054	1108.8	1031.3	54.622	1420.6	1286.6
78	87.737	986.89	1084.2	106.89	1575.3	1753.4
79	73.796	1096.8	778.16	82.768	1255.7	1111.9
80	196.2	1626.5	2527.1	208.11	1850.1	2875.5
81	79.168	1030.2	821.33	91.295	1659.9	1074.6
82	95.47	1325.1	797.4	134.89	1614.4	1062.7
83	81.595	1221.3	916.7	114.16	1522.2	1279.3
84	86.665	934.9	1031.5	94.991	1280.4	1295.5
85	74.036	1007.1	870.94	80.826	1799.7	1153.5
86	64.521	1189.3	798.46	74.365	1531.1	1043.3
87	126.47	1730.2	1996.7	139.5	2036.3	2342.4
88	68.238	998.7	843.24	78.881	1270.5	1135.1
89	172.78	1507.9	1398.8	186.09	2427.9	1678.6
90	60.871	996.54	770.54	74.318	1226.2	1058.3
91	61.653	1332.1	891.02	68.518	1730.4	1202.8
92	164.96	1347.6	1566.1	175.5	1699.6	1904.6
93	106.52	1403.1	918.03	127.49	1715	1202
94	46.538	1330.8	943.57	50.126	1629.4	1197.1
95	100.26	1267.2	1253.7	112.23	1497.5	1511.9
96	71.584	1335.5	911.26	77.231	1661	1142.4
97	110.07	1402.2	1041.6	95.537	1656.8	1105.3
98	70.291	968.23	799.38	90.736	1451.5	1071.3
99	56.301	944.95	748.83	65.248	1205	954.86
100	81.086	1008.2	788.08	100.49	1486.2	1078.4

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 3

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	15.681	41.528	44.446	32.304	49.59	66.083
2	24.008	51.01	46.064	24.749	57.263	56.158
3	22.389	39.486	70.526	18.605	41.307	58.288
4	17.435	32.248	199.6	19.526	36.014	56.485
5	17.643	26.608	47.632	22.957	50.544	49.946
6	28.324	50.067	43.512	23.442	40.186	60.805
7	26.39	45.835	107.1	24.179	54.876	50.945
8	27.038	27.923	45.262	26.588	41.068	74.532
9	25.117	44.664	46.604	34.062	55.355	50.753
10	24.415	32.784	52.013	33.774	42.502	71.499
11	18.623	41.936	63.87	30.56	43.165	55.9
12	35.394	29.163	44.812	33.31	39.173	64.564
13	32.797	58.102	48.454	37.869	48.542	53.01
14	28.046	75.237	58.018	26.352	55.714	54.499
15	30.283	46.853	43.369	28.548	45.524	115.4
16	24.847	44.981	55.423	38.445	52.189	62.821
17	33.498	54.131	57.263	27.487	46.781	242.9
18	21.494	41.772	45.978	36.994	49.616	117.34
19	30.911	49.408	64.034	26.183	38.574	77.503
20	21.361	54.262	41.986	21.151	46.899	54.259
21	27.012	43.059	44.821	48.304	62.278	66.552
22	28.958	40.848	66.504	17.289	40.676	51.472
23	15.971	32.611	51.954	21.976	41.466	48.872
24	20.071	29.196	43.345	35.157	45.991	82.898
25	30.712	30.069	57.978	19.776	49.585	75.228
26	19.112	27.882	59.857	21.912	38.853	111.5
27	21.118	33.158	45.903	32.391	50.455	48.684
28	22.281	44.793	56.551	26.15	45.412	208.48
29	20.094	34.783	41.67	28.226	55.236	50.455
30	18.561	29.938	43.366	26.459	42.066	55.47
31	33.356	47.153	48.997	56.176	93.305	490.43
32	21.841	39.364	49.138	27.634	43.604	71.68
33	17.754	24.663	44.733	19.845	36.026	51.362
34	26.17	55.828	45.958	22.436	52.764	52.733
35	16.085	32.201	42.653	33.887	54.228	151.3
36	20.036	41.543	58.321	28.126	34.939	54.546

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 3 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
37	23.042	40.9	48.202	21.061	56.406	61.78
38	18.938	30.115	44.14	7.5096	18.186	49.337
39	38.177	64.503	44.124	9.1035	43.74	72.722
40	25.789	32.764	48.868	25.22	44.005	69.7
41	39.402	33.745	1029	16.727	64.431	53.276
42	18.131	46.259	42.829	24.387	59.798	61.983
43	13.456	46.406	53.629	24.104	48.88	64.923
44	29.357	42.964	42.645	25.685	33	76.523
45	24.548	36.297	55.063	23.368	37.474	50.473
46	30.337	34.41	46.719	37.33	55.84	73.916
47	23.198	41.418	73.621	23.045	41.494	70.727
48	21.925	32.369	50.762	40.317	51.904	56.489
49	18.465	34.704	58.024	43.056	49.706	51.734
50	19.048	46.124	46.512	30.55	38.987	49.529
51	34.926	32.277	44.103	22.853	43.116	54.299
52	37.571	34.099	58.481	38.192	50.933	64.148
53	34.25	44.118	46.325	23.36	36.742	48.939
54	41.551	49.903	64.275	18.796	45.023	65.278
55	28.819	38.258	63.685	20.032	42.195	170.49
56	20.693	48.124	44.832	25.22	39.621	67.551
57	24.067	34.515	53.794	30.797	46.606	90.736
58	20.024	36.393	40.996	19.918	34.611	91.716
59	31.607	36.273	127.41	18.284	38.564	54.835
60	25.899	21.224	46.735	32.68	50.247	256.21
61	32.135	47.069	60.328	24.004	50.096	49.328
62	30.854	44.668	45.072	26.038	46.751	54.597
63	27.034	40.148	44.132	18.12	43.155	57.236
64	25.932	48.402	47.917	24.867	41.056	54.879
65	19.028	42.974	52.009	16.6	52.071	56.519
66	28.81	42.097	61.901	27.718	37.215	110.2
67	18.279	37.716	43.61	23.011	31.882	54.841
68	19.107	32.861	46.551	30.662	50.138	67.496
69	16.246	26.339	45.823	19.479	54.328	49.944
70	30.406	34.311	46.155	22.523	51.976	49.503
71	19.857	50.449	72.707	27.183	48.136	80.265
72	17.91	27.171	43.64	37.506	52.661	77.624

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 3 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
73	27.221	40.763	48.797	22.011	51.694	67.209
74	31.057	45.023	51.152	42.989	42.259	349.01
75	20.982	42.628	60.214	24.921	46.485	431.99
76	42.625	46.356	52.288	45.346	44.939	66.631
77	25.852	45.991	105.01	25.085	39.873	66.841
78	27.983	26.938	101.15	23.064	38.243	51.983
79	26.952	39.084	48.416	22.44	42.622	70.879
80	17.618	42.709	43.67	25.083	48.499	53.744
81	16.028	39.249	41.637	28.271	50.387	82.802
82	25.334	56.412	50.65	32.003	62.549	67.842
83	21.209	35.324	46.272	22.407	57.33	73.282
84	25.349	31.422	44.567	20.44	50.812	52.353
85	24.55	39.206	55.819	49.382	48.53	54.013
86	21.767	43.01	48.81	18.814	43.434	65.736
87	19.147	39.69	58.525	35.405	34.583	55.913
88	11.821	30.739	46.609	35.946	57.001	67.402
89	11.052	41.003	43.088	24.625	61.373	60.839
90	28.015	29.289	54.912	30.23	29.567	62.602
91	23.366	36.678	47.562	25.032	41.449	135.14
92	19.795	34.377	58.755	22.292	47.155	56.2
93	29.3	33.383	55.213	29.306	66.384	66.772
94	33.682	45.305	48.563	21.269	48.212	83.14
95	24.749	34.06	42.632	33.47	42.316	50.388
96	29.715	39.527	56.316	27.584	59.372	50.312
97	23.629	40.209	48.196	21.03	39.236	55.047
98	37.665	42.489	329.85	26.694	42.296	56.123
99	25.328	39.843	44.348	33.779	55.623	186.42
100	25.654	36.44	61.339	23.452	48.47	52.874

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 3

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	52.917	780.85	784.63	127.67	1233	1577.5
2	73.188	1421.8	867.33	140.4	2019.2	1042.9
3	80.243	1143.9	878.44	68.515	1080.8	1067
4	66.258	673.68	3180.1	116.12	1201.7	1100.2
5	37.006	676.12	841.5	74.743	1232.1	980.57
6	83.502	1554.4	780.74	57.641	1247	1094
7	84.612	1341.6	1207.5	99.583	1702.5	1081.5
8	55.765	837.14	921.35	69.239	1446.8	1760.3
9	54.175	955.07	857.52	103.36	1179.6	1056.7
10	46.488	606.21	955.56	68.792	1184.5	1117.6
11	42.358	1077	814.44	75.217	1421.1	1118.1
12	117.16	1160.7	796.43	50.691	1438.6	1133.1
13	62.983	1180	797.46	139.94	1947	1032.1
14	61.805	1444.9	853.31	87.683	1998.1	1113.8
15	93.999	1451.1	771.03	88.895	1193.9	1785.9
16	55.236	1226.6	861.57	184.09	1610.8	1161.1
17	98.177	1375.1	1194.7	106.84	1372.3	2267
18	57.827	1406.9	814.47	83.809	1559.8	1441.1
19	80.784	1043.3	885.11	84.758	1240.4	1113
20	67.48	1310.7	718.96	73.986	1551	1127.9
21	53.108	859.32	795.92	142.1	1963.2	1498.2
22	62.066	947.51	869.38	84.19	1574.1	1028.6
23	38.115	716.84	771.11	63.228	1427.7	984.44
24	77.799	754.23	803.25	63.154	1090.9	1118
25	61.797	875.1	932.85	62.279	1117.1	1122.8
26	90.682	737.62	784.2	81.927	1146	3332.1
27	64.754	920.93	814.7	67.287	1868.3	959.45
28	53.85	1353	861.16	103.5	1339.3	2646.7
29	57.843	938.95	757.48	78.599	1806.5	1033
30	47.914	728.34	770.36	51.766	1224.9	1020.5
31	66.792	1442.1	942.78	259.46	2432	7173
32	59.618	968.06	849.37	68.633	1143.4	1088.9
33	89.27	852.67	776.52	72.341	976.49	1073.8
34	73.475	958.72	802.49	81.137	1126.6	1067.7
35	51.959	833.93	804.13	96.264	1888.3	2665.2
36	64.379	1252.7	878.31	116.06	991.76	1029

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 3 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
37	47.003	980.05	947.03	69.044	1747.2	1213.5
38	46.151	831.39	900.4	32.77	673.82	1044.9
39	81.988	1722.3	818.13	61.408	1161.8	1246.3
40	61.971	668.71	817.34	63.373	1723.2	1109.9
41	62.021	771.94	31511	43.268	1041.1	1005.9
42	58.366	831.98	790.38	107.73	2318.1	1084.7
43	55.313	1021.5	783.08	129.32	1573.7	1060.7
44	100.28	1176.4	744.08	44.513	1261.9	1007.4
45	70.449	1001.6	767.68	80.184	1196.7	1088.1
46	160.67	939.03	856.68	117.69	1486	1167.7
47	90.584	1485.5	1124	87.577	1212.3	1384.7
48	59.112	1077.4	919.06	88.469	1482.1	1143.7
49	76.703	833.68	814.13	102.59	1584.4	1119.8
50	55.427	855.74	789.56	98.766	1271.2	1035.5
51	82.838	901.31	775.77	82.746	1415.2	1097.4
52	108.68	1066.3	868.82	109.68	1485.9	1302.4
53	97.402	1024.1	858.38	56.438	1461.2	1040.4
54	116.3	1525.1	1127	55.114	1094.4	1136
55	64.747	934.53	877.35	45.91	1021.1	2702.1
56	72.571	1075.1	832.32	59.22	1474.4	1204.3
57	51.591	850.55	738.07	120.41	1910.7	1436.9
58	55.847	902.75	748.76	54.584	1106.5	1513.6
59	54.88	1051	1751.6	76.779	877.27	1035.3
60	83.035	796.09	802.48	149.31	1561.7	3169.6
61	88.852	1074.6	910.47	78.813	1176	1027.1
62	77.57	988.09	844.63	67.238	1652.9	1148.4
63	70.163	1235.2	766.36	61.429	918.84	1104.5
64	86.048	1622.9	824.72	83.007	1640.8	1073.4
65	50.982	857.34	990.73	61.92	1204.3	1121.5
66	184.9	1255.1	860.4	80.011	1373.3	1536.4
67	50.6	1333.2	1009.3	71.886	1343.9	1189
68	46.206	762.08	956.58	75.519	1804.6	1132.6
69	39.507	762.57	750.15	76.603	1792.8	1070.6
70	65.201	807.68	1019.6	99.13	1457.7	1052
71	60.792	1286.9	968.54	52.475	1153	1136.2
72	63.207	804.38	780.54	94.989	1485.2	1204.6

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 3 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
73	89.398	1125	888.34	55.838	987.24	1109.3
74	91.785	1039.8	838.9	71.284	1177	9524
75	63.692	992.84	810.65	108.04	2060.8	5049.7
76	116.22	1713.7	938.78	147	1729	1134.8
77	77.587	1250.7	1359.1	59.025	1259.5	987.8
78	61.027	1122	1191.9	68.662	972.67	1036.3
79	110.17	1052.4	955.34	61.588	1119.1	1346.2
80	72.589	937.46	772.85	66.378	1657.5	1116.3
81	72.914	1131.7	742.35	70.922	2059.5	1251.8
82	37.045	950.24	944.75	86.873	1569.8	1136.1
83	75.971	1064.3	823.26	77.609	1356.6	1161.5
84	60.872	861.74	773.79	74.295	1357.1	1080.7
85	44.408	757.09	798.54	95.662	1316	1116.9
86	68.438	1204.2	811.41	80.127	1649.3	1235.9
87	61.321	989.37	809.35	110.03	1381.2	1085.4
88	46.292	897.62	830.06	111.8	1405.9	1164.9
89	45.481	1148.7	753.77	90.339	1398.6	1144.4
90	100.28	1038.5	1065.6	55.521	1715.7	999.54
91	61.918	712.15	816.72	71.681	1085.7	1742.3
92	56.541	864.6	754.9	87.532	1490.4	1151.4
93	61.835	899.35	802.56	99.632	1571	1023.4
94	95.542	1220.3	883.84	96.385	1540.6	1067.6
95	70.557	1172.5	751.6	74.269	1202.8	1065.3
96	95.5	958.61	973.49	104.38	2033.8	1085.4
97	71.7	1233.6	914.27	77.307	1293.6	1113.6
98	65.881	1416	5270.5	86.827	1063.2	1248.4
99	58.473	831.24	800.94	135.11	1833.3	1855.9
100	50.483	1183.4	891.76	78.191	1133.8	1072.8

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 4

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	26.958	43.152	56.573	24.173	38.997	52.204
2	32.709	42.184	46.38	42.355	62.954	58.685
3	19.49	36.715	38.644	38.738	48.388	76.528
4	55.925	56.598	72.572	23.043	38.86	45.973
5	31.271	45.332	40.768	22.338	56.302	62.505
6	37.978	53.867	81.951	22.924	28.884	41.064
7	37.353	45.54	56.499	24.765	33.023	43.341
8	21.814	47.374	50.378	16.711	38.855	52.562
9	37.452	50.472	44.914	33.138	50.129	67.774
10	23.405	48.854	43.708	33.19	30.218	65.979
11	40.55	47.046	171.95	25.846	49.844	50.796
12	51.032	67.533	88.86	34.33	40.605	47.812
13	54.439	60.748	77.115	39.473	49.841	51.205
14	40.781	47.583	73.951	43.511	64.48	143.11
15	31.62	49.712	54.234	33.803	46.085	82.838
16	38.622	45.469	65.91	39.069	70.898	57.529
17	21.658	31.003	62.725	24.845	32.562	47.24
18	41.354	48.885	52.439	28.086	44.649	51.79
19	44.773	61.473	121.09	33.367	48.925	49.783
20	31.591	45.378	42.92	30.905	47.447	63.556
21	150.32	164.96	224.45	31.547	58.161	76.197
22	96.792	94.406	264.3	19.232	40.777	49.509
23	21.789	31.224	53.599	17.322	53.114	58.549
24	32.395	36.206	46.253	16.832	65.014	46.675
25	53.141	59.096	68.858	34.252	79.034	45.638
26	31.043	66.181	71.957	35.702	38.818	46.876
27	31.18	50.098	67.565	24.827	30.416	48.764
28	38.005	56.611	51.831	74.409	82.766	241.66
29	27.691	58.756	42.637	27.162	41.986	64.081
30	34.605	34.11	59.652	30.261	45.649	55.593
31	30.076	35.916	65.015	31.543	34.986	59.821
32	22.36	34.856	43.349	37.357	53.064	89.295
33	38.001	58.708	91.66	14.71	37.672	46.798
34	29.016	51.928	42.03	34.489	41.247	71.687
35	29.496	49.388	43.652	32.75	42.716	52.244
36	33.847	48.032	63.773	40.962	40.185	90.306

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 4 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
37	52.964	63.096	74.466	42.907	40.678	63.483
38	26.997	38.043	60.203	32.307	59.48	82.269
39	29.966	59.746	50.263	25.85	50.958	51.278
40	22.111	41.145	47.295	27.384	43.331	160.88
41	18.996	33.488	45.741	31.077	42.512	59.942
42	26.517	37.733	61.341	37.07	43.119	58.862
43	23.034	58.328	41.698	31.44	38.475	53.956
44	37.292	52.886	49.926	33.367	52.727	46.996
45	32.761	40.601	40.152	22.382	35.688	50.716
46	36.784	40.576	62.925	34.174	52.888	45.346
47	61.592	82.579	344.35	28.533	35.499	50.282
48	48.809	40.224	47.762	30.056	36.837	47.522
49	45.108	41.822	67.009	28.797	48.848	77.725
50	30.887	47.841	64.033	43.63	45.886	57.525
51	352.05	263.91	677.82	37.845	43.818	70.207
52	25.025	40.218	59.45	59.429	84.341	134.64
53	98.474	125.29	361.68	38.961	40.679	46.342
54	39.18	51.426	50.889	46.167	54.932	47.905
55	31.345	34.934	43.405	43.752	44.031	65.317
56	39.55	58.358	81.519	32.628	44.827	61.616
57	69.915	70.978	183.22	15.254	38.482	54.678
58	23.356	33.612	39.53	55.118	80.63	104.16
59	30.519	40.321	59.242	25.347	52.45	45.785
60	27.106	44.586	44.31	22.901	54.972	47.359
61	41.273	49.96	62.221	30.175	38.677	47.862
62	42.567	47.164	45.363	49.537	61.168	96.837
63	50.437	47.539	52.405	25.501	54.513	54.272
64	43.666	49.727	59.529	40.27	46.03	65.817
65	49.573	43.852	52.058	55.294	52.239	69.089
66	29.005	39.19	45.8	38.326	49.945	59.178
67	51.291	63.458	75.679	39.604	54.773	71.876
68	37.183	42.585	63.435	59.171	80.805	185.79
69	29.753	34.013	42.325	27.122	31.759	46.643
70	32.651	39.968	69.006	31.906	33.099	49.824
71	33.371	55.669	66.221	28.38	50.375	56.733
72	28.748	43.833	55.689	31.636	53.007	60.859

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 4 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
73	37.656	41.128	59.653	27.426	48.692	60.496
74	49.255	47.199	75.388	30.997	46.796	48.459
75	23.207	33.051	50.116	92.541	122.91	706.7
76	38.909	40.529	60.379	32.437	54.371	115.78
77	62.203	60.376	140.1	27.332	46.922	52.338
78	32.333	37.893	65.523	39.644	49.28	67.458
79	36.665	31.11	59.424	23.862	50.559	56.932
80	29.45	42.977	48.209	44.288	31.285	46.406
81	110.67	116.36	169.68	41.325	47.487	152.4
82	30.614	38.942	60.102	29.439	43.185	63.431
83	31.119	33.849	75.795	29.837	40.511	59.102
84	22.946	47.678	56.452	25.214	35.9	48.652
85	31.816	43.02	79.843	33.636	35.461	48.45
86	39.336	41.597	70.718	27.501	42.054	48.494
87	26.736	33.981	53.177	43.199	42.319	141.03
88	18.964	32.567	56.166	32.521	57.274	79.638
89	21.284	31.908	40.562	21.617	44.817	49.876
90	29.799	51.65	55.971	26.693	33.446	60.327
91	22.406	34.04	46.088	20.901	39.571	51.948
92	51.225	58.845	60.238	30.396	42.958	58.763
93	25.656	37.768	54.351	211.42	164.54	615.69
94	41.102	32.9	44.163	29.248	42.116	59.327
95	34.544	40.804	38.136	42.071	57.991	113.59
96	38.329	38.809	84.157	25.157	37.949	46.711
97	30.472	35.051	39.118	34.024	50.616	50.406
98	20.424	39.445	77.27	33.264	70.072	108.93
99	35.382	51.395	54.417	26.33	50.261	48.6
100	33.493	36.572	57.845	30.567	56.65	83.571

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 4

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	65.388	1083.6	762.37	73.922	1498.7	957.75
2	114.59	1452.1	809.53	145.76	2484.1	1156.1
3	60.428	1021.9	706.58	87.192	1558.1	1179.1
4	201.2	1978.6	1045.8	45.975	1043	997.36
5	91.894	1481.7	737.96	94.238	1803.2	1060.3
6	153.69	1344.9	1066.9	87.909	1069.1	943.81
7	95.332	1296.2	937.72	60.607	1290.7	879.61
8	78.458	1010.1	701.82	68.276	1952	997.06
9	136.39	1114.6	863.59	99.401	1290.8	1077.7
10	82.183	1461.4	782.62	71.358	1293.1	1098
11	143.78	1315.2	1660.5	111.79	1736.7	1042.4
12	134.25	1505	1127.9	102.97	1245.5	908.06
13	138.11	1280.9	1634.9	97.691	1797.6	1104.4
14	122.74	1215.4	912.82	142.62	2350.1	1521.7
15	109.64	1633.5	966.28	127.49	1406.2	1333.5
16	106.22	1283.1	1110.5	90.97	2005.4	1067.7
17	69.219	858.75	904.42	114.98	1312.7	1006.8
18	80.831	1359.6	937.88	72.329	1831.3	1091.4
19	104.69	1375.3	1248.1	78.677	2098	1005.6
20	70.892	1383.6	774.78	76.24	1634.7	1097.5
21	312.78	3769.5	3135	142.92	1832.6	1123
22	320.94	2609.6	2924.2	78.16	1093.6	1080.7
23	41.684	1020	914.53	85.448	1607.1	950.33
24	116.38	1271.7	786.03	70.473	1777.3	1019.8
25	123.44	1624.2	1283	91.496	1489.4	957.79
26	103.42	1704.9	946.57	125.49	1141.2	974.91
27	115.4	1827	893.61	79.203	1293	1035.4
28	166.27	1576.2	1022.5	173.84	2944.8	2239.7
29	105.17	1417.3	765.02	75.467	2006.9	1084.9
30	83.648	1135.8	845.37	95.809	1301	1025
31	88.316	1404.8	852.97	84.039	1254.1	1017.5
32	50.326	889.84	747.55	104.99	1603.2	1726
33	133.97	1588.1	1272.9	73.279	1201.4	963.24
34	69.13	1851.4	786.5	109.16	1474.7	3321.3
35	89.739	980.8	791.37	104.4	1432.6	1097.5
36	123.34	1478.1	883.6	121.44	1215.4	1209.3

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 4

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
37	137.71	1384.3	4063.2	135.39	1486.6	1070.2
38	87.398	1538.5	916.8	109.72	1494.5	1085.8
39	106.84	1348.5	899.34	105.74	1917	1122.8
40	65.378	1027	831.32	130.54	2084.8	3384.5
41	70.418	1064.2	870.44	99.643	1143.8	928.43
42	76.393	1578.8	846.73	69.1	1452	1008.4
43	58.545	965.8	694.9	84.363	1391.5	1225.3
44	120.92	1568.8	934.02	98.217	2385	995.2
45	84.35	1284.6	762.54	109.26	1499.2	994.56
46	93.313	1189.1	837.87	105.1	2188.9	972.36
47	207.87	1895.5	4258.8	68.387	1304.9	988.46
48	193.01	1232.5	902.64	118.22	1396.9	989.33
49	132.73	1394.9	1137	108.91	1185.2	1407.8
50	176.03	1428.4	1390.9	107.3	2041.4	1208.3
51	1173.4	4928.6	11701	189.68	1395.4	1102.9
52	70.826	1311	842.34	220.15	1664.4	2377.6
53	291.21	2396.2	3468.2	102.69	1112.8	987.47
54	78.68	2259.8	876.24	146.71	1833.7	1245.3
55	117.39	1928.4	785.74	99.389	1726.2	1132.4
56	136.37	1741.3	1123.5	121.2	1206.9	1224.6
57	193.02	1770.8	2024.5	53.279	1211	924.37
58	68.708	889.18	796.82	153.09	1710.6	1230.4
59	102.88	1292.5	1030.4	81.433	1914.3	996.99
60	86.359	1555	808.93	105.53	1788	978.65
61	93.832	1448	1752.5	81.441	1386.2	1015.9
62	130.74	1367.2	864.63	140.98	2844.8	1519.5
63	107.18	1767.6	954.88	78.811	1946.4	975.74
64	122.51	1358.8	956.06	100.14	1744.5	1032.9
65	130.26	1239.9	955.95	231.61	1377.9	1592.9
66	80.271	895.53	783.98	93.269	1713.7	1050.8
67	140.23	2433.9	1141.5	117.13	1676.6	1118.1
68	86.618	1280	856.76	137.09	2251.8	2222.5
69	106.67	1111.3	749.39	82.885	933.8	945.21
70	102.19	1286.4	878.84	82.372	1824.9	1083
71	102.9	1637.9	1296.7	85.725	1052.8	941.98
72	93.183	1338.5	784.57	134.27	1604.8	1031.8

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 4

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
73	110.71	1404.8	992.25	66.854	1428.4	1102.5
74	145.95	1456.3	1111.7	81.66	1601	948.24
75	82.248	964.69	843.29	355.65	4927.2	14387
76	78.265	1140.7	1128.9	123.37	1785.8	1598.7
77	229.94	1197.7	1721.1	241.27	1156	914.96
78	105.7	1072.6	964.02	103.15	2185.8	1305.8
79	77.264	906.64	839.32	102.67	2340.6	1133
80	70.455	1306.6	862.57	131.41	1593.6	961.19
81	374.22	2781.3	7751.5	177.9	2458	1966.8
82	85.361	996.45	938.43	70.851	1223.2	1047.1
83	84.68	911.27	821.06	131.5	1425.8	1113.5
84	78.527	1099.5	855.25	90.788	1442.6	984.71
85	156.53	1151.9	1150	78.852	1520.3	959.21
86	120.05	1249	951.68	90.035	1257.2	1086.8
87	134.67	937.04	759.26	150.98	1288.3	1822.6
88	78.128	1146.2	795.94	95.91	1742.7	1366.9
89	66.642	885.23	696.23	95.425	1484.7	964.39
90	69.984	1388.9	811.11	91.961	863.28	940.57
91	74.918	1194.5	885.57	74.631	1713.9	1120.3
92	163.77	1583.4	1083.4	97.211	1290.5	1010.4
93	89.81	988.33	775.92	379.3	3554.3	8809.9
94	78.211	1038.6	780.12	75.785	1895.2	1035.8
95	101.08	1064.5	707.49	119.66	1821	1601.1
96	131.01	970.6	1050.4	97.358	2043.9	913.26
97	81.396	894.66	750.39	148.12	1985.6	1008.2
98	87.656	1283.9	1876.8	112.85	1457.3	2237.7
99	116.06	1527.7	809.44	115.65	1590.3	1041.8
100	107.15	1284.6	905.91	71.889	1390.3	1084.5

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 6

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	15.681	41.528	44.446	24.354	51.966	53.181
2	24.008	51.01	46.064	20.073	42.222	47.341
3	22.389	39.486	70.526	35.265	56.083	50.781
4	17.435	32.248	199.6	35.023	40.902	58.268
5	17.643	26.608	47.632	33.339	50.458	64.491
6	28.324	50.067	43.512	28.289	46.77	52.393
7	26.39	45.835	107.1	39.17	61.53	68.814
8	27.038	27.923	45.262	42.58	56.633	81.348
9	25.117	44.664	46.604	19.751	39.074	82.209
10	24.415	32.784	52.013	22.404	42.41	87.9
11	18.623	41.936	63.87	60.073	62.691	85.939
12	35.394	29.163	44.812	33.327	48.15	63.478
13	32.797	58.102	48.454	38.824	48.166	176.16
14	28.046	75.237	58.018	32.317	36.136	61.334
15	30.283	46.853	43.369	29.44	52.288	49.514
16	24.847	44.981	55.423	35.868	48.929	60.299
17	33.498	54.131	57.263	35.591	38.719	53.816
18	21.494	41.772	45.978	37.059	56.003	127.91
19	30.911	49.408	64.034	41.833	44.266	57.342
20	21.361	54.262	41.986	27.423	46.957	45.666
21	27.012	43.059	44.821	32.433	36.483	54.84
22	28.958	40.848	66.504	54.391	51.468	73.406
23	15.971	32.611	51.954	51.41	57.971	215.58
24	20.071	29.196	43.345	20.579	44.242	55.197
25	30.712	30.069	57.978	35.432	66.513	62.728
26	19.112	27.882	59.857	26.026	37.305	54.83
27	21.118	33.158	45.903	54.224	66.318	110.81
28	22.281	44.793	56.551	26.121	51.83	51.355
29	20.094	34.783	41.67	48.725	88.471	102.34
30	18.561	29.938	43.366	32.613	60.524	83.142
31	33.356	47.153	48.997	30.729	52.543	50.521
32	21.841	39.364	49.138	42.891	41.235	48.431
33	17.754	24.663	44.733	31.901	50.819	50.382
34	26.17	55.828	45.958	20.036	53.065	50.19
35	16.085	32.201	42.653	28.747	41.26	71.819
36	20.036	41.543	58.321	25.706	55.761	78.865

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 6 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
37	23.042	40.9	48.202	30.162	40.748	63.402
38	18.938	30.115	44.14	34.245	62.435	50.442
39	38.177	64.503	44.124	19.487	41.851	63.715
40	25.789	32.764	48.868	22.631	42.996	50.718
41	39.402	33.745	1029	23.236	36.477	55.194
42	18.131	46.259	42.829	22.358	44.691	54.774
43	13.456	46.406	53.629	31.389	53.307	79.85
44	29.357	42.964	42.645	25.02	44.822	81.007
45	24.548	36.297	55.063	22.367	42.636	48.79
46	30.337	34.41	46.719	31.268	58.278	61.35
47	23.198	41.418	73.621	36.436	61.462	54.507
48	21.925	32.369	50.762	28.928	50.925	85.585
49	18.465	34.704	58.024	44.865	59.754	67.223
50	19.048	46.124	46.512	34.195	48.258	121.07
51	34.926	32.277	44.103	39.236	66.475	242.99
52	37.571	34.099	58.481	29.961	48.769	55.641
53	34.25	44.118	46.325	15.987	41.2	58.704
54	41.551	49.903	64.275	20.73	52.076	56.378
55	28.819	38.258	63.685	26.108	40.557	57.049
56	20.693	48.124	44.832	22.924	44.484	54.748
57	24.067	34.515	53.794	22.255	49.67	118.84
58	20.024	36.393	40.996	27.627	47.639	51.912
59	31.607	36.273	127.41	32.438	58.596	75.48
60	25.899	21.224	46.735	25.39	45.83	67.715
61	32.135	47.069	60.328	32.037	48.614	56.987
62	30.854	44.668	45.072	29.411	45.455	48.849
63	27.034	40.148	44.132	28.687	57.911	77.313
64	25.932	48.402	47.917	42.604	38.581	45.097
65	19.028	42.974	52.009	23.394	38.815	48.193
66	28.81	42.097	61.901	25.836	41.771	49.552
67	18.279	37.716	43.61	42.519	63.424	97.423
68	19.107	32.861	46.551	23.789	51.99	47.702
69	16.246	26.339	45.823	20.245	43.562	62.691
70	30.406	34.311	46.155	36.04	43.575	64.158
71	19.857	50.449	72.707	30.098	47.303	78.118
72	17.91	27.171	43.64	44.911	51.444	92.23

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 6 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
73	27.221	40.763	48.797	32.561	61.375	126.84
74	31.057	45.023	51.152	26.757	45.224	56.403
75	20.982	42.628	60.214	20.338	34.657	50.272
76	42.625	46.356	52.288	29.063	48.039	53.841
77	25.852	45.991	105.01	29.584	50.339	54.703
78	27.983	26.938	101.15	24.298	51.17	89.388
79	26.952	39.084	48.416	37.891	41.944	68.165
80	17.618	42.709	43.67	43.798	94.991	221.77
81	16.028	39.249	41.637	24.198	50.132	60.574
82	25.334	56.412	50.65	37.785	52.621	52.09
83	21.209	35.324	46.272	34.771	60.913	94.474
84	25.349	31.422	44.567	30.743	54.203	72.754
85	24.55	39.206	55.819	40.099	54.883	49.333
86	21.767	43.01	48.81	22.32	51.963	47.732
87	19.147	39.69	58.525	59.042	74.893	132.74
88	11.821	30.739	46.609	30.108	43.439	52.87
89	11.052	41.003	43.088	42.459	55.763	100.97
90	28.015	29.289	54.912	13.41	61.304	65.491
91	23.366	36.678	47.562	26.622	49.747	88.381
92	19.795	34.377	58.755	42.466	63.387	150.52
93	29.3	33.383	55.213	47.367	63.203	69.533
94	33.682	45.305	48.563	33.646	53.276	54.755
95	24.749	34.06	42.632	51.222	59.754	98.663
96	29.715	39.527	56.316	35.474	55.545	53.157
97	23.629	40.209	48.196	25.626	53.453	62.082
98	37.665	42.489	329.85	20.946	40.803	52.802
99	25.328	39.843	44.348	19.991	61.67	47.04
100	25.654	36.44	61.339	23.499	46.508	65.169

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 6

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	52.917	780.85	784.63	70.118	1796.8	1109.3
2	73.188	1421.8	867.33	114.28	1285.7	991.59
3	80.243	1143.9	878.44	109.45	1765	1079.8
4	66.258	673.68	3180.1	114.45	1290.8	1116.4
5	37.006	676.12	841.5	104.55	1518	1039.3
6	83.502	1554.4	780.74	92.003	1942.5	1091.5
7	84.612	1341.6	1207.5	126.18	1945.2	1621.5
8	55.765	837.14	921.35	117.64	1418.7	1191.6
9	54.175	955.07	857.52	64.412	1348.4	1435.5
10	46.488	606.21	955.56	57.731	1894.1	1251.9
11	42.358	1077	814.44	135.02	1601.5	1130.3
12	117.16	1160.7	796.43	79.171	1446.3	1099.1
13	62.983	1180	797.46	158.18	1364.1	3756.2
14	61.805	1444.9	853.31	79.344	1034.9	1048.1
15	93.999	1451.1	771.03	116.91	1290.4	1116.3
16	55.236	1226.6	861.57	95.319	1533.5	1233.3
17	98.177	1375.1	1194.7	135.48	1396.5	1058.6
18	57.827	1406.9	814.47	145.56	1218.7	1564.5
19	80.784	1043.3	885.11	111.97	1240.9	1029.7
20	67.48	1310.7	718.96	57.816	1492.8	983.07
21	53.108	859.32	795.92	97.731	1262.9	1124.4
22	62.066	947.51	869.38	98.335	1785.5	1260.1
23	38.115	716.84	771.11	129.12	1789.2	2314.8
24	77.799	754.23	803.25	50.05	1270.8	1042.5
25	61.797	875.1	932.85	113.63	2227.6	1171.8
26	90.682	737.62	784.2	69.933	954.48	1028.9
27	64.754	920.93	814.7	167.67	1775.8	1762.3
28	53.85	1353	861.16	75.54	1514.2	1103.6
29	57.843	938.95	757.48	200.69	2399.5	2305
30	47.914	728.34	770.36	96.719	1248.3	1267.3
31	66.792	1442.1	942.78	67.917	1534.6	1106
32	59.618	968.06	849.37	137.12	1632.2	1028.2
33	89.27	852.67	776.52	72.116	1350	1033.6
34	73.475	958.72	802.49	67.989	1206.3	1085.9
35	51.959	833.93	804.13	85.404	1220	1089.9
36	64.379	1252.7	878.31	98.317	2557.6	1270

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 6 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
37	47.003	980.05	947.03	134.95	1382.3	1041.2
38	46.151	831.39	900.4	159.95	1096	1078.3
39	81.988	1722.3	818.13	74.07	1545.2	1023.7
40	61.971	668.71	817.34	69.583	1593.2	1012.5
41	62.021	771.94	31511	73.491	1319.7	1094.7
42	58.366	831.98	790.38	37.835	782.1	1152.9
43	55.313	1021.5	783.08	65.147	3001.3	1181.6
44	100.28	1176.4	744.08	60.787	2122.6	1171.4
45	70.449	1001.6	767.68	76.589	1192.7	968.09
46	160.67	939.03	856.68	77.054	1745	1068.9
47	90.584	1485.5	1124	118.82	2300	1162.6
48	59.112	1077.4	919.06	111.19	1100.3	1267.9
49	76.703	833.68	814.13	85.011	1652.6	1121.6
50	55.427	855.74	789.56	120.25	1550.1	1285.7
51	82.838	901.31	775.77	131.93	1869.4	2470.9
52	108.68	1066.3	868.82	138.66	2179.7	954
53	97.402	1024.1	858.38	44.788	943.66	1213.3
54	116.3	1525.1	1127	53.458	1128.9	1075.6
55	64.747	934.53	877.35	112.88	1149.5	1157.1
56	72.571	1075.1	832.32	76.943	1115.3	1143.1
57	51.591	850.55	738.07	78.162	1720.8	1272.7
58	55.847	902.75	748.76	88.584	1473.8	1126.5
59	54.88	1051	1751.6	82	2200.4	1200.4
60	83.035	796.09	802.48	70.392	1238.8	1143.5
61	88.852	1074.6	910.47	76.608	1295.4	1086.5
62	77.57	988.09	844.63	50.652	1915.7	1367.1
63	70.163	1235.2	766.36	76.018	2036	1172.5
64	86.048	1622.9	824.72	108.44	1095.4	957.43
65	50.982	857.34	990.73	71.768	1594.5	1043.4
66	184.9	1255.1	860.4	75.141	1301.2	1014.7
67	50.6	1333.2	1009.3	193.65	2111.4	1585.7
68	46.206	762.08	956.58	48.33	1095.7	981.59
69	39.507	762.57	750.15	75.023	1028.2	1027.8
70	65.201	807.68	1019.6	78.848	1767.2	1120.5
71	60.792	1286.9	968.54	86.788	1997.8	1435.5
72	63.207	804.38	780.54	190.55	1330.4	1230.9

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 6 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
73	89.398	1125	888.34	110.98	1182.9	1924.4
74	91.785	1039.8	838.9	93.208	1941.6	1158.2
75	63.692	992.84	810.65	66.347	1518.8	1083.2
76	116.22	1713.7	938.78	86.882	1512.9	1078.1
77	77.587	1250.7	1359.1	53.889	1357.3	1287.2
78	61.027	1122	1191.9	102.3	1575.3	1950.1
79	110.17	1052.4	955.34	80.064	1435.7	1043.9
80	72.589	937.46	772.85	205.47	1886.3	2913.6
81	72.914	1131.7	742.35	90.72	1658.8	1074.9
82	37.045	950.24	944.75	119.98	1614.3	1062.4
83	75.971	1064.3	823.26	93.21	1527.9	1333
84	60.872	861.74	773.79	93.603	1281.8	1296.5
85	44.408	757.09	798.54	79.787	1795.6	1153
86	68.438	1204.2	811.41	72.413	1527.1	1042.5
87	61.321	989.37	809.35	134.57	2031.8	2385.5
88	46.292	897.62	830.06	76.619	1297.8	1133.9
89	45.481	1148.7	753.77	184.02	1884.7	1683.4
90	100.28	1038.5	1065.6	72.437	1220.5	1073.1
91	61.918	712.15	816.72	67.47	1593	1207
92	56.541	864.6	754.9	173.74	1697.9	1875.7
93	61.835	899.35	802.56	124.78	1995.7	1195.4
94	95.542	1220.3	883.84	49.739	1619.5	1195
95	70.557	1172.5	751.6	120.5	1515.4	1512.3
96	95.5	958.61	973.49	76.112	1639.4	1141.2
97	71.7	1233.6	914.27	84.064	1663.9	1103.9
98	65.881	1416	5270.5	85.793	1450	1084.6
99	58.473	831.24	800.94	63.307	1211.4	954.29
100	50.483	1183.4	891.76	96.126	1371.5	1061.5

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 7

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	15.681	41.528	44.446	16.186	44.333	61.574
2	24.008	51.01	46.064	24.086	51.888	59.832
3	22.389	39.486	70.526	22.645	41.382	90.351
4	17.435	32.248	199.6	18.197	35.491	219.61
5	17.643	26.608	47.632	18.072	29.63	55.511
6	28.324	50.067	43.512	28.961	57.977	51.288
7	26.39	45.835	107.1	31.331	49.452	102.88
8	27.038	27.923	45.262	27.538	30.5	52.837
9	25.117	44.664	46.604	25.686	82.094	54.82
10	24.415	32.784	52.013	24.861	37.16	81.799
11	18.623	41.936	63.87	19.406	51.724	71.785
12	35.394	29.163	44.812	35.878	32.904	51.731
13	32.797	58.102	48.454	33.329	74.233	60.558
14	28.046	75.237	58.018	30.65	77.32	70.416
15	30.283	46.853	43.369	16.7	39.664	65.454
16	24.847	44.981	55.423	41.435	76.748	73.463
17	33.498	54.131	57.263	34.432	56.805	65.033
18	21.494	41.772	45.978	22.823	46.403	58.035
19	30.911	49.408	64.034	31.695	59.986	79.176
20	21.361	54.262	41.986	25.006	56.742	49.955
21	27.012	43.059	44.821	29.179	43.645	51.884
22	28.958	40.848	66.504	29.997	43.752	69.816
23	15.971	32.611	51.954	16.652	35.585	60.202
24	20.071	29.196	43.345	19.522	31.29	51.01
25	30.712	30.069	57.978	31.51	37.031	66.58
26	19.112	27.882	59.857	19.858	30.355	69.55
27	21.118	33.158	45.903	22.002	42.598	54.248
28	22.281	44.793	56.551	22.83	47.35	64.261
29	20.094	34.783	41.67	26.546	42.892	49.134
30	18.561	29.938	43.366	19.15	34.93	51.375
31	33.356	47.153	48.997	35.599	51.513	58.232
32	21.841	39.364	49.138	29.192	42.449	56.926
33	17.754	24.663	44.733	18.188	30.842	53.076
34	26.17	55.828	45.958	26.835	59.258	54.553
35	16.085	32.201	42.653	16.598	36.754	50.338
36	20.036	41.543	58.321	20.594	44.722	67.569

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 7 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
37	23.042	40.9	48.202	23.883	50.064	55.67
38	18.938	30.115	44.14	19.527	36.947	53.513
39	38.177	64.503	44.124	38.851	67.032	51.892
40	25.789	32.764	48.868	26.447	34.443	59.041
41	39.402	33.745	1029	40.004	35.362	1091.7
42	18.131	46.259	42.829	18.759	50.29	51.071
43	13.456	46.406	53.629	23.738	47.023	52.062
44	29.357	42.964	42.645	29.908	53.226	50.188
45	24.548	36.297	55.063	27.695	48.154	62.401
46	30.337	34.41	46.719	38.112	36.216	55.252
47	23.198	41.418	73.621	23.951	44.349	101.81
48	21.925	32.369	50.762	23.011	41.42	59.607
49	18.465	34.704	58.024	20.291	41.561	80.792
50	19.048	46.124	46.512	19.595	48.802	54.17
51	34.926	32.277	44.103	38.951	36.428	51.35
52	37.571	34.099	58.481	37.771	36.908	71.195
53	34.25	44.118	46.325	37.541	45.547	54.85
54	41.551	49.903	64.275	42.294	57.356	73.399
55	28.819	38.258	63.685	29.78	42.554	72.841
56	20.693	48.124	44.832	21.182	98.64	53.548
57	24.067	34.515	53.794	25.951	43.17	61.859
58	20.024	36.393	40.996	20.384	39.389	49.491
59	31.607	36.273	127.41	39.195	43.26	57.455
60	25.899	21.224	46.735	26.496	25.108	54.311
61	32.135	47.069	60.328	34.102	50.262	72.829
62	30.854	44.668	45.072	33.718	47.211	52.214
63	27.034	40.148	44.132	27.588	44.266	51.52
64	25.932	48.402	47.917	27.051	52.886	58.689
65	19.028	42.974	52.009	19.606	46.107	60.454
66	28.81	42.097	61.901	29.386	45.329	72.908
67	18.279	37.716	43.61	18.802	42.037	51.473
68	19.107	32.861	46.551	19.921	35.046	55.508
69	16.246	26.339	45.823	16.859	32.717	57.146
70	30.406	34.311	46.155	30.959	39.199	56.767
71	19.857	50.449	72.707	21.405	61.216	82.62
72	17.91	27.171	43.64	18.486	30.544	52.029

Flowtimes (hours) for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 7 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
73	27.221	40.763	48.797	29.089	49.981	51.48
74	31.057	45.023	51.152	33.56	54.548	64.154
75	20.982	42.628	60.214	22.244	44.97	69.739
76	42.625	46.356	52.288	43.356	53.387	59.959
77	25.852	45.991	105.01	27.725	53.691	215
78	27.983	26.938	101.15	28.624	33.017	118.56
79	26.952	39.084	48.416	64.351	64.351	64.351
80	17.618	42.709	43.67	18.295	60.146	52.627
81	16.028	39.249	41.637	16.638	43.943	50.196
82	25.334	56.412	50.65	27.476	60.179	65.944
83	21.209	35.324	46.272	21.997	37.169	54.258
84	25.349	31.422	44.567	25.922	41.265	52.994
85	24.55	39.206	55.819	25.011	48.335	65.374
86	21.767	43.01	48.81	22.339	49.76	57.258
87	19.147	39.69	58.525	19.927	46.27	70.95
88	11.821	30.739	46.609	12.375	32.865	54.298
89	11.052	41.003	43.088	11.513	45.098	50.621
90	28.015	29.289	54.912	29.51	31.225	62.984
91	23.366	36.678	47.562	27.562	44.067	57.938
92	19.795	34.377	58.755	20.296	37.636	80.782
93	29.3	33.383	55.213	35.934	36.56	66.881
94	33.682	45.305	48.563	40.389	48.415	58.267
95	24.749	34.06	42.632	23.919	33.462	56.109
96	29.715	39.527	56.316	30.78	48.156	68.154
97	23.629	40.209	48.196	24.279	42.065	55.227
98	37.665	42.489	329.85	40.877	45.073	352.29
99	25.328	39.843	44.348	26.042	49.147	52.171
100	25.654	36.44	61.339	27.098	39.064	69.232

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 7

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	52.917	780.85	784.63	61.69	1007	1059.9
2	73.188	1421.8	867.33	62.159	1460.2	1217.6
3	80.243	1143.9	878.44	82.69	1385.6	1220.6
4	66.258	673.68	3180.1	74.971	852.27	3563.4
5	37.006	676.12	841.5	42.625	846.62	1099.8
6	83.502	1554.4	780.74	93.332	1804.6	1046
7	84.612	1341.6	1207.5	93.206	1606.9	1484
8	55.765	837.14	921.35	63.996	1005.5	1184.4
9	54.175	955.07	857.52	61.741	1379.1	1148.3
10	46.488	606.21	955.56	51.058	778.75	1257.9
11	42.358	1077	814.44	55.194	1992.1	1056.3
12	117.16	1160.7	796.43	144.14	1454.9	1019.5
13	62.983	1180	797.46	71.425	1802.4	1072.2
14	61.805	1444.9	853.31	67.912	1731.6	1135.1
15	93.999	1451.1	771.03	61.536	2060.9	1057.9
16	55.236	1226.6	861.57	130.49	2435.2	1259.5
17	98.177	1375.1	1194.7	110.91	1657.7	1492.2
18	57.827	1406.9	814.47	67.989	1704.3	1116.3
19	80.784	1043.3	885.11	92.265	2101	1297.9
20	67.48	1310.7	718.96	73.571	1603	974.98
21	53.108	859.32	795.92	61.88	1064.5	1037.7
22	62.066	947.51	869.38	66.422	1174.5	1153.3
23	38.115	716.84	771.11	44.488	891.08	1037.5
24	77.799	754.23	803.25	82.118	968.22	1055.1
25	61.797	875.1	932.85	67.751	1087.5	1239.7
26	90.682	737.62	784.2	108.16	936.07	1047.7
27	64.754	920.93	814.7	71.486	1270.1	1094.6
28	53.85	1353	861.16	59.958	1679.2	1133.2
29	57.843	938.95	757.48	70.052	1696.4	1013.5
30	47.914	728.34	770.36	53.957	923.02	1026
31	66.792	1442.1	942.78	79.282	1850.3	1207.2
32	59.618	968.06	849.37	65.617	1212.2	1109.1
33	89.27	852.67	776.52	95.194	1240.7	1062
34	73.475	958.72	802.49	81.738	1185.8	1088.8
35	51.959	833.93	804.13	59.989	1185	1066.8
36	64.379	1252.7	878.31	71.958	1564.6	1163

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 7 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
37	47.003	980.05	947.03	51.558	1451.1	1211.1
38	46.151	831.39	900.4	58.533	1126.5	1146.9
39	81.988	1722.3	818.13	88.432	1998.4	1075.8
40	61.971	668.71	817.34	74.191	853.96	1073.3
41	62.021	771.94	31511	68.217	946.66	32073
42	58.366	831.98	790.38	67.006	1050.1	1075.5
43	55.313	1021.5	783.08	89.318	1377.7	1107.1
44	100.28	1176.4	744.08	108.98	2064.9	992.13
45	70.449	1001.6	767.68	78.479	1233.2	1015.4
46	160.67	939.03	856.68	180.48	1169.3	1146.2
47	90.584	1485.5	1124	100.52	2023.3	1437.7
48	59.112	1077.4	919.06	65.453	1810.9	1211.4
49	76.703	833.68	814.13	93.851	1081.3	1162.6
50	55.427	855.74	789.56	61.794	1491.9	1030.5
51	82.838	901.31	775.77	90.418	1171.2	1026.7
52	108.68	1066.3	868.82	121.06	1352.2	1176.9
53	97.402	1024.1	858.38	106.33	1244.8	1154.3
54	116.3	1525.1	1127	125.13	1816.5	1478.2
55	64.747	934.53	877.35	76.07	1251.8	1153.2
56	72.571	1075.1	832.32	82.999	1335.7	1105.7
57	51.591	850.55	738.07	57.576	1065.7	997.32
58	55.847	902.75	748.76	70.341	1113.9	1030.1
59	54.88	1051	1751.6	56.432	1393.7	2052.1
60	83.035	796.09	802.48	95.771	1012.7	1046.9
61	88.852	1074.6	910.47	97.404	1693.8	1194.5
62	77.57	988.09	844.63	90.098	1198.8	1100.6
63	70.163	1235.2	766.36	79.827	1866.9	1007.7
64	86.048	1622.9	824.72	92.907	1982.6	1105.4
65	50.982	857.34	990.73	56.644	1072.2	1279.5
66	184.9	1255.1	860.4	195.31	1524.9	1130.1
67	50.6	1333.2	1009.3	60.113	1570.6	1302.9
68	46.206	762.08	956.58	52.271	945.6	1293.4
69	39.507	762.57	750.15	48.091	954.24	979.46
70	65.201	807.68	1019.6	70.742	1252	1292.2
71	60.792	1286.9	968.54	67.567	1814.7	1257.4
72	63.207	804.38	780.54	73.698	1178.1	1059.2

Work in process for Family 1, Family2, and Family 3 for connected and disconnected systems – case 1B, Model 7 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
73	89.398	1125	888.34	129.01	1369.4	1031
74	91.785	1039.8	838.9	103.14	1378	1132.3
75	63.692	992.84	810.65	70.401	1229	1084.4
76	116.22	1713.7	938.78	130.1	2083.7	1200.5
77	77.587	1250.7	1359.1	85.363	1906.3	1692.6
78	61.027	1122	1191.9	64.351	1538.4	1556.4
79	110.17	1052.4	955.34	122.97	1291.5	1261.5
80	72.589	937.46	772.85	82.191	1631.5	1051.3
81	72.914	1131.7	742.35	83.089	1559.2	1023.5
82	37.045	950.24	944.75	45.618	1175.4	1246.1
83	75.971	1064.3	823.26	84.547	1308	1097.6
84	60.872	861.74	773.79	68.798	1118.3	1052.6
85	44.408	757.09	798.54	50.805	952.59	1066.2
86	68.438	1204.2	811.41	77.594	1474.3	1090.6
87	61.321	989.37	809.35	68.883	1205.6	1085.5
88	46.292	897.62	830.06	53.502	1144.4	1094.6
89	45.481	1148.7	753.77	51.948	1378	1006.3
90	100.28	1038.5	1065.6	114.72	1293.6	1358.2
91	61.918	712.15	816.72	77.608	1022.8	1113.5
92	56.541	864.6	754.9	63.825	1157.1	1140.2
93	61.835	899.35	802.56	68.523	1111.7	1075.5
94	95.542	1220.3	883.84	109.31	1496.7	1170.7
95	70.557	1172.5	751.6	86.855	1281.9	1088.6
96	95.5	958.61	973.49	108.45	1208.5	1280.8
97	71.7	1233.6	914.27	79.022	1506.2	1167.1
98	65.881	1416	5270.5	69.643	1651.6	5609.1
99	58.473	831.24	800.94	67.29	1079.8	1062
100	50.483	1183.4	891.76	60.256	1432.9	1159.1

Finished Goods inventory for Family 1, Family2, and Family 3 for connected and disconnected systems – case 2

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	5443.9	13393	14658	5026.5	14384.84	2692.5
2	5758.8	12317	15120	5205	13468.97	3936.7
3	5785.6	13584	15386	6167.3	14753.65	3206.6
4	5154.2	12631	15187	5833.2	15144.52	5350
5	4874.1	12421	13216	4796.3	15221.31	3662.8
6	5263.3	12967	15781	5574.8	14306.06	4272.5
7	7410.5	14010	15600	4422	15571.24	4381.7
8	6237.1	12463	14850	6077	15139.79	4809.3
9	5187.3	13912	15839	5147.1	14432.48	4347.6
10	6682	13111	14632	4604.9	14669.35	4658.6
11	4864.1	12284	15862	5516.6	13793.62	3484.4
12	4878.8	13456	16102	5234.9	15283.1	4141.9
13	4583.7	12282	15152	5037.4	14349.28	5622
14	4795.3	12698	15876	5440.6	15798.5	4724.9
15	5739.4	12975	15685	5619.5	15353.37	5365
16	4573.3	12090	14905	5674.4	16144.94	4592.2
17	5373.7	14138	15076	5653.3	16031.31	3597.7
18	7192.3	13247	14331	5587.2	14880.92	5104.3
19	5111.2	11787	15931	4670.9	13865.28	4421.6
20	5491.7	13622	14198	5701	14433.57	4276.1
21	5636.8	12700	14972	4893.2	14565.33	2420.9
22	6154.6	12155	15175	5512.2	15542.85	3255.5
23	5669.7	12440	14956	5025.6	14958.11	3906.7
24	5215	12922	13676	6246	14508.3	3778.4
25	6215.9	13404	14369	5213.4	14225.32	4105.1
26	4786.6	12646	16444	5506.9	14760.04	4837.9
27	5095.1	13340	14887	4807.4	13132.01	4852.1
28	6424	12719	15811	6498	14657.86	3871.3
29	4618.4	12479	14129	5054.6	15100.88	5010.2
30	5676.3	12893	16790	5124.2	14709.57	2677.1
31	6915.6	12700	15938	5413.4	15377.57	4262.9
32	5850.8	11895	15861	5942.5	14968.02	4350.1
33	4733.4	13495	16029	5317.6	15225.18	3462.8
34	5914.3	12021	14771	4435.2	14979.9	4051.1
35	5920.4	11901	16663	5130.7	14959.88	5395
36	5722.3	11878	15559	5481.8	15541.83	4236.8

Finished Goods inventory for Family 1, Family2, and Family 3 for connected and disconnected systems – case 2 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
37	5155.4	12429	15408	5937.5	15136.7	4278.6
38	5342.4	12889	15321	5370	15865.65	4798.8
39	5043.3	12626	17004	5389.9	16545.69	3903.3
40	6052.4	12203	15052	4901	15187.67	5843.1
41	5655.2	11810	17894	4785.4	14738.51	4593
42	5361.8	12256	14040	5372.4	14694.41	4744
43	5031.4	11896	15803	4404.9	14565.89	3798
44	6550.3	12746	15238	5199.4	15384.85	3907.7
45	5297.4	12363	15642	5347.3	14906.46	3215.6
46	5672.3	11482	16289	5746.2	16203.5	3703.1
47	6009.9	12991	14460	5013.1	14285.91	4206.5
48	5840.6	15059	14593	5321.7	14449.53	3855
49	5196.1	12741	14403	4979.5	14019.11	4489.2
50	5516.3	13229	16795	5226.2	13918.51	4527.2
51	6912	12646	15354	6014.8	15129.57	3911.7
52	4992.3	12019	14834	4863.7	15029.01	3869.9
53	5258.6	13796	15387	4920.2	13805.69	4014.1
54	5191.2	12051	14576	5771	15739.55	3983.5
55	5027.7	13015	14962	4982.5	15134.06	4306
56	6247.5	12702	14668	4107.8	14137.87	4479.9
57	5523.5	12790	15550	5696	15479.09	5391.1
58	5066	12798	14234	4590.7	14352.34	4384.5
59	5445.7	11610	15182	5870.1	15307.63	4220.7
60	6751.8	12684	17376	4562.4	14812.19	4384.3
61	5951	13071	14478	5452.3	13880.31	4822.9
62	5806.2	11033	15573	5487.6	14744.7	4975.5
63	6249.6	12016	15728	4760.4	14486.07	4500
64	5691.5	11821	12115	4419.6	15285.61	4625.2
65	6023.2	12733	14954	5120.8	15689.45	4380.9
66	5819.4	13047	16069	6752.1	14490.59	5579.8
67	5002.9	12939	14646	6422.4	13995	5069.7
68	5858.6	12513	15252	4930.5	15189.53	3867.2
69	5660.1	12378	13244	5461.2	14197.7	4979
70	5501.1	12868	14932	5657.4	14179.63	4126
71	5935.1	12367	15051	5723.7	15731.18	3578.2
72	5166.3	11214	15243	6120.3	13806.02	5266.6

Finished Goods inventory for Family 1, Family2, and Family 3 for connected and disconnected systems – case 2 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
73	6260	12210	13847	4585.7	13733.05	4164.9
74	5708.8	13931	14389	4261.1	15155.9	5204.4
75	4681.7	13070	14784	5628.2	14049.19	3966.5
76	5762.4	11713	14957	5068	14792.36	4312.1
77	5832.4	13281	14179	6026.4	15740.97	4147.3
78	4840.8	12832	14712	5053.2	13901.86	4387.8
79	6618.3	12650	14802	4999.3	14374.74	3060.4
80	5332.6	12732	16606	5476.5	15487.02	3754.9
81	4758.9	13509	15830	5015	14555.25	3994.4
82	5920.1	13095	16505	5586.3	15244.8	5387.2
83	5759.5	13925	13772	5310.1	15358.21	4512.7
84	6257.8	13749	14810	4856.9	15055.61	4576.4
85	5442.5	13637	14188	4812	13654.13	4762.2
86	6246.5	12942	16280	5040	14960.93	5967.3
87	5706.2	12328	15336	5641.3	15152.88	5217.7
88	6494	10787	16236	5456.4	14824.58	4268
89	5040	12177	14376	5274.2	14404.52	3584.7
90	5775.2	12205	14060	5450.8	14014.52	3918.4
91	4788	11752	14446	5661	15138.56	6037.7
92	7828	11624	14852	5057.6	14061.75	4628.8
93	6288	13346	16566	4534.4	13967.75	4501.9
94	5243.1	11812	14941	5645	15159.09	4269.7
95	5749.8	12684	15549	5513.1	14562.99	4904.5
96	5002.3	13926	13761	4835.9	14359.23	4659.6
97	5202.9	12504	16071	5180.5	15314.72	3511.5
98	5177.2	12130	16079	5162.3	15410.56	3770.5
99	6040.3	13352	13711	4998.3	15634.65	5169
100	4934.3	11899	13961	4655.6	14721.85	4597.7

Work in process inventory for Family 1, Family2, and Family 3 for connected and disconnected systems – case 2

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
1	51.1	180	262	473.9	1005.16	511.7
2	58.2	190	259	622.4	816.03	683.6
3	43.3	183	263	705.7	1010.35	290
4	47.9	178	269	701.5	1369.48	208.2
5	65.4	180	268	469.5	1239.69	707.8
6	54.8	168	273	389.8	1060.94	379.9
7	51.2	194	255	466.9	1335.76	282.8
8	51.3	196	255	820.5	1493.21	422.8
9	45.6	201	249	504	923.52	677.2
10	53.4	184	265	545.9	899.65	333.8
11	61.4	184	258	725.9	1118.38	744.2
12	61.7	177	267	586.5	1043.9	507
13	56.8	182	259	602.2	1090.72	1009.3
14	62.1	185	259	567.5	1431.5	693
15	49.2	182	261	502.7	1244.63	1613.5
16	51.2	193	255	662.2	1626.06	359.2
17	55.6	185	263	610.1	1006.69	357.4
18	52.4	182	263	475.1	1158.08	242.4
19	49.5	181	264	492.7	896.72	464.6
20	59.4	186	257	830.8	1124.43	883.1
21	58.2	193	256	548.6	1821.67	261.7
22	53.5	181	263	577.1	930.15	639.3
23	52.9	181	261	660	1519.89	687.1
24	56	184	260	1044.8	1082.7	323.1
25	65.1	178	266	676.6	1343.68	565.8
26	55.6	188	261	683.2	1129.96	428.5
27	58.8	180	262	460.8	1167.99	943.7
28	60.8	177	266	1058.4	1095.14	526.2
29	54.4	179	266	385.7	1461.12	471.5
30	55.3	180	264	396.6	1056.43	353.1
31	53.5	178	270	731.5	969.43	346.8
32	59.1	189	259	738	1036.98	178.8
33	67.9	176	267	566.6	1020.82	409.4
34	60.4	182	261	619	857.1	389.2
35	57.9	187	264	581.1	1047.12	555
36	49	182	261	720.5	971.17	228.6

Work in process inventory for Family 1, Family2, and Family 3 for connected and disconnected systems – case 2 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
37	55.6	197	253	645.6	1080.3	1415.6
38	45	182	265	619.5	1213.35	943.8
39	50.6	189	255	588.7	1320.31	632.7
40	39.4	192	255	355	1068.33	293.9
41	64.6	177	260	435.2	1685.49	217.9
42	52.2	184	259	906.3	1015.59	430.1
43	40.3	194	258	465.8	1129.11	837
44	54.3	194	252	773.4	1121.15	488.4
45	56	184	261	519.4	948.54	186.4
46	57.5	189	259	618.1	1356.5	827.8
47	62.1	176	260	855.7	905.09	381.9
48	56.7	185	261	576.4	1485.47	415
49	51.7	180	266	412.6	956.89	337.8
50	63.3	187	257	536.6	2026.49	198.8
51	55.8	176	269	558.2	1393.43	551.4
52	61.7	175	271	575.8	1452.99	404.2
53	60.4	184	260	883	826.31	424.9
54	57.3	197	251	678.3	1330.45	668.6
55	51.4	185	259	719	1213.94	696.2
56	67.7	176	264	346.7	1121.13	369.6
57	47.5	189	265	951.3	1287.91	274.3
58	55.9	191	256	549	1112.66	1625.2
59	50.5	179	269	894.7	1119.37	1185.3
60	53.6	180	267	772.8	1108.81	532.7
61	52.8	188	259	536.1	2112.69	269.7
62	64.4	174	261	705.1	941.3	572.2
63	49.4	193	258	643.5	1070.93	374
64	67.6	177	264	357.4	902.39	485.6
65	52	183	262	522.9	1082.55	818.7
66	63.9	173	262	853.6	1294.41	537.2
67	69.4	192	256	625.4	1092	503.6
68	53.9	173	269	589.6	1068.47	516.8
69	64.2	183	263	739.6	1075.3	487.7
70	42.8	195	257	604.9	925.37	590.3
71	55.2	187	260	565.5	1038.82	964.5
72	56.5	185	262	715	1035.98	464.3

Work in process inventory for Family 1, Family2, and Family 3 for connected and disconnected systems – case 2 (continued)

Replication No.	Connected System			Disconnected System		
	Family 1	Family 2	Family 3	Family 1	Family 2	Family 3
73	61.9	179	266	346.9	825.95	677.4
74	58.3	195	253	517.1	1071.1	472.8
75	41.4	185	265	635.3	1197.81	1096.8
76	44	192	255	607.4	1049.64	984.7
77	55	183	256	788.6	1166.03	263.8
78	49	193	253	660.7	1192.14	345.6
79	44.1	188	261	450.4	1161.26	510.4
80	48.3	190	262	457.3	1213.98	373
81	63.8	181	264	414	1084.75	230.5
82	57.2	183	263	674.9	917.2	251.7
83	53.6	189	256	604.1	1149.79	876.6
84	56	187	257	396.4	980.39	1393
85	56.4	186	258	578.6	820.87	577.4
86	49.5	189	260	516.7	1201.07	321.3
87	64.6	182	264	738.5	1027.12	476.6
88	56.4	179	268	560.1	902.42	456.1
89	60	181	263	490	1184.48	729
90	52.7	184	262	584.9	1122.48	633.1
91	47.6	178	268	547.9	1155.44	254.1
92	57.7	182	261	538.3	779.25	212.2
93	47.7	180	268	435.9	1174.25	919.3
94	52.9	184	263	655.3	1199.91	503.3
95	49	180	268	585.4	908.01	504.3
96	64.1	189	262	570.9	1008.77	537
97	48.2	175	271	554	1314.28	317.5
98	68	181	257	501.1	1299.44	463.6
99	54.8	182	265	485.8	1139.35	544.1
100	47.4	181	263	400.6	1252.15	267

APPENDIX C – STATISTICAL RESULTS FOR FLOWTIMES AND WORK IN PROCESS FOR CONNECTED AND DISCONNECTED SYSTEMS

T-test for Family 1, Family 2, and, Family 3 flowtimes for connected and disconnected systems assuming unequal variances – case 1A

Family		Connected System	Disconnected System
Family 1	Mean	42.66792	31.19106
	Variance	2850.292	184.2219
	Observations	100	100
	Hypothesized Mean Difference	0	
	Df	112	
	t Stat	2.083428	
	P(T<=t) one-tail	0.019744	
	t Critical one-tail	2.360104	
	P(T<=t) two-tail	0.039488	
	t Critical two-tail	2.62044	
Family 2	Mean	50.52395	54.39673
	Variance	2210.059	353.7324
	Df	130	
	t Stat	-0.76486	
	P(T<=t) one-tail	0.222871	
	t Critical one-tail	2.355375	
	P(T<=t) two-tail	0.445742	
	t Critical two-tail	2.614177	
Family 3	Mean	87.534	71.61304
	Variance	16129	3004.617
	Df	135	
	t Stat	1.151	
	P(T<=t) one-tail	0.1259	
	t Critical one-tail	2.3543	
	P(T<=t) two-tail	0.2518	
	t Critical two-tail	2.6127	

T-test for Family 1, Family 2, and, Family 3 work in process for connected and disconnected systems assuming unequal variances – case 1A

Family		Connected System	Disconnected System
Family 1	Mean	128.5918	100.1562
	Variance	22037.88	3267.242
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	128	
	t Stat	1.78755	
	P(T<=t) one-tail	0.038107	
	t Critical one-tail	2.355834	
	P(T<=t) two-tail	0.076215	
	t Critical two-tail	2.614785	
Family 2	Mean	1403.77	1622.523
	Variance	484578.1	244221
	df	179	
	t Stat	-2.56242	
	P(T<=t) one-tail	0.005609	
	t Critical one-tail	2.34736	
	P(T<=t) two-tail	0.011218	
	t Critical two-tail	2.603574	
Family 3	Mean	1381.4	1182.29
	Variance	4E+06	88088.63
	df	103	
	t Stat	0.9471	
	P(T<=t) one-tail	0.1729	
	t Critical one-tail	2.3631	
	P(T<=t) two-tail	0.3458	
	t Critical two-tail	2.6244	

T-test for Family 1, Family 2, and, Family 3 flowtimes for connected and disconnected systems assuming unequal variances – case 1B, Model 2

Family		Connected System	Disconnected System
Family 1	Mean	31.08836	32.55187
	Variance	203.735	93.74068
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	174	
	t Stat	-0.84854	
	P(T<=t) one-tail	0.198653	
	t Critical one-tail	1.653658	
	P(T<=t) two-tail	0.397306	
	t Critical two-tail	1.973691	
Family 2	Mean	45.9897	51.62108
	Variance	238.1854	111.8879
	df	175	
	t Stat	-3.00978	
	P(T<=t) one-tail	0.0015	
	t Critical one-tail	1.653607	
	P(T<=t) two-tail	0.003001	
	t Critical two-tail	1.973612	
Family 3	Mean	66.61163	73.79538
	Variance	2869.616	1438.173
	df	178	
	t Stat	-1.09452	
	P(T<=t) one-tail	0.137603	
	t Critical one-tail	1.653459	
	P(T<=t) two-tail	0.275205	
	t Critical two-tail	1.973381	

T-test for Family 1, Family 2, and, Family 3 work in process for connected and disconnected systems assuming unequal variances – case 1B, Model 2

Family		Connected System	Disconnected System
Family 1	Mean	90.00296	99.70663
	Variance	2290.069	1337.748
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	185	
	t Stat	-1.61107	
	P(T<=t) one-tail	0.054435	
	t Critical one-tail	1.653132	
	P(T<=t) two-tail	0.10887	
	t Critical two-tail	1.97287	
Family 2	Mean	1184.196	1563.946
	Variance	105669	150828.8
	df	192	
	t Stat	-7.49818	
	P(T<=t) one-tail	1.16E-12	
	t Critical one-tail	1.652829	
	P(T<=t) two-tail	2.33E-12	
	t Critical two-tail	1.972396	
Family 3	Mean	1052.064	1267.131
	Variance	686582.1	178673.9
	df	147	
	t Stat	-2.31207	
	P(T<=t) one-tail	0.011081	
	t Critical one-tail	1.655285	
	P(T<=t) two-tail	0.022162	
	t Critical two-tail	1.976233	

T-test for Family 1, Family 2, and, Family 3 flowtimes for connected and disconnected systems assuming unequal variances – case 1B, Model 3

Family		Connected System	Disconnected System
Family 1	Mean	24.91089	27.24505
	Variance	42.89339	65.14405
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	190	
	t Stat	-2.24566	
	P(T<=t) one-tail	0.012939	
	t Critical one-tail	1.652913	
	P(T<=t) two-tail	0.025878	
	t Critical two-tail	1.972528	
Family 2	Mean	39.84601	46.93433
	Variance	77.52394	88.30738
	df	197	
	t Stat	-5.5044	
	P(T<=t) one-tail	5.72E-08	
	t Critical one-tail	1.652625	
	P(T<=t) two-tail	1.14E-07	
	t Critical two-tail	1.972079	
Family 3	Mean	67.06694	83.48585
	Variance	10609	5144.79
	df	177	
	t Stat	-1.30813	
	P(T<=t) one-tail	0.096262	
	t Critical one-tail	1.653508	
	P(T<=t) two-tail	0.192525	
	t Critical two-tail	1.973457	

T-test for Family 1, Family 2, and, Family 3 work in process for connected and disconnected systems assuming unequal variances – case 1B, Model 3

Family		Connected System	Disconnected System
Family 1	Mean	70.67261	86.36117
	Variance	565.0489	1012.903
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	183	
	t Stat	-3.94945	
	P(T<=t) one-tail	5.58E-05	
	t Critical one-tail	1.653223	
	P(T<=t) two-tail	0.000112	
	t Critical two-tail	1.973012	
Family 2	Mean	1046.903	1425.427
	Variance	62252.73	108909.2
	df	184	
	t Stat	-9.14934	
	P(T<=t) one-tail	5.41E-17	
	t Critical one-tail	1.653177	
	P(T<=t) two-tail	1.08E-16	
	t Critical two-tail	1.972941	
Family 3	Mean	1246.106	1442.675
	Variance	9610643	1344601
	df	126	
	t Stat	-0.59389	
	P(T<=t) one-tail	0.276826	
	t Critical one-tail	1.657037	
	P(T<=t) two-tail	0.553652	
	t Critical two-tail	1.978971	

T-test for Family 1, Family 2, and, Family 3 flowtimes for connected and disconnected systems assuming unequal variances – case 1B, Model 4

Family		Connected System	Disconnected System
Family 1	Mean	41.26383	35.14152
	Variance	1351.835	448.3888
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	158	
	t Stat	1.442953	
	P(T<=t) one-tail	0.075507	
	t Critical one-tail	1.654555	
	P(T<=t) two-tail	0.151013	
	t Critical two-tail	1.975092	
Family 2	Mean	51.15537	49.66022
	Variance	833.3142	328.198
	df	167	
	t Stat	0.438705	
	P(T<=t) one-tail	0.330721	
	t Critical one-tail	1.654029	
	P(T<=t) two-tail	0.661442	
	t Critical two-tail	1.974271	
Family 3	Mean	78.25163	79.49043
	Variance	6608.326	8067.216
	df	196	
	t Stat	-0.10226	
	P(T<=t) one-tail	0.459328	
	t Critical one-tail	1.652665	
	P(T<=t) two-tail	0.918655	
	t Critical two-tail	1.972141	

T-test for Family 1, Family 2, and, Family 3 work in process for connected and disconnected systems assuming unequal variances – case 1B, Model 4

Family		Connected System	Disconnected System
Family 1	Mean	126.106	111.2746
	Variance	14323.04	2580.586
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	134	
	t Stat	1.140748	
	P(T<=t) one-tail	0.128005	
	t Critical one-tail	1.656305	
	P(T<=t) two-tail	0.256009	
	t Critical two-tail	1.977826	
Family 2	Mean	1425.71	1667.293
	Variance	320649.9	305735.9
	df	198	
	t Stat	-3.05242	
	P(T<=t) one-tail	0.001291	
	t Critical one-tail	1.652586	
	P(T<=t) two-tail	0.002582	
	t Critical two-tail	1.972017	
Family 3	Mean	1269.427	1409.316
	Variance	1956293	2484191
	df	195	
	t Stat	-0.66385	
	P(T<=t) one-tail	0.253786	
	t Critical one-tail	1.652705	
	P(T<=t) two-tail	0.507571	
	t Critical two-tail	1.972204	

T-test for Family 1, Family 2, and, Family 3 flowtimes for connected and disconnected systems assuming unequal variances – case 1B, Model 6

Family		Connected System	Disconnected System
Family 1	Mean	24.91089	31.88865
	Variance	42.89339	91.51185
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	175	
	t Stat	-6.01877	
	P(T<=t) one-tail	5.02E-09	
	t Critical one-tail	1.653607	
	P(T<=t) two-tail	1E-08	
	t Critical two-tail	1.973612	
Family 2	Mean	39.84601	51.17741
	Variance	77.52394	102.8929
	df	194	
	t Stat	-8.43617	
	P(T<=t) one-tail	3.73E-15	
	t Critical one-tail	1.652746	
	P(T<=t) two-tail	7.45E-15	
	t Critical two-tail	1.972267	
Family 3	Mean	67.06694	73.80529
	Variance	10609	1322.475
	df	123	
	t Stat	-0.61689	
	P(T<=t) one-tail	0.269224	
	t Critical one-tail	1.657336	
	P(T<=t) two-tail	0.538449	
	t Critical two-tail	1.979439	

T-test for Family 1, Family 2, and, Family 3 work in process for connected and disconnected systems assuming unequal variances – case 1B, Model 6

Family		Connected System	Disconnected System
Family 1	Mean	70.67261	97.46335
	Variance	565.0489	1323.951
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	170	
	t Stat	-6.16409	
	P(T<=t) one-tail	2.49E-09	
	t Critical one-tail	1.653866	
	P(T<=t) two-tail	4.99E-09	
	t Critical two-tail	1.974017	
Family 2	Mean	1046.903	1555.348
	Variance	62252.73	142480.4
	df	172	
	t Stat	-11.237	
	P(T<=t) one-tail	1.27E-22	
	t Critical one-tail	1.653761	
	P(T<=t) two-tail	2.55E-22	
	t Critical two-tail	1.973852	
Family 3	Mean	1246.106	1273.615
	Variance	9610643	186178.4
	df	103	
	t Stat	-0.08789	
	P(T<=t) one-tail	0.465068	
	t Critical one-tail	1.659782	
	P(T<=t) two-tail	0.930137	
	t Critical two-tail	1.983264	

T-test for Family 1, Family 2, and, Family 3 flowtimes for connected and disconnected systems assuming unequal variances – case 1B, Model 7

Family		Connected System	Disconnected System
Family 1	Mean	24.91089	70.67261
	Variance	42.89339	565.0489
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	114	
	t Stat	-18.5597	
	P(T<=t) one-tail	1.52E-36	
	t Critical one-tail	1.65833	
	P(T<=t) two-tail	3.04E-36	
	t Critical two-tail	1.980992	
Family 2	Mean	39.84601	45.91316
	Variance	77.52394	146.2002
	df	181	
	t Stat	-4.05628	
	P(T<=t) one-tail	3.7E-05	
	t Critical one-tail	1.653316	
	P(T<=t) two-tail	7.4E-05	
	t Critical two-tail	1.973157	
Family 3	Mean	67.06694	78.06285
	Variance	10609	11933.96
	df	197	
	t Stat	-0.73236	
	P(T<=t) one-tail	0.232409	
	t Critical one-tail	1.652625	
	P(T<=t) two-tail	0.464818	
	t Critical two-tail	1.972079	

T-test for Family 1, Family 2, and, Family 3 work in process for connected and disconnected systems assuming unequal variances – case 1B, Model 7

Family		Connected System	Disconnected System
Family 1	Mean	70.67261	80.34373
	Variance	565.0489	707.085
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	196	
	t Stat	-2.7115	
	P(T<=t) one-tail	0.003646	
	t Critical one-tail	1.652665	
	P(T<=t) two-tail	0.007293	
	t Critical two-tail	1.972141	
Family 2	Mean	1046.903	1380.771
	Variance	62252.73	123445.5
	df	179	
	t Stat	-7.74766	
	P(T<=t) one-tail	3.36E-13	
	t Critical one-tail	1.653411	
	P(T<=t) two-tail	6.72E-13	
	t Critical two-tail	1.973305	
Family 3	Mean	1246.106	1532.792
	Variance	9610643	9795447
	df	198	
	t Stat	-0.65078	
	P(T<=t) one-tail	0.25797	
	t Critical one-tail	1.652586	
	P(T<=t) two-tail	0.51594	
	t Critical two-tail	1.972017	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 2 and Model 3, Model 6, Model 7 assuming unequal variances – case 1, connected systems

Family		Model 2	Models 3, 6, 7
Family 1	Mean	31.08836	24.91089
	Variance	203.735	42.89339
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	139	
	t Stat	3.93359	
	P(T<=t) one-tail	6.58E-05	
	t Critical one-tail	1.65589	
	P(T<=t) two-tail	0.000132	
	t Critical two-tail	1.977178	
Family 2	Mean	45.9897	39.84601
	Variance	238.1854	77.52394
	df	157	
	t Stat	3.457686	
	P(T<=t) one-tail	0.000351	
	t Critical one-tail	1.654617	
	P(T<=t) two-tail	0.000701	
	t Critical two-tail	1.975189	
Family 3	Mean	66.61163	67.06694
	Variance	2869.616	10609
	df	149	
	t Stat	-0.03922	
	P(T<=t) one-tail	0.484385	
	t Critical one-tail	1.655145	
	P(T<=t) two-tail	0.968769	
	t Critical two-tail	1.976013	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 2 and Model 3, Model 6, Model 7 assuming unequal variances – case 1, connected systems

Family		Model 2	Models 3, 6, 7
Family 1	Mean	90.00296	70.67261
	Variance	2290.069	565.0489
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	145	
	t Stat	3.617659	
	P(T<=t) one-tail	0.000205	
	t Critical one-tail	1.65543	
	P(T<=t) two-tail	0.00041	
	t Critical two-tail	1.97646	
Family 2	Mean	1184.196	1046.903
	Variance	105669	62252.73
	df	186	
	t Stat	3.350392	
	P(T<=t) one-tail	0.000489	
	t Critical one-tail	1.653087	
	P(T<=t) two-tail	0.000977	
	t Critical two-tail	1.9728	
Family 3	Mean	1052.064	1246.106
	Variance	686582.1	9610643
	df	113	
	t Stat	-0.6047	
	P(T<=t) one-tail	0.273297	
	t Critical one-tail	1.65845	
	P(T<=t) two-tail	0.546594	
	t Critical two-tail	1.98118	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 2 and Model 4 assuming unequal variances – case 1, connected systems

Family		Model 2	Model 4
Family 1	Mean	31.08836	41.26383
	Variance	203.735	1351.835
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	128	
	t Stat	-2.57994	
	P(T<=t) one-tail	0.005505	
	t Critical one-tail	1.656845	
	P(T<=t) two-tail	0.011011	
	t Critical two-tail	1.978671	
Family 2	Mean	45.9897	51.15537
	Variance	238.1854	833.3142
	df	151	
	t Stat	-1.57809	
	P(T<=t) one-tail	0.058319	
	t Critical one-tail	1.655007	
	P(T<=t) two-tail	0.116638	
	t Critical two-tail	1.975799	
Family 3	Mean	66.61163	78.25163
	Variance	2869.616	6608.326
	df	171	
	t Stat	-1.19563	
	P(T<=t) one-tail	0.116749	
	t Critical one-tail	1.653813	
	P(T<=t) two-tail	0.233497	
	t Critical two-tail	1.973934	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 2 and Model 4 assuming unequal variances – case 1, connected systems

Family		Model 2	Model 4
Family 1	Mean	90.00296	126.106
	Variance	2290.069	14323.04
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	130	
	t Stat	-2.80103	
	P(T<=t) one-tail	0.002936	
	t Critical one-tail	1.656659	
	P(T<=t) two-tail	0.005872	
	t Critical two-tail	1.97838	
Family 2	Mean	1184.196	1425.71
	Variance	105669	320649.9
	df	158	
	t Stat	-3.69892	
	P(T<=t) one-tail	0.000149	
	t Critical one-tail	1.654555	
	P(T<=t) two-tail	0.000298	
	t Critical two-tail	1.975092	
Family 3	Mean	1052.064	1269.427
	Variance	686582.1	1956293
	df	161	
	t Stat	-1.33705	
	P(T<=t) one-tail	0.091546	
	t Critical one-tail	1.654373	
	P(T<=t) two-tail	0.183092	
	t Critical two-tail	1.974808	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 3, Model 6, Model 7 and Model 4 assuming unequal variances – case 1, connected systems

Family		Models 3, 6, 7	Model 4
Family 1	Mean	24.91089	41.26383
	Variance	42.89339	1351.835
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	-4.37876	
	t Stat	1.42E-05	
	P(T<=t) one-tail	1.659495	
	t Critical one-tail	2.83E-05	
	P(T<=t) two-tail	1.982815	
	t Critical two-tail	105	
Family 2	Mean	39.84601	51.15537
	Variance	77.52394	833.3142
	df	117	
	t Stat	-3.74729	
	P(T<=t) one-tail	0.00014	
	t Critical one-tail	1.657982	
	P(T<=t) two-tail	0.000279	
	t Critical two-tail	1.980448	
Family 3	Mean	67.06694	78.25163
	Variance	10609	6608.326
	df	188	
	t Stat	-0.8524	
	P(T<=t) one-tail	0.19754	
	t Critical one-tail	1.652999	
	P(T<=t) two-tail	0.395079	
	t Critical two-tail	1.972663	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 3, Model 6, Model 7 and Model 4 assuming unequal variances – case 1, connected systems

Family		Models 3, 6, 7	Model 4
Family 1	Mean	70.67261	126.106
	Variance	565.0489	14323.04
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	107	
	t Stat	-4.54309	
	P(T<=t) one-tail	7.31E-06	
	t Critical one-tail	1.659219	
	P(T<=t) two-tail	1.46E-05	
	t Critical two-tail	1.982383	
Family 2	Mean	1046.903	1425.71
	Variance	62252.73	320649.9
	df	136	
	t Stat	-6.12173	
	P(T<=t) one-tail	4.65E-09	
	t Critical one-tail	1.656135	
	P(T<=t) two-tail	9.31E-09	
	t Critical two-tail	1.977561	
Family 3	Mean	1246.106	1269.427
	Variance	9610643	1956293
	df	138	
	t Stat	-0.06857	
	P(T<=t) one-tail	0.472716	
	t Critical one-tail	1.65597	
	P(T<=t) two-tail	0.945431	
	t Critical two-tail	1.977304	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 1A and Model 2 assuming unequal variances – case 1, connected systems

Family		Model 1A	Model 2
Family 1	Mean	42.66792	31.08836
	Variance	2850.292	203.735
	Observations	100	100
	Hypothesized Mean Difference	113	
	df	2.095345	
	t Stat	0.019187	
	P(T<=t) one-tail	1.65845	
	t Critical one-tail	0.038374	
	P(T<=t) two-tail	1.98118	
	t Critical two-tail	113	
Family 2	Mean	50.52395	45.9897
	Variance	2210.059	238.1854
	df	120	
	t Stat	0.916385	
	P(T<=t) one-tail	0.180651	
	t Critical one-tail	1.657651	
	P(T<=t) two-tail	0.361303	
	t Critical two-tail	1.97993	
Family 3	Mean	87.53434	66.61163
	Variance	16128.66	2869.616
	df	133	
	t Stat	1.517962	
	P(T<=t) one-tail	0.065699	
	t Critical one-tail	1.656391	
	P(T<=t) two-tail	0.131397	
	t Critical two-tail	1.977961	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 1A and Model 2 assuming unequal variances – case 1, connected systems

Family		Model 1A	Model 2
Family 1	Mean	128.5918	90.00296
	Variance	22037.88	2290.069
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	2.474051	
	t Stat	0.007385	
	P(T<=t) one-tail	1.657759	
	t Critical one-tail	0.014769	
	P(T<=t) two-tail	1.9801	
	t Critical two-tail	119	
Family 2	Mean	1403.77	1184.196
	Variance	484578.1	105669
	t Stat	140	
	df	2.85801	
	P(T<=t) one-tail	0.002457	
	t Critical one-tail	1.655811	
	P(T<=t) two-tail	0.004914	
	t Critical two-tail	1.977054	
Family 3	Mean	1381.395	1052.064
	Variance	4331570	686582.1
	df	130	
	t Stat	1.470149	
	P(T<=t) one-tail	0.071969	
	t Critical one-tail	1.656659	
	P(T<=t) two-tail	0.143938	
	t Critical two-tail	1.97838	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 1A and Models 3, 6, 7 assuming unequal variances – case 1, connected systems

Family		Model 1A	Models 3, 6, 7
Family 1	Mean	42.66792	24.91089
	Variance	2850.292	42.89339
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	3.301279	
	t Stat	0.000664	
	P(T<=t) one-tail	1.65993	
	t Critical one-tail	0.001327	
	P(T<=t) two-tail	1.983495	
	t Critical two-tail	102	
Family 2	Mean	50.52395	39.84601
	Variance	2210.059	77.52394
	df	106	
	t Stat	2.232539	
	P(T<=t) one-tail	0.013841	
	t Critical one-tail	1.659356	
	P(T<=t) two-tail	0.027682	
	t Critical two-tail	1.982597	
Family 3	Mean	87.53434	67.06694
	Variance	16128.66	10609
	df	190	
	t Stat	1.251702	
	P(T<=t) one-tail	0.106109	
	t Critical one-tail	1.652913	
	P(T<=t) two-tail	0.212217	
	t Critical two-tail	1.972528	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 1A and Models 3, 6, 7 assuming unequal variances – case 1, connected systems

Family		Model 1A	Models 3, 6, 7
Family 1	Mean	128.5918	70.67261
	Variance	22037.88	565.0489
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	104	
	t Stat	3.852475	
	P(T<=t) one-tail	0.000101	
	t Critical one-tail	1.659637	
	P(T<=t) two-tail	0.000202	
	t Critical two-tail	1.983037	
Family 2	Mean	1403.77	1046.903
	Variance	484578.1	62252.73
	df	124	
	t Stat	4.825919	
	P(T<=t) one-tail	2.01E-06	
	t Critical one-tail	1.657235	
	P(T<=t) two-tail	4.01E-06	
	t Critical two-tail	1.97928	
Family 3	Mean	1381.395	1246.106
	Variance	4331570	9610643
	df	173	
	t Stat	0.362323	
	P(T<=t) one-tail	0.358776	
	t Critical one-tail	1.653709	
	P(T<=t) two-tail	0.717553	
	t Critical two-tail	1.973771	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 1A and Model 4 assuming unequal variances – case 1, connected systems

Family		Model 1A	Model 4
Family 1	Mean	42.66792	41.26383
	Variance	2850.292	1351.835
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	176	
	t Stat	0.216601	
	P(T<=t) one-tail	0.414385	
	t Critical one-tail	1.653557	
	P(T<=t) two-tail	0.82877	
	t Critical two-tail	1.973534	
Family 2	Mean	50.52395	51.15537
	Variance	2210.059	833.3142
	df	164	
	t Stat	-0.11446	
	P(T<=t) one-tail	0.454508	
	t Critical one-tail	1.654198	
	P(T<=t) two-tail	0.909016	
	t Critical two-tail	1.974535	
Family 3	Mean	87.53434	78.25163
	Variance	16128.66	6608.326
	df	168	
	t Stat	0.615614	
	P(T<=t) one-tail	0.269491	
	t Critical one-tail	1.653974	
	P(T<=t) two-tail	0.538983	
	t Critical two-tail	1.974185	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 1A and Model 4 assuming unequal variances – case 1, connected systems

Family		Model 1A	Model 4
Family 1	Mean	128.5918	126.106
	Variance	22037.88	14323.04
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	189	
	t Stat	0.130362	
	P(T<=t) one-tail	0.448209	
	t Critical one-tail	1.652956	
	P(T<=t) two-tail	0.896418	
	t Critical two-tail	1.972595	
Family 2	Mean	1403.77	1425.71
	Variance	484578.1	320649.9
	df	190	
	t Stat	-0.2445	
	P(T<=t) one-tail	0.403554	
	t Critical one-tail	1.652913	
	P(T<=t) two-tail	0.807107	
	t Critical two-tail	1.972528	
Family 3	Mean	1381.395	1269.427
	Variance	4331570	1956293
	df	173	
	t Stat	0.446522	
	P(T<=t) one-tail	0.327889	
	t Critical one-tail	1.653709	
	P(T<=t) two-tail	0.655778	
	t Critical two-tail	1.973771	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 2 and Model 3 assuming unequal variances – case 1, disconnected systems

Family		Model 2	Model 3
Family 1	Mean	32.55187	27.24505
	Variance	93.74068	65.14405
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	192	
	t Stat	4.210108	
	P(T<=t) one-tail	1.96E-05	
	t Critical one-tail	1.652829	
	P(T<=t) two-tail	3.92E-05	
	t Critical two-tail	1.972396	
Family 2	Mean	51.62108	46.93433
	Variance	111.8879	88.30738
	df	195	
	t Stat	3.312416	
	P(T<=t) one-tail	0.000551	
	t Critical one-tail	1.652705	
	P(T<=t) two-tail	0.001102	
	t Critical two-tail	1.972204	
Family 3	Mean	73.79538	83.48585
	Variance	1438.173	5144.79
	df	150	
	t Stat	-1.19436	
	P(T<=t) one-tail	0.117112	
	t Critical one-tail	1.655076	
	P(T<=t) two-tail	0.234224	
	t Critical two-tail	1.975905	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 2 and Model 3 assuming unequal variances – case 1, disconnected systems

Family		Model 2	Model 3
Family 1	Mean	99.70663	86.36117
	Variance	1337.748	1012.903
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	2.752577	
	t Stat	0.003237	
	P(T<=t) one-tail	1.652746	
	t Critical one-tail	0.006474	
	P(T<=t) two-tail	1.972267	
	t Critical two-tail	194	
Family 2	Mean	1563.946	1425.427
	Variance	150828.8	108909.2
	df	193	
	t Stat	2.717949	
	P(T<=t) one-tail	0.003583	
	t Critical one-tail	1.652787	
	P(T<=t) two-tail	0.007167	
	t Critical two-tail	1.972332	
Family 3	Mean	1267.131	1442.675
	Variance	178673.9	1344601
	df	125	
	t Stat	-1.42232	
	P(T<=t) one-tail	0.078712	
	t Critical one-tail	1.657135	
	P(T<=t) two-tail	0.157423	
	t Critical two-tail	1.979124	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 2 and Model 4 assuming unequal variances – case 1, disconnected systems

Family		Model 2	Model 4
Family 1	Mean	32.55187	27.24505
	Variance	93.74068	65.14405
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	192	
	t Stat	4.210108	
	P(T<=t) one-tail	1.96E-05	
	t Critical one-tail	1.652829	
	P(T<=t) two-tail	3.92E-05	
	t Critical two-tail	1.972396	
Family 2	Mean	51.62108	46.93433
	Variance	111.8879	88.30738
	df	195	
	t Stat	3.312416	
	P(T<=t) one-tail	0.000551	
	t Critical one-tail	1.652705	
	P(T<=t) two-tail	0.001102	
	t Critical two-tail	1.972204	
Family 3	Mean	73.79538	83.48585
	Variance	1438.173	5144.79
	df	150	
	t Stat	-1.19436	
	P(T<=t) one-tail	0.117112	
	t Critical one-tail	1.655076	
	P(T<=t) two-tail	0.234224	
	t Critical two-tail	1.975905	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 2 and Model 4 assuming unequal variances – case 1, disconnected systems

Family		Model 2	Model 4
Family 1	Mean	99.70663	86.36117
	Variance	1337.748	1012.903
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	2.752577	
	t Stat	0.003237	
	P(T<=t) one-tail	1.652746	
	t Critical one-tail	0.006474	
	P(T<=t) two-tail	1.972267	
	t Critical two-tail	194	
Family 2	Mean	1563.946	1425.427
	Variance	150828.8	108909.2
	df	193	
	t Stat	2.717949	
	P(T<=t) one-tail	0.003583	
	t Critical one-tail	1.652787	
	P(T<=t) two-tail	0.007167	
	t Critical two-tail	1.972332	
Family 3	Mean	1267.131	1442.675
	Variance	178673.9	1344601
	df	125	
	t Stat	-1.42232	
	P(T<=t) one-tail	0.078712	
	t Critical one-tail	1.657135	
	P(T<=t) two-tail	0.157423	
	t Critical two-tail	1.979124	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 2 and Model 6 assuming unequal variances – case 1, disconnected systems

Family		Model 2	Model 6
Family 1	Mean	32.55187	27.24505
	Variance	93.74068	65.14405
	Observations	100	100
	Hypothesized Mean Difference	192	
	df	4.210108	
	t Stat	1.96E-05	
	P(T<=t) one-tail	1.652829	
	t Critical one-tail	3.92E-05	
	P(T<=t) two-tail	1.972396	
	t Critical two-tail	192	
Family 2	Mean	51.62108	46.93433
	Variance	111.8879	88.30738
	df	195	
	t Stat	3.312416	
	P(T<=t) one-tail	0.000551	
	t Critical one-tail	1.652705	
	P(T<=t) two-tail	0.001102	
	t Critical two-tail	1.972204	
Family 3	Mean	73.79538	83.48585
	Variance	1438.173	5144.79
	df	150	
	t Stat	-1.19436	
	P(T<=t) one-tail	0.117112	
	t Critical one-tail	1.655076	
	P(T<=t) two-tail	0.234224	
	t Critical two-tail	1.975905	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 2 and Model 6 assuming unequal variances – case 1, disconnected systems

Family		Model 2	Model 6
Family 1	Mean	99.70663	86.36117
	Variance	1337.748	1012.903
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	194	
	t Stat	2.752577	
	P(T<=t) one-tail	0.003237	
	t Critical one-tail	1.652746	
	P(T<=t) two-tail	0.006474	
	t Critical two-tail	1.972267	
Family 2	Mean	1563.946	1425.427
	Variance	150828.8	108909.2
	df	193	
	t Stat	2.717949	
	P(T<=t) one-tail	0.003583	
	t Critical one-tail	1.652787	
	P(T<=t) two-tail	0.007167	
	t Critical two-tail	1.972332	
Family 3	Mean	1267.131	1442.675
	Variance	178673.9	1344601
	df	125	
	t Stat	-1.42232	
	P(T<=t) one-tail	0.078712	
	t Critical one-tail	1.657135	
	P(T<=t) two-tail	0.157423	
	t Critical two-tail	1.979124	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 2 and Model 7 assuming unequal variances – case 1, disconnected systems

Family		Model 2	Model 7
Family 1	Mean	32.55187	27.24505
	Variance	93.74068	65.14405
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	192	
	t Stat	4.210108	
	P(T<=t) one-tail	1.96E-05	
	t Critical one-tail	1.652829	
	P(T<=t) two-tail	3.92E-05	
	t Critical two-tail	1.972396	
Family 2	Mean	51.62108	46.93433
	Variance	111.8879	88.30738
	df	195	
	t Stat	3.312416	
	P(T<=t) one-tail	0.000551	
	t Critical one-tail	1.652705	
	P(T<=t) two-tail	0.001102	
	t Critical two-tail	1.972204	
Family 3	Mean	73.79538	83.48585
	Variance	1438.173	5144.79
	df	150	
	t Stat	-1.19436	
	P(T<=t) one-tail	0.117112	
	t Critical one-tail	1.655076	
	P(T<=t) two-tail	0.234224	
	t Critical two-tail	1.975905	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 2 and Model 7 assuming unequal variances – case 1, disconnected systems

Family		Model 2	Model 7
Family 1	Mean	99.70663	86.36117
	Variance	1337.748	1012.903
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	194	
	t Stat	2.752577	
	P(T<=t) one-tail	0.003237	
	t Critical one-tail	1.652746	
	P(T<=t) two-tail	0.006474	
	t Critical two-tail	1.972267	
Family 2	Mean	1563.946	1425.427
	Variance	150828.8	108909.2
	df	193	
	t Stat	2.717949	
	P(T<=t) one-tail	0.003583	
	t Critical one-tail	1.652787	
	P(T<=t) two-tail	0.007167	
	t Critical two-tail	1.972332	
Family 3	Mean	1267.131	1442.675
	Variance	178673.9	1344601
	df	125	
	t Stat	-1.42232	
	P(T<=t) one-tail	0.078712	
	t Critical one-tail	1.657135	
	P(T<=t) two-tail	0.157423	
	t Critical two-tail	1.979124	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 3 and Model 4 assuming unequal variances – case 1, disconnected systems

Family		Model 3	Model 4
Family 1	Mean	27.24505	35.14152
	Variance	65.14405	448.3888
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	127	
	t Stat	-3.48457	
	P(T<=t) one-tail	0.000339	
	t Critical one-tail	1.65694	
	P(T<=t) two-tail	0.000677	
	t Critical two-tail	1.97882	
Family 2	Mean	46.93433	49.66022
	Variance	88.30738	328.198
	df	149	
	t Stat	-1.33567	
	P(T<=t) one-tail	0.091847	
	t Critical one-tail	1.655145	
	P(T<=t) two-tail	0.183695	
	t Critical two-tail	1.976013	
Family 3	Mean	83.48585	79.49043
	Variance	5144.79	8067.216
	df	189	
	t Stat	0.347599	
	P(T<=t) one-tail	0.364264	
	t Critical one-tail	1.652956	
	P(T<=t) two-tail	0.728528	
	t Critical two-tail	1.972595	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 3 and Model 4 assuming unequal variances – case 1, disconnected systems

Family		Model 3	Model 4
Family 1	Mean	86.36117	111.2746
	Variance	1012.903	2580.586
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	166	
	t Stat	-4.156	
	P(T<=t) one-tail	2.59E-05	
	t Critical one-tail	1.654085	
	P(T<=t) two-tail	5.18E-05	
	t Critical two-tail	1.974358	
Family 2	Mean	1425.427	1667.293
	Variance	108909.2	305735.9
	df	162	
	t Stat	-3.75609	
	P(T<=t) one-tail	0.00012	
	t Critical one-tail	1.654314	
	P(T<=t) two-tail	0.00024	
	t Critical two-tail	1.974716	
Family 3	Mean	1442.675	1409.316
	Variance	1344601	2484191
	df	182	
	t Stat	0.170483	
	P(T<=t) one-tail	0.43241	
	t Critical one-tail	1.653269	
	P(T<=t) two-tail	0.864819	
	t Critical two-tail	1.973084	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 3 and Model 6 assuming unequal variances – case 1, disconnected systems

Family		Model 3	Model 6
Family 1	Mean	27.24505	31.88865
	Variance	65.14405	91.51185
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	193	
	t Stat	-3.71006	
	P(T<=t) one-tail	0.000135	
	t Critical one-tail	1.652787	
	P(T<=t) two-tail	0.000271	
	t Critical two-tail	1.972332	
Family 2	Mean	46.93433	51.17741
	Variance	88.30738	102.8929
	df	197	
	t Stat	-3.06858	
	P(T<=t) one-tail	0.001227	
	t Critical one-tail	1.652625	
	P(T<=t) two-tail	0.002454	
	t Critical two-tail	1.972079	
Family 3	Mean	83.48585	73.80529
	Variance	5144.79	1322.475
	df	147	
	t Stat	1.203761	
	P(T<=t) one-tail	0.115308	
	t Critical one-tail	1.655285	
	P(T<=t) two-tail	0.230617	
	t Critical two-tail	1.976233	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 3 and Model 6 assuming unequal variances – case 1, disconnected systems

Family		Model 3	Model 6
Family 1	Mean	86.36117	97.46335
	Variance	1012.903	1323.951
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	195	
	t Stat	-2.29664	
	P(T<=t) one-tail	0.011351	
	t Critical one-tail	1.652705	
	P(T<=t) two-tail	0.022702	
	t Critical two-tail	1.972204	
Family 2	Mean	1425.427	1555.348
	Variance	108909.2	142480.4
	df	195	
	t Stat	-2.59124	
	P(T<=t) one-tail	0.005143	
	t Critical one-tail	1.652705	
	P(T<=t) two-tail	0.010286	
	t Critical two-tail	1.972204	
Family 3	Mean	1442.675	1273.615
	Variance	1344601	186178.4
	df	126	
	t Stat	1.366424	
	P(T<=t) one-tail	0.08712	
	t Critical one-tail	1.657037	
	P(T<=t) two-tail	0.174239	
	t Critical two-tail	1.978971	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 3 and Model 7 assuming unequal variances – case 1, disconnected systems

Family		Model 3	Model 7
Family 1	Mean	27.24505	26.81497
	Variance	65.14405	67.12228
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	198	
	t Stat	0.37396	
	P(T<=t) one-tail	0.354417	
	t Critical one-tail	1.652586	
	P(T<=t) two-tail	0.708834	
	t Critical two-tail	1.972017	
Family 2	Mean	46.93433	45.91316
	Variance	88.30738	146.2002
	df	187	
	t Stat	0.666837	
	P(T<=t) one-tail	0.252849	
	t Critical one-tail	1.653043	
	P(T<=t) two-tail	0.505698	
	t Critical two-tail	1.972731	
Family 3	Mean	83.48585	78.06285
	Variance	5144.79	11933.96
	df	171	
	t Stat	0.414965	
	P(T<=t) one-tail	0.339344	
	t Critical one-tail	1.653813	
	P(T<=t) two-tail	0.678688	
	t Critical two-tail	1.973934	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 3 and Model 7 assuming unequal variances – case 1, disconnected systems

Family		Model 3	Model 7
Family 1	Mean	86.36117	80.34373
	Variance	1012.903	707.085
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	192	
	t Stat	1.450939	
	P(T<=t) one-tail	0.074214	
	t Critical one-tail	1.652829	
	P(T<=t) two-tail	0.148429	
	t Critical two-tail	1.972396	
Family 2	Mean	1425.427	1380.771
	Variance	108909.2	123445.5
	df	197	
	t Stat	0.926414	
	P(T<=t) one-tail	0.177682	
	t Critical one-tail	1.652625	
	P(T<=t) two-tail	0.355364	
	t Critical two-tail	1.972079	
Family 3	Mean	1442.675	1532.792
	Variance	1344601	9795447
	df	126	
	t Stat	-0.27	
	P(T<=t) one-tail	0.393801	
	t Critical one-tail	1.657037	
	P(T<=t) two-tail	0.787602	
	t Critical two-tail	1.978971	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 4 and Model 6 assuming unequal variances – case 1, disconnected systems

Family		Model 4	Model 6
Family 1	Mean	35.14152	31.88865
	Variance	448.3888	91.51185
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	138	
	t Stat	1.399941	
	P(T<=t) one-tail	0.081888	
	t Critical one-tail	1.65597	
	P(T<=t) two-tail	0.163775	
	t Critical two-tail	1.977304	
Family 2	Mean	49.66022	51.17741
	Variance	328.198	102.8929
	df	156	
	t Stat	-0.73073	
	P(T<=t) one-tail	0.233021	
	t Critical one-tail	1.65468	
	P(T<=t) two-tail	0.466042	
	t Critical two-tail	1.975287	
Family 3	Mean	79.49043	73.80529
	Variance	8067.216	1322.475
	df	131	
	t Stat	0.586699	
	P(T<=t) one-tail	0.279208	
	t Critical one-tail	1.656569	
	P(T<=t) two-tail	0.558415	
	t Critical two-tail	1.978239	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 4 and Model 6 assuming unequal variances – case 1, disconnected systems

Family		Model 4	Model 6
Family 1	Mean	111.2746	97.46335
	Variance	2580.586	1323.951
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	179	
	t Stat	2.210289	
	P(T<=t) one-tail	0.014176	
	t Critical one-tail	1.653411	
	P(T<=t) two-tail	0.028353	
	t Critical two-tail	1.973305	
Family 2	Mean	1667.293	1555.348
	Variance	305735.9	142480.4
	df	175	
	t Stat	1.672086	
	P(T<=t) one-tail	0.048147	
	t Critical one-tail	1.653607	
	P(T<=t) two-tail	0.096294	
	t Critical two-tail	1.973612	
Family 3	Mean	1409.316	1273.615
	Variance	2484191	186178.4
	df	114	
	t Stat	0.830422	
	P(T<=t) one-tail	0.204018	
	t Critical one-tail	1.65833	
	P(T<=t) two-tail	0.408036	
	t Critical two-tail	1.980992	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 4 and Model 7 assuming unequal variances – case 1, disconnected systems

Family		Model 4	Model 7
Family 1	Mean	35.14152	26.81497
	Variance	448.3888	67.12228
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	128	
	t Stat	3.667297	
	P(T<=t) one-tail	0.000179	
	t Critical one-tail	1.656845	
	P(T<=t) two-tail	0.000358	
	t Critical two-tail	1.978671	
Family 2	Mean	49.66022	45.91316
	Variance	328.198	146.2002
	df	173	
	t Stat	1.720359	
	P(T<=t) one-tail	0.043578	
	t Critical one-tail	1.653709	
	P(T<=t) two-tail	0.087155	
	t Critical two-tail	1.973771	
Family 3	Mean	79.49043	78.06285
	Variance	8067.216	11933.96
	df	191	
	t Stat	0.100942	
	P(T<=t) one-tail	0.459851	
	t Critical one-tail	1.652871	
	P(T<=t) two-tail	0.919702	
	t Critical two-tail	1.972462	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 4 and Model 7 assuming unequal variances – case 1, disconnected systems

Family		Model 4	Model 7
Family 1	Mean	111.2746	80.34373
	Variance	2580.586	707.085
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	149	
	t Stat	5.394465	
	P(T<=t) one-tail	1.32E-07	
	t Critical one-tail	1.655145	
	P(T<=t) two-tail	2.64E-07	
	t Critical two-tail	1.976013	
Family 2	Mean	1667.293	1380.771
	Variance	305735.9	123445.5
	df	168	
	t Stat	4.373585	
	P(T<=t) one-tail	1.07E-05	
	t Critical one-tail	1.653974	
	P(T<=t) two-tail	2.14E-05	
	t Critical two-tail	1.974185	
Family 3	Mean	1409.316	1532.792
	Variance	2484191	9795447
	df	146	
	t Stat	-0.35236	
	P(T<=t) one-tail	0.362537	
	t Critical one-tail	1.655357	
	P(T<=t) two-tail	0.725075	
	t Critical two-tail	1.976346	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 6 and Model 7 assuming unequal variances – case 1, disconnected systems

Family		Model 6	Model 7
Family 1	Mean	31.88865	26.81497
	Variance	91.51185	67.12228
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	193	
	t Stat	4.028327	
	P(T<=t) one-tail	4.04E-05	
	t Critical one-tail	1.652787	
	P(T<=t) two-tail	8.07E-05	
	t Critical two-tail	1.972332	
Family 2	Mean	51.17741	45.91316
	Variance	102.8929	146.2002
	df	192	
	t Stat	3.33546	
	P(T<=t) one-tail	0.000511	
	t Critical one-tail	1.652829	
	P(T<=t) two-tail	0.001022	
	t Critical two-tail	1.972396	
Family 3	Mean	73.80529	78.06285
	Variance	1322.475	11933.96
	df	121	
	t Stat	-0.36978	
	P(T<=t) one-tail	0.356095	
	t Critical one-tail	1.657544	
	P(T<=t) two-tail	0.71219	
	t Critical two-tail	1.979764	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 6 and Model 7 assuming unequal variances – case 1, disconnected systems

Family		Model 6	Model 7
Family 1	Mean	97.46335	80.34373
	Variance	1323.951	707.085
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	181	
	t Stat	3.798703	
	P(T<=t) one-tail	9.92E-05	
	t Critical one-tail	1.653316	
	P(T<=t) two-tail	0.000198	
	t Critical two-tail	1.973157	
Family 2	Mean	1555.348	1380.771
	Variance	142480.4	123445.5
	df	197	
	t Stat	3.385386	
	P(T<=t) one-tail	0.000429	
	t Critical one-tail	1.652625	
	P(T<=t) two-tail	0.000858	
	t Critical two-tail	1.972079	
Family 3	Mean	1273.615	1532.792
	Variance	186178.4	9795447
	df	103	
	t Stat	-0.82034	
	P(T<=t) one-tail	0.206957	
	t Critical one-tail	1.659782	
	P(T<=t) two-tail	0.413914	
	t Critical two-tail	1.983264	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 1A and Model 2 assuming unequal variances – case 1, disconnected systems

Family		Model 1A	Model 2
Family 1	Mean	31.19106	32.55187
	Variance	184.2219	93.74068
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	179	
	t Stat	-0.81621	
	P(T<=t) one-tail	0.207731	
	t Critical one-tail	1.653411	
	P(T<=t) two-tail	0.415462	
	t Critical two-tail	1.973305	
Family 2	Mean	54.39673	51.62108
	Variance	353.7324	111.8879
	df	156	
	t Stat	1.286319	
	P(T<=t) one-tail	0.100119	
	t Critical one-tail	1.65468	
	P(T<=t) two-tail	0.200237	
	t Critical two-tail	1.975287	
Family 3	Mean	71.61304	73.79538
	Variance	3004.617	1438.173
	df	176	
	t Stat	-0.32741	
	P(T<=t) one-tail	0.371873	
	t Critical one-tail	1.653557	
	P(T<=t) two-tail	0.743745	
	t Critical two-tail	1.973534	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 1A and Model 2 assuming unequal variances – case 1, disconnected systems

Family		Model 1A	Model 2
Family 1	Mean	100.4955	99.70663
	Variance	3288.948	1337.748
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	166	
	t Stat	0.115566	
	P(T<=t) one-tail	0.454068	
	t Critical one-tail	1.654085	
	P(T<=t) two-tail	0.908136	
	t Critical two-tail	1.974358	
Family 2	Mean	1625.428	1563.946
	Variance	245860.3	150828.8
	df	0	
	t Stat	185	
	P(T<=t) one-tail	0.973126	
	t Critical one-tail	0.165881	
	P(T<=t) two-tail	1.653132	
	t Critical two-tail	0.331762	
Family 3	Mean	1184.107	1267.131
	Variance	88653.95	178673.9
	df	178	
	t Stat	-1.60307	
	P(T<=t) one-tail	0.055347	
	t Critical one-tail	1.653459	
	P(T<=t) two-tail	0.110693	
	t Critical two-tail	1.973381	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 1A and Model 3 assuming unequal variances – case 1, disconnected systems

Family		Model 1A	Model 3
Family 1	Mean	31.19106	27.24505
	Variance	184.2219	65.14405
	Observations	100	100
	Hypothesized Mean Difference	161	
	df	2.498846	
	t Stat	0.006731	
	P(T<=t) one-tail	1.654373	
	t Critical one-tail	0.013463	
	P(T<=t) two-tail	1.974808	
	t Critical two-tail	161	
Family 2	Mean	54.39673	46.93433
	Variance	353.7324	88.30738
	df	146	
	t Stat	3.549342	
	P(T<=t) one-tail	0.00026	
	t Critical one-tail	1.655357	
	P(T<=t) two-tail	0.00052	
	t Critical two-tail	1.976346	
Family 3	Mean	71.61304	83.48585
	Variance	3004.617	5144.79
	df	185	
	t Stat	-1.3152	
	P(T<=t) one-tail	0.095036	
	t Critical one-tail	1.653132	
	P(T<=t) two-tail	0.190072	
	t Critical two-tail	1.97287	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 1A and Model 3 assuming unequal variances – case 1, disconnected systems

Family		Model 1A	Model 3
Family 1	Mean	100.4955	86.36117
	Variance	3288.948	1012.903
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	153	
	t Stat	2.146732	
	P(T<=t) one-tail	0.016695	
	t Critical one-tail	1.654874	
	P(T<=t) two-tail	0.033391	
	t Critical two-tail	1.97559	
Family 2	Mean	1625.428	1425.427
	Variance	245860.3	108909.2
	df	170	
	t Stat	3.346142	
	P(T<=t) one-tail	0.000504	
	t Critical one-tail	1.653866	
	P(T<=t) two-tail	0.001009	
	t Critical two-tail	1.974017	
Family 3	Mean	1184.107	1442.675
	Variance	88653.95	1344601
	df	112	
	t Stat	-2.15912	
	P(T<=t) one-tail	0.016487	
	t Critical one-tail	1.658573	
	P(T<=t) two-tail	0.032974	
	t Critical two-tail	1.981372	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 1A and Model 4 assuming unequal variances – case 1, disconnected systems

Family		Model 1A	Model 4
Family 1	Mean	31.19106	35.14152
	Variance	184.2219	448.3888
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	169	
	t Stat	-1.57065	
	P(T<=t) one-tail	0.059067	
	t Critical one-tail	1.65392	
	P(T<=t) two-tail	0.118134	
	t Critical two-tail	1.9741	
Family 2	Mean	54.39673	49.66022
	Variance	353.7324	328.198
	df	198	
	t Stat	1.813796	
	P(T<=t) one-tail	0.035612	
	t Critical one-tail	1.652586	
	P(T<=t) two-tail	0.071223	
	t Critical two-tail	1.972017	
Family 3	Mean	71.61304	79.49043
	Variance	3004.617	8067.216
	df	164	
	t Stat	-0.74864	
	P(T<=t) one-tail	0.227574	
	t Critical one-tail	1.654198	
	P(T<=t) two-tail	0.455147	
	t Critical two-tail	1.974535	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 1A and Model 4 assuming unequal variances – case 1, disconnected systems

Family		Model 1A	Model 4
Family 1	Mean	100.4955	111.2746
	Variance	3288.948	2580.586
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	194	
	t Stat	-1.40299	
	P(T<=t) one-tail	0.081109	
	t Critical one-tail	1.652746	
	P(T<=t) two-tail	0.162218	
	t Critical two-tail	1.972267	
Family 2	Mean	1625.428	1667.293
	Variance	245860.3	305735.9
	df	195	
	t Stat	-0.56242	
	P(T<=t) one-tail	0.287237	
	t Critical one-tail	1.652705	
	P(T<=t) two-tail	0.574474	
	t Critical two-tail	1.972204	
Family 3	Mean	1184.107	1409.316
	Variance	88653.95	2484191
	df	106	
	t Stat	-1.40379	
	P(T<=t) one-tail	0.081652	
	t Critical one-tail	1.659356	
	P(T<=t) two-tail	0.163304	
	t Critical two-tail	1.982597	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 1A and Model 6 assuming unequal variances – case 1, disconnected systems

Family		Model 1A	Model 4
Family 1	Mean	31.19106	31.88865
	Variance	184.2219	91.51185
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	178	
	t Stat	-0.4201	
	P(T<=t) one-tail	0.337459	
	t Critical one-tail	1.653459	
	P(T<=t) two-tail	0.674917	
	t Critical two-tail	1.973381	
Family 2	Mean	54.39673	51.17741
	Variance	353.7324	102.8929
	df	152	
	t Stat	1.506552	
	P(T<=t) one-tail	0.067	
	t Critical one-tail	1.65494	
	P(T<=t) two-tail	0.134001	
	t Critical two-tail	1.975694	
Family 3	Mean	71.61304	73.80529
	Variance	3004.617	1322.475
	df	172	
	t Stat	-0.33327	
	P(T<=t) one-tail	0.369669	
	t Critical one-tail	1.653761	
	P(T<=t) two-tail	0.739339	
	t Critical two-tail	1.973852	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 1A and Model 6 assuming unequal variances – case 1, disconnected systems

Family		Model 1A	Model 6
Family 1	Mean	100.4955	97.46335
	Variance	3288.948	1323.951
	Observations	99	100
	Hypothesized Mean Difference	0	
	df	166	
	t Stat	0.444845	
	P(T<=t) one-tail	0.328505	
	t Critical one-tail	1.654085	
	P(T<=t) two-tail	0.657011	
	t Critical two-tail	1.974358	
Family 2	Mean	1625.428	1555.348
	Variance	245860.3	142480.4
	df	183	
	t Stat	1.120987	
	P(T<=t) one-tail	0.131881	
	t Critical one-tail	1.653223	
	P(T<=t) two-tail	0.263762	
	t Critical two-tail	1.973012	
Family 3	Mean	1184.107	1273.615
	Variance	88653.95	186178.4
	df	176	
	t Stat	-1.70458	
	P(T<=t) one-tail	0.045018	
	t Critical one-tail	1.653557	
	P(T<=t) two-tail	0.090037	
	t Critical two-tail	1.973534	

T-test for Family 1, Family 2, and, Family 3 flowtimes for Model 1A and Model 7 assuming unequal variances – case 1, disconnected systems

Family		Model 1A	Model 7
Family 1	Mean	31.19106	26.81497
	Variance	184.2219	67.12228
	Observations	100	100
	Hypothesized Mean Difference	163	
	df	2.760272	
	t Stat	0.003219	
	P(T<=t) one-tail	1.654256	
	t Critical one-tail	0.006437	
	P(T<=t) two-tail	1.974625	
	t Critical two-tail	163	
Family 2	Mean	54.39673	45.91316
	Variance	353.7324	146.2002
	df	169	
	t Stat	3.794224	
	P(T<=t) one-tail	0.000103	
	t Critical one-tail	1.65392	
	P(T<=t) two-tail	0.000206	
	t Critical two-tail	1.9741	
Family 3	Mean	71.61304	78.06285
	Variance	3004.617	11933.96
	df	146	
	t Stat	-0.52771	
	P(T<=t) one-tail	0.299252	
	t Critical one-tail	1.655357	
	P(T<=t) two-tail	0.598504	
	t Critical two-tail	1.976346	

T-test for Family 1, Family 2, and, Family 3 work in process for Model 1A and Model 7 assuming unequal variances – case 1, disconnected systems

Family		Model 1A	Model 7
Family 1	Mean	100.4955	80.34373
	Variance	3288.948	707.085
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	138	
	t Stat	3.174691	
	P(T<=t) one-tail	0.000925	
	t Critical one-tail	1.65597	
	P(T<=t) two-tail	0.00185	
	t Critical two-tail	1.977304	
Family 2	Mean	1625.428	1380.771
	Variance	245860.3	123445.5
	df	176	
	t Stat	4.012449	
	P(T<=t) one-tail	4.44E-05	
	t Critical one-tail	1.653557	
	P(T<=t) two-tail	8.88E-05	
	t Critical two-tail	1.973534	
Family 3	Mean	1184.107	1532.792
	Variance	88653.95	9795447
	df	101	
	t Stat	-1.10903	
	P(T<=t) one-tail	0.135025	
	t Critical one-tail	1.660081	
	P(T<=t) two-tail	0.27005	
	t Critical two-tail	1.983731	

T-test for Family 1, Family 2, Family 3, and overall finished goods inventory for connected and disconnected systems assuming unequal variances – case 2

Family		Connected System	Disconnected System
Family 1	Mean	5624.472	5280.597
	Variance	415027.2	257563.3
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	188	
	t Stat	-4.193	
	P(T<=t) one-tail	2.12E-05	
	t Critical one-tail	1.652999	
	P(T<=t) two-tail	4.24E-05	
	t Critical two-tail	1.972663	
Family 2	Mean	12676.09	14815.36
	Variance	531571.3	436606.2
	t Stat	196	
	df	21.74139	
	P(T<=t) one-tail	1.99E-54	
	t Critical one-tail	1.652665	
	P(T<=t) two-tail	3.97E-54	
	t Critical two-tail	1.972141	
Family 3	Mean	15163.73	4349.403
	Variance	894511.1	484481.5
	df	182	
	t Stat	-92.0913	
	P(T<=t) one-tail	6.5E-155	
	t Critical one-tail	1.653269	
	P(T<=t) two-tail	1.3E-154	
	t Critical two-tail	1.973084	
Overall	Mean	33464.29	24445.36
	Variance	1785650	1317049
	df	194	
	t Stat	-51.2018	
	P(T<=t) one-tail	6E-115	
	t Critical one-tail	1.652746	
	P(T<=t) two-tail	1.2E-114	
	t Critical two-tail	1.972267	

T-test for Family 1, Family 2, Family 3, and overall work in process inventory for connected and disconnected systems assuming unequal variances – case 2

Family		Connected System	Disconnected System
Family 1	Mean	55.127	601.971
	Variance	44.41936	22097.43
	Observations	100	100
	Hypothesized Mean Difference	0	
	df	99	
	t Stat	36.74993	
	P(T<=t) one-tail	8.31E-60	
	t Critical one-tail	1.660391	
	P(T<=t) two-tail	1.66E-59	
	t Critical two-tail	1.984217	
Family 2	Mean	184.09	1148.254
	Variance	39.49687	54994.33
	t Stat	99	
	df	41.09945	
	P(T<=t) one-tail	2.53E-64	
	t Critical one-tail	1.660391	
	P(T<=t) two-tail	5.07E-64	
	t Critical two-tail	1.984217	
Family 3	Mean	547.956	261.48
	Variance	88823.63	23.58545
	df	99	
	t Stat	9.61095	
	P(T<=t) one-tail	3.86E-16	
	t Critical one-tail	1.660391	
	P(T<=t) two-tail	7.72E-16	
	t Critical two-tail	1.984217	
Overall	Mean	2298.181	547.956
	Variance	144677.9	88823.63
	df	99	
	t Stat	47.2511	
	P(T<=t) one-tail	4.96E-70	
	t Critical one-tail	1.660391	
	P(T<=t) two-tail	9.92E-70	
	t Critical two-tail	1.984217	