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Design and analysis of meal assembly and delivery methods in hospital foodservice systems

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DESIGN AND ANALYSIS OF MEAL ASSEMBLY AND DELIVERY METHODS IN HOSPITAL FOODSERVICE SYSTEMS

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Design and Analysis of Meal Assembly and Delivery Methods in Hospital Foodservice Systems

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Abstract

Foodservice systems are a necessary and integral part of virtually every hospital. Although hospital foodservice is not the primary function hospitals perform, the foodservice system is a significant part of a hospital's operating budget and floor space, and as a result, should be operated in an optimal way. The main objective of this thesis is to determine the best foodservice system for alternative hospital configurations focusing on the tray assembly and ordering/delivery methods used in providing meals to patients. Four main factors are evaluated at two different levels for each factor using a full factorial experiment. These four factors are hospital size, tray assembly method, ordering and delivery system, and the type of menu offered. A detailed experiment and analysis is performed using simulation modeling to accurately evaluate the alternative hospital configurations. Other industrial engineering tools are used in the creation and analysis of alternative foodservice systems including lean manufacturing concepts. The alternative foodservice systems are compared based on system performance that includes measures of timeliness, productivity, and patient satisfaction. In addition, this thesis examines the foodservice system in a local hospital, F.F. Thompson Hospital, and applies the results of the experiments to provide a recommendation for implementing a new foodservice system. The final result provides hospitals with a basis for establishing a foodservice system that meets the needs of hospitals and their patients.

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1 Introduction

In the United States, hospitals serve patients over 2 million meals per day in addition to meals provided to hospital personnel and visitors. The cost of providing these meals can account for 3-5% of a hospital's overall budget. There are currently 4,908 community hospitals in the United States (AHA 2003), therefore, taken at the national level, a conservative estimate of hospital foodservice costs is over $4 billion per year. Furthermore, an average size hospital kitchen and cafeteria can occupy 2–5% of a hospital's floor space. Clearly, hospital foodservice is a significant aspect of hospital operations. However, since foodservice is not the primary function of a hospital, efforts to study and improve foodservice systems in hospitals are often overlooked. In this thesis, foodservice systems are analyzed in order to draw conclusions about the operational aspects of the system.

A hospital foodservice system consists of preparing food for hospital patients as well as hospital cafeteria patrons (doctors, nurses, staff, and visitors). Figure 1.1 illustrates the components of a foodservice system in a hospital. Conceptually, the cafeteria and patient meals components of the foodservice system can be considered separately since the food prepared for patients is, in general, different from food served in the cafeteria. (Patient food is prepared to meet medical and nutritional requirements and would not sell well in the cafeteria.) The focus of this thesis is the patient meals component of the foodservice system. The patient meals component can be broken down into preparation and serving methods. Meal preparation involves making a variety of food in large quantities. In many hospitals, the staff that prepares the cafeteria food and the staff that prepares the patient meals are one and the same. The equipment is commonly shared; therefore a large amount of planning must be done to organize the utilization of the equipment and labor for each meal. The serving methods for patient meals

include the process of taking patient meal orders, assembling them on trays, and then delivering the meals to the patients. Since the food preparation requirements are primarily determined by the menu items for a particular meal, food preparation methods are beyond the scope of this work. The focus of this thesis is on the operational issues involved in serving meals to hospital patients.

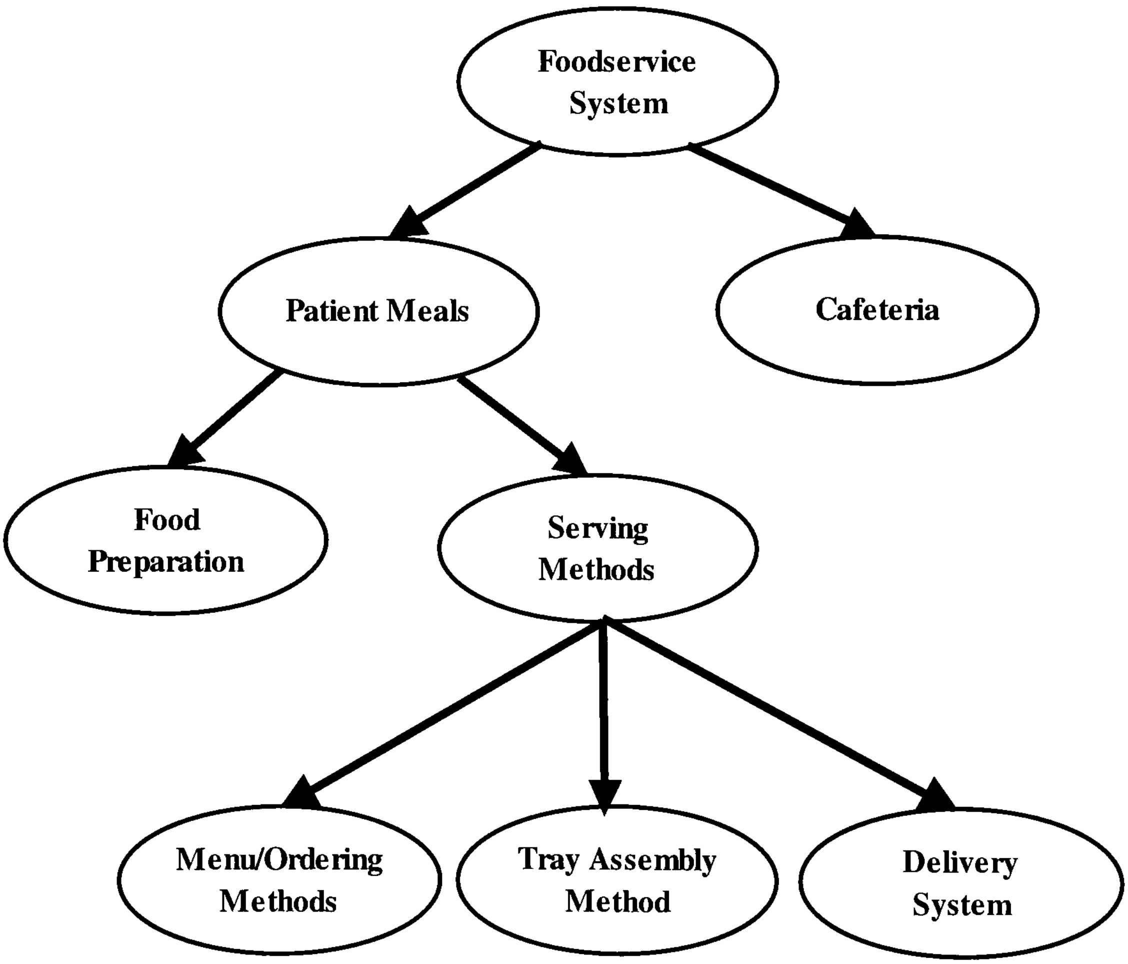

Figure 1.1: Components of a Foodservice System

The first major operational issue the foodservice system must deal with in terms of serving meals to patients is the method of ordering and delivery that is used. In terms of placing an order, the hospital generally provides the patient with a menu and the patient chooses what they would like to eat. The menus are collected from the patients and the information is input into a computer. The patient's selections are then examined by a dietician to verify that the patient has ordered items that will not violate any dietary restrictions placed on the patient by the physician. Once the menus are approved, the menus are printed out on cards, organized into the order in which the meals will be delivered, and then placed at the start of the assembly system and used to assemble the tray of each patient.

The second major operational issue the foodservice system must contend with is the assembly method that is used to prepare the trays in terms of placing the food items, utensils, and other dining needs, onto the tray and arranging the tray for delivery to the patients. When selecting the assembly system, it is important to consider the amount of floor space that the assembly method will require, the number of employees needed, the equipment needed, and the time required to assemble the trays.

The assembly system feeds into the delivery system. The delivery system encompasses the method and order in which the trays are delivered to the patients. This too, is an important component of the foodservice system in terms of the timeliness and efficiency of delivering the prepared food to the patients.

The foodservice system should be run effectively so that both the patients and executives are satisfied with the outcomes. For the patient, who is in this case the customer, a foodservice system that is run effectively would provide them with quality food in a timely manner. From an executive's point of view, an effective system is one that efficiently utilizes hospital resources

including workers, equipment, and budget, as well as satisfies patients. Therefore, it is important that a hospital foodservice system be organized and operated efficiently.

The effectiveness of a foodservice system can be evaluated based on both quantitative and qualitative performance measures. The quantitative performance measures consist of efficiency measures including productivity, cycle time, make-span, and number of employees needed. Qualitative measures may include a measure such as the visual appearance of the tray. Patient satisfaction is a performance measure that can be evaluated both quantitatively and qualitatively. One method to attempt to quantify aspects of patient satisfaction is to assign a numeric ranking that is equivalent to a qualitative ranking of the customer.

Patient satisfaction is a performance measure whose importance should not be underestimated. One issue that hospital foodservice faces is that they are host to a captive audience. Patients may be unhappy with being in the hospital because they are away from their homes and familiar surroundings and may be experiencing uncomfortable side effects from treatments. Furthermore, patients may experience low morale. Another inherent issue related to hospital foodservice is the fact that dietary and nutritional requirements often times dictate menu selection and food preparation methods which deviate from the usual diet of most patients. As one would expect, a patient's dissatisfaction can be furthered if their meal arrives late, arrives too early, is not hot, is arranged in an unappealing manner, is of low quality, is not what they ordered, etc. The downsides to this dissatisfaction include wasted food and more importantly, slower recovery due to uneaten food needed for nutrition. Hospitals are finding that patients who are eating more of the food on their tray are recovering faster because they are getting the required amount of calories that they need to keep their strength up (Riell, 2001) as illustrated in Figure 1.2.

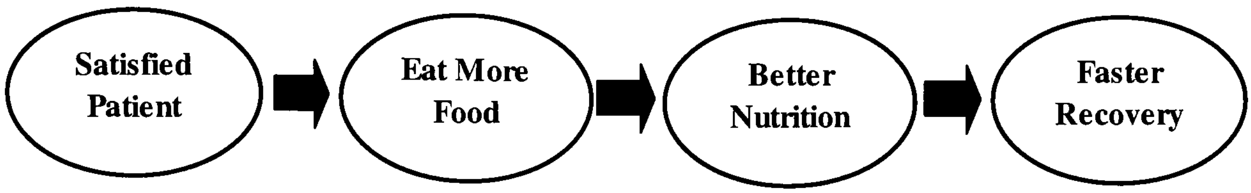

Figure 1.2: Link Between Patient Satisfaction and Recovery

Clearly, foodservice and nutrition are critical to the treatment and recovery of patients. Consequently, hospitals must strive to provide not only high quality nutrition but also strive to provide a high level of service that will result in a high level of satisfaction for patients. Although there are many aspects of the foodservice system that contribute to the overall success of the system, the focus of this work is on the production control aspects of the system including the design and analysis of alternative tray assembly and delivery methods.

There are several factors that can affect the system and must be considered in order to create an efficient system. One of the major factors is the size of the hospital in terms of the number of beds. This factor is strongly correlated with the number of meals the kitchen is expected to produce. Consequently, the meal capacity of the kitchen must at least be able to meet the patient capacity of the hospital. It would be unrealistic to build a hospital with a large number of beds and then not provide the kitchen with enough equipment and labor capacity to meet the hospital's needs. The number of trays that need to be prepared could influence which tray assembly methods should be used. Furthermore, the different tray assembly processes may require different functional specifications such as layouts, methods, and number of workers required. Some of the possible assembly methods could involve an assembly line or a cellular layout.

The other factors that could have an impact on efficiency include: the location of kitchen in regards to all the patient floors, the variety of menu items provided to the patient, the resource capacity, and any constraints in terms of labor and equipment, any menu preparation tasks, the layout of the kitchen, and if the foodservice system chooses to service any outside operations such as long-term care or meals on wheels. Some of these such as location of the kitchen and the variety of menu items could have an impact on the time to deliver the patient trays and the time to assemble the trays, respectively. Other factors such as capacity constraints may also be sensitive to the tray assembly method and affect the amount of time required for a tray to be assembled and delivered to the patient.

The purpose of this thesis is to investigate alternative system configurations for serving meals to patients in hospitals. Furthermore, the results of this work are applied in to the foodservice system at F.F. Thompson Hospital. This study of foodservice systems is based on industrial engineering principles that are rooted in productivity and efficiency. By applying industrial engineering tools such as lean manufacturing concepts and computer simulation, this thesis develops and analyzes alternative foodservice system configurations in an attempt to optimize system performance. Many lean manufacturing concepts can be applied to the foodservice system even though it is not a manufacturing process. Lean manufacturing focuses on one-piece flow, just-in-time, and reduced waste in terms of motions. Computer simulation is a systems analysis tool that allows the analyst to create a model of a system and investigate how the system will perform. One of the main benefits of this is that the actual system remains untouched and unaltered during this design and analysis, which can save a company time and money by not interfering with its day-to-day operations.

2 Problem Statement

The goal of this thesis is to design and evaluate alternative foodservice systems with respect to the order/delivery and tray assembly methods relative to some key performance parameters. These key performance measures are the make-span, cycle time, patient satisfaction, and productivity of the system. The make-span refers to the time required to serve all the patients at a given meal, while cycle time refers to the time required for an individual tray to be assembled and delivered to the patient. Patient satisfaction encompasses several aspects of the system. A patient's perceived satisfaction of the meal will be better if the meal reaches them while the food is still at an appropriate temperature, and if the tray is delivered at a time that the patient prefers to eat. Therefore, in order to meet the desired patient satisfaction, the system must assemble and deliver the trays in an efficient manner. Productivity measures the ability of the system to effectively meet the demand of the system as a function of the time and labor required. Each of these performance measures is used in the analysis to compare alternative system configurations.

To meet this goal, the main objective is to determine the best foodservice system for the alternative hospital configurations; in particular, to determine the best tray assembly, ordering, and delivery methods based on hospital size and menu options. Thus, a four-factor experiment is conducted using the following factors and levels, which are summarized in Table 2.1.

Table 2.1: Four-Factor Experiment

Factor	Factor Levels	
Hospital Size	Small	Large
Tray Assembly Method	Assembly Line	Cellular
Ordering and Delivery System	Traditional	Room Service
Menu Type	Fixed	Choice

For the first factor, hospital size, a comparison is made between hospitals serving a relatively small number of patients per meal (200) with those serving a relatively large number (600). For the second factor, the tray assembly method, an assembly line system where each worker on the line is responsible for placing one category of items on the tray as the tray moves along on a conveyor is considered versus a cellular system where each worker moves around a U-shaped assembly cell to place all items on the tray. For the third factor, the ordering and delivery system, the focus is on the traditional delivery system where trays are delivered to the patients in turn by floor or department versus a room service system where the patient may request the time that their tray will be delivered. Finally the fourth factor, the menu type, compares a fixed or standard menu for all patients with a choice menu where a patient can specify items from a given menu for their meal.

In addition to this experiment, other opportunities for system improvements that have the potential to impact productivity measures, reduce cost, and maintain a high level of customer service are investigated. In particular, the application of lean enterprise techniques is utilized to develop the alternative hospital configurations.

Finally, the analysis is applied to the foodservice system at F.F. Thompson Hospital in Canandaigua, New York. This case study provides the opportunity to verify and validate the results of the experimental performance evaluation and apply the results in a practical setting that is representative of full service hospitals.

3 Literature Review

Having foodservice in hospitals has always been a fundamental aspect of hospital operations. However, the primary focus of research and changes to hospital foodservice systems has been based on nutritional and medical requirements as opposed to productivity issues. Since these issues are not independent, a broad understanding of the operational, nutritional, and medical requirements of the foodservice system is necessary to solve problems relative to productivity.

Therefore, this literature review examines and explains the general aspects of the foodservice system including the quality of foodservice, menus, meal preparation methods, meal delivery and serving methods, and space and resource issues. In addition, simulation, which is used in this thesis to investigate and measure the productivity of hospital foodservice systems, is discussed. In particular, the discussion entailing the use of simulation as applied in the area of health care demonstrates that simulation can be a useful tool to improve operational aspects of health care systems.

3.1 The Quality of Foodservice in Health Care

There are many issues to consider when examining the quality of a foodservice system in a health care environment such as a hospital. Not only is the process of delivering the food to the patient important to quality, but also is the production of the food. Moreover, these two components can affect the quality of the other, and one or both of these processes could have a large impact on the satisfaction of the patient. The goals are to satisfy the patient, but also to make the entire system as efficient as possible. It is important to remember that making something more efficient does not mean that quality has to suffer. In fact, it is imperative that

quality does not suffer and the methods that can be developed to improve efficiency will also focus on improving quality.

The quality of the food can be affected at every stage of the process: meal preparation, assembly, distribution, and service. Quality food can be defined as "...food which has been selected, prepared, and served in such a manner that the food is microbiologically and chemically safe, retains or enhances sensory properties, conserves nutrients, and is acceptable to the customer" (Hospital, 1982). There are some factors that can greatly affect the palatability of the food. One such factor is the ingredient quantity. Some people may think that it is not necessary to maintain strict ingredient quantities when producing food in mass quantities. However, this is not the case. The slight incorrect quantity of ingredients can destroy the palatability of the food. In fact, it has been suggested by some, to have a group of people involved in the production process that are in charge of weighing, packaging, and labeling all the ingredients (Pinkert, 1973). These aspects of quality focus on the meal preparation. Quality is also important in the assembly and distribution of the trays. Quality present in the assembly portion is the presentation of the food on the tray as well as the correct content of food on the tray. An "orderly and neat presentation of the food on the plate suggests to the patient that the food is clean and has been carefully handled" (Hospital, 1982). The presence of quality in the distribution of the trays is in the time it takes for the tray to reach the patient once the tray has been completed on the assembly portion of the system. It is important to deliver the trays as efficiently as possible so that the food maintains the proper temperature, thus maintaining the quality of the food. Another portion of the tray distribution that can affect the patient's perceived quality of the meal is the disposition of the employee delivering the tray. All of these components of the foodservice system are related to quality.

3.2 Hospital Menus for Patient Meals

There are several decisions that hospital foodservice managers must make regarding the menu that they plan to offer to their patients. One must consider the meal pattern of the hospital and the type of menu to offer to the patients, all while considering the many diet varieties that must be accommodated in the hospital environment. The options commonly used with each of these components are described in detail in the following subsections.

3.2.1 Meal and Menu Patterns

The selection of daily menus can be influenced greatly by the meal pattern that the hospital uses. There are a variety of meal patterns, therefore, it is important for each hospital to choose which pattern best fits their needs. Some of the factors that must be considered when selecting a meal pattern are resource availability of labor and equipment, the skills and abilities of the personnel, equipment utilization, and also foodservice regulations. One such regulation by the Joint Commission of the Accreditation of Hospitals is that not more than 15 hours elapse between meals (Hospital, 1982). This is most pertinent for the time between dinner and breakfast. Generally, hospitals use a three-meal plan. The hospital offers the three main meals: breakfast, lunch and dinner. This is the normal pattern that most people are accustomed to and so it is most likely what the patients will be expecting. Serving three meals a day could span at least nine hours plus the preparation before the first meal and the clean up after the last meal. Therefore, two groups of employees will be required for this meal pattern. Some hospitals serve three meals a day but serve a large meal in the middle of the day and a lighter meal in the evening.

However, some hospitals have meal plans that consist of four or five meals a day. A four-meal plan consists of a continental breakfast in the early morning, brunch, a main meal in the late afternoon, and a substantial snack in the evening. A five-meal plan consists of an early continental breakfast, a midmorning brunch, a light early afternoon refreshment, a main meal in the late afternoon, and an evening snack (Miller, 1988). These meal patterns are associated with the conventional cooking method. Hence, the benefits of having the more substantial meals, a brunch and a main meal in the afternoon, with either plan, the labor is effectively utilized because a larger number of employees are usually working during the day when both of these meals will occur. Therefore, with lighter meals in the evening, a smaller staff may be used, thus saving money.

In terms of generating the actual menus that are to be used, most hospitals create a plethora of recipes and then use these recipes to plan the menus. These recipes must be in accordance with the American Dietary Association regulations in terms of the dietary requirements. So, by creating the recipes one time and then using them repeatedly, the hospitals are certain that the recipes are within standards and do not have to spend time continuously checking the dietary components of each recipe. Many hospitals now have software packages that allow them to input the recipes into a program that will generate the menus, taking into account the dietary requirements. Hospital foodservice departments must also make a decision of how many days will be in the menu cycle rotation. It is generally a good idea to use an eight-day menu cycle as the least amount of menus. If less days are used, the repetition of the food will be very noticeable to the patients, even those patients who are there for a short stay. One of the prime benefits of an eight-day menu cycle is that it eliminates the association of a particular menu with a certain day of the week (Pinkert, 1973). Therefore, if a patient is in the hospital

longer than a week, he/she will not notice, for example, that roast beef is always served on Mondays and chicken on Tuesdays. An eight-day menu cycle can be sufficient, however it is wise to use a longer menu cycle so that patients are not bored of the food. Some hospitals use as many as twenty-eight days in a menu cycle. This gives both the kitchen staff and the patients a good variety in the food. The disadvantage of this, of course, is that the generation of more recipes is required.

3.2.2 Fixed vs. Choice Menus

There are two classifications of menus that are offered to the patients: choice and fixed. A choice menu consists of the patient selecting among several items within each menu category. In general, the patient will make the selection from the menu which is verified by a nutritionist prior to delivery. The menu usually provides the patient with the choice between a hot and a cold entrée, soup or salad, choice of beverage(s), and choice of dessert. In some hospitals, an alternative menu is always available to the patients if they do not prefer the choices of entrées. Although the choice menu requires more variety in the preparation of the food, it has been shown to improve patient satisfaction (Ovenshire, 2003).

A fixed menu is one in which the patients are all served the same menu with the only variation in preparation being in the diets that the doctors have prescribed. The benefit of a fixed menu is that the kitchen only has to prepare one basic meal and then alter it into the appropriate diet forms, such as purée. A disadvantage of this menu type, though, is that patients may not be satisfied with their food being chosen for them or with the food that is served. Therefore, the patients' perception of the quality of the food is likely to be negatively biased.

3.2.3 Dietary Requirements

Every hospital faces the issue of generating a variety of diets for its patients based on their medical needs. In some instances, there can be more than 80 different diet varieties (Ovenshire, 2003). One cause of this is that purées come in many different consistencies. Each patient's diet is chosen based on their physician's diagnosis. The patients are not always aware of which diet the doctor chooses for them and may be dissatisfied when their food arrives. In some cases, the patient may not even realize that they have been assigned to a low salt diet, for instance, and the patient assuming that they were given a regular meal may attribute its lack of taste to poor quality of the hospital food.

3.3 Meal Preparation Methods

There are two common types of food preparation used in the health care environment. These two methods are conventional and cook-chill. The conventional method is to prepare the food immediately before serving it to the patients. The cook-chill system, though, involves the production of mass quantities of food and then using an extensive freezing process to store the food. These two methods are discussed in further detail in the subsections that follow.

3.3.1 Conventional Food Preparation

The conventional method of preparing food in a foodservice system is to cook the food and then serve the meals immediately to the patients. However, the food may not be immediately served to the patients, as generally hundreds of trays need to be assembled at one meal. Therefore, hospitals, as do other food institutions, utilize equipment that keeps the food at a certain temperature while the trays are being assembled. Some of this equipment could include

heated carts that the entire batch of food will be kept in until placed on the tray, a plate heater that warms the plate up to a high temperature to help the food retain heat, and/or an activated pallet and an insulated plate dome that holds the temperature for 45 minutes to an hour. These heat retention devices are used in conjunction with one another so that by the time the patient receives their meal the food is still hot. Note that these devices retain the heat of the food rather than reheating the food (Hospital, 1982).

There are several benefits of this method. One such benefit is that the food is not wasted because the orders are known as much as twenty-four hours before the meal. This allows the kitchen to prepare what is needed without producing excess that will only be wasted. The quantity of food is forecasted originally so that enough ingredients can be available, but prior to production, the actual quantity is in fact known. Another benefit is that the food is fresh for the patient. The food will not be sitting around or have to be defrosted and reheated from a frozen state. Thus, the palatability of the food is most likely to be maximized. In addition to this, the menus and recipes can consist of fresh fruits or vegetables as opposed to canned or frozen, thus being more appealing and healthier for the patient. The ability to take advantage of the seasonal fruits and vegetables can also make the meals more appetizing (Ovenshire, 2003). However, one of the main disadvantages of this system is that it requires a full staff for the production of each meal. The equipment needed for this method is less than for the Cook-Chill method. The equipment the kitchen requires is the normal production equipment. Additional freezer space is not required for this method because only ingredients and possibly some pre-made purées are kept in the freezer.

3.3.2 Cook-Chill Food Preparation System

A prime example of the Cook-Chill system is the Ready Foods System. The concept of Ready Foods is to produce the food in the hospital in which it will be served in mass quantities and then freeze the food and store it for later use. This improves the efficiency of production because the food can be produced during the normal workday when the largest support of kitchen staff is available. Therefore, on the other shifts, the food can easily be defrosted and reheated. However, the reheating process does not take place in the central kitchen but rather in galleys around the hospital (Pinkert, 1973).

Ready Foods implemented this method to solve several foodservice problems that they identified. These problems are: spread of service periods, peak periods of activity, perishability, palatability, and cost of delivery to patients. The problem with the spread of the service periods is that the workday in many hospital kitchens could span over a 13-to 15-hour period every day of the week. Therefore, the mass production of 3-5 recipes a day rather than smaller quantities of numerous recipes a few times a day, improves the daily workload and decreases the number of people required on the off shifts. Another benefit is that no production personnel have to work weekends, only the service personnel. Reducing the variability in the process and number of recipes also reduces the cost by eliminating the waste of extra material handling and preparation. Because the food is frozen after being produced in mass quantities, perishability is no longer an issue and the palatability is maintained by reheating the food immediately before being served to the patient (Pinkert, 1973).

In order for the mass production of food to be extremely efficient, it is important to carefully plan the production schedule. Several factors should be considered in the planning: preparation time of the food, the equipment needed for preparation, cooking time, the equipment

needed for cooking, the time needed to reheat the food immediately before serving to the patient, and packaging time. An efficient scheduling strategy would be to schedule recipes that do not utilize the same equipment so that no wait time will be encountered during production. In the Ready Foods System, once the food has been produced, the food must be covered with a lid or plastic wrap while the food is still hot. The food will then be frozen using one of the following two techniques: freeze-processing or tunnel freezing. Freeze-processing uses blast freeze cabinets or in the case of smaller hospitals, blast freeze rooms. Tunnel freezing is used for large volumes and involves a conveyor belt "...through a series of chambers, in which vaporization of liquid nitrogen produces a temperature of approximately -320° F" (Pinkert, 1973). Once the food has been completely frozen to 0° F, the food is placed in a holding freezer where the shelf life of Ready Foods is three to six months at a temperature of -10° F. When it is time to defrost the food, a method referred to as tempering is used. This method brings up the temperature of the food to between 34° F and 38°F and usually takes about eight to twenty-four hours to complete. It is important to perform this tempering task prior to reheating the food because the food will heat faster and more evenly. A benefit of this cook-chill method is that food in the tempered state lasts for up to 72 hours (Pinkert, 1973). This makes the system flexible and attempts to minimize food waste.

One of the ways in which this system attempts to minimize the time for tray assembly is that the entrée components are pre-plated at the time of production and then frozen together. However, a disadvantage of this is that it limits the patient's choice. If the entrée sounds appetizing to the patient and he/she selects the entrée, then the patient must also take the pre-plated components.

3.4 Meal Delivery Methods

There are a variety of methods that hospitals can use for the preparation and distribution of their food. The Ready Foods system, mentioned previously, involves producing the food in mass quantities and then using a special freezing system, followed by tempering and reheating of the food when it needs to be served. The other systems are similar, however, with any preparation system, a different distribution system may be employed. With the technology that exists today, there are a variety of carts that can be used to transport the food from the kitchen to the patients while maintaining the temperature of the food.

There are two distinct methods of delivering the trays to the patients: traditional and room service. The traditional system consists of the meals being delivered to the patients in order of location whereas the room service system's order of delivery is determined by window times that are set up in the system. These methods are discussed in the following subsections.

3.4.1 Traditional

The traditional method of delivering meals to patients is the process that most hospitals currently use. This method involves the foodservice staff delivering the trays to the patients by location (perhaps by department or by floor.) Therefore, the trays are assembled by location and loaded onto a cart so that the entire cart is delivered to one location (Ovenshire, 2003).

There are advantages and disadvantages to this system. One of the main advantages is that the delivery time is reduced because traveling to only one location per cart minimizes the distance. A disadvantage though, is that the patient receives the food whenever the kitchen determines. The delivery schedule then is based on location rather than on the patient's choice of meal time. This could cause some patient dissatisfaction because the patient may or may not

be hungry when they receive their meal. However, in logical terms the system makes sense because it is an efficient method of delivering the trays.

3.4.2 Room Service

In the last few years, a number of hospitals have begun to implement a room service type of delivery system. The room service method operates similar to that of a hotel room service system. In fact, some of the hospitals have sought assistance from hotel foodservice employees in implementing the system in the hospital environment. The room service method allows the patients to order their meals when they are hungry and provides them with a diverse menu to choose from. Although some of the specifics differ among the hospitals that are currently using a room service method, the concept is the same. Each hospital provides the patient with a set delivery time, in most cases they guarantee that the meal will be there in 30-45 minutes, however, the average delivery time is closer to 20-25 minutes (Food Quality, 2002). The food is delivered by one of the foodservice employees. In some room service systems, the employees dress in white dress shirts and black vests to make the service seem more elegant like a restaurant or hotel (FSD, 2000). The employees also offer to help the patient pour any of his/her beverages and make sure the patient is satisfied before leaving to deliver the next tray (Service, 2002).

In terms of the ordering process, the patients have a menu in their rooms and they can order their meal by phone. The employees involved in answering the phones are trained in nutrition so that the employee can offer advice to the patient based on the patient's dietary requirements. The patient's information is already input into a computer so that when the patient calls to order, a caller-ID program aids the employee in retrieving the patient's dietary

information. The employee can then check to make sure what the patient is ordering fits their dietary restrictions (if any). If the patient orders something that they are not supposed to eat, the employee can counsel the patient about which items they can eat and provide recommendations (For Patients, 2000). Some of the health care personnel involved in the room service method have commented that this method of ordering by phone allows the hospital to educate the patients on what they should and should not eat. Many of the menu items are normal items that one could order in a restaurant. So, by educating the patients on which foods they should eat and which they should avoid, the hospital is helping to reduce some health risks for the patients and improve their overall diet.

Once the patient orders their food, the order is given to the kitchen to prepare and deliver the food. In most systems, the kitchen will determine a number of trays that should be prepared during a predetermined interval of time and then make the deliveries. The goal is to allow the system to be efficient in the delivery process as well as still meet the delivery window that was promised to the patient.

There are many benefits associated with a room service delivery system, some of which one may not have originally thought. One of the most obvious benefits is increased patient satisfaction. The patients have more control of their meal times as well as their meal choices. This is especially important since patients are in a different environment in which they have very little control over anything and may be experiencing discomfort due to their injury or illness. (University, 2001). The patient satisfaction can also be improved by the interaction between the foodservice employees and the patient in both the ordering method and the delivery process. The menu options also aid in the improved patient satisfaction because the options may be similar to restaurant choices and may also offer a great variety. In some of the systems, a patient can order

any of the food at any time of the day. So, if the patient wants scrambled eggs for dinner, they can have it. This is beneficial especially to cancer patients whose palatability is often affected by their treatments (Entrees, 1999). In addition, hospitals that have implemented a room service system have noticed that patients are eating more of the food on their trays. This can be attributed to the fact that patients can order what they want to eat when they are hungry (90% Made-to-order, 2001). So, the food is appealing to patient when received and more of the food is eaten. This is beneficial for two reasons. The first reason is that patients are receiving more calories, thus keeping their strength up. This aids in the recovery process and hospitals are finding that patients are recovering faster (Riell, 2001).

The other more obvious benefit is that less food is being wasted, thus resulting in savings for the hospitals. The hospitals have then been able to use this money that they are saving to improve other aspects of the system. For instance, one hospital purchased good quality china with a nice design around the perimeter of the plate. This has made the tray arrangement more visually appealing and has reduced the amount of garnishing that needs to be done to improve the look of the tray (Service, 2002). Some hospitals have been able to better quantify adding labor to the room service process by the savings that have resulted from the reduced food waste.

Another benefit is the reduction in lead-time for ordering and a reduction in order processing time. The patient no longer is required to order their meals twenty-four hours in advance. Due to the call center that receives the patients' orders being staffed by nutritionists, the patients' orders can be checked as the orders are being input into the computer resulting in each order being handled only once. Also, as mentioned previously, there is an educational benefit to the order call center. As a dietician stated, "I love the educational side of the program because it

allows the patients to order from a regular menu and learn what they can and cannot enjoy when they are back home in the real world" (For Patients, 2000).

3.5 Hospital Foodservice Issues

There are four main issues that hospitals face: lack of space, lack of resources, budget constraints, and productivity. Most hospitals share the same frustrations in that they are not allotted a large percentage of the floor space of the hospital. In many hospitals, the cafeteria and patient foodservice systems utilize the same equipment and sometimes the same people. This creates difficulties in preparing, assembling and serving the food. Often times, foodservice departments do not receive a generous budget proportion either (Ovenshire, 2003). The reason of course is that foodservice systems in hospitals are often overlooked due to the primary focus of the hospital: to save lives. However, the foodservice system could play a role in the patient's recovery. It may not be a drastic or noticeable difference, but the food that is served can affect the morale of the patient. Another foodservice factor that can affect the patient's recovery is providing them with the correct diet for their diagnosis. The fourth main obstacle that hospital foodservice systems are faced with is productivity. This is logical based on the other concerns. If the system is lacking space, resources, or monetary funds, it will be more challenging to satisfy the daily meal demands.

3.5.1 Discussion of Space Issues

Aside from the issue that not a great deal of space is usually provided for the foodservice operations in a hospital, the output of food from the kitchen is affected by the production space. The amount of space required for the production of the food is different depending on the production system that is used. These are discussed in more detail in the following sections.

3.5.1.1 Conventional System

The conventional production system requires adequate space for any cooking equipment as well as preparation areas and the tray assembly. The amount of ovens and stoves is dependent on the number of meals that need to be produced. The tray assembly area must be large enough to accommodate the entrées, side dishes, condiments and beverages that have to be placed on the trays without causing a large backup on the line (Ovenshire, 2003). This method can be flexible with the amount of space that is provided for the foodservice operations. However, the capacity and utilization of each piece of equipment is important and must be taken into consideration. If at all possible, the preparation system should be designed so that a piece of equipment is not a limiter to the foodservice system in terms of productivity.

3.5.1.2 Cook-Chill

As described earlier, it is apparent that the cook-chill system requires a great deal of space. In addition to the normal amount of space required for production, cook-chill systems require the necessary freezing equipment, a large freezer for storage, and an area for tempering to take place. This could cause a problem for most hospitals since only a small percentage of the hospital floor space is allotted for the kitchen. Because the food must be reheated close to the time of delivery, the food is delivered to galleys on each floor where it is reheated right before it is served to the patient. Therefore, in addition to the space needed for the kitchen and the freezing equipment, extra space is needed for the end-heating process at each floor. This means that the cook-chill system requires a great deal of floor space. However, a trade-off for this increased equipment cost and floor space is that less labor is required since the meals are produced during the standard day shift and only a small service staff is required for the other meals to reheat and deliver the food (Pinkert, 1973).

3.5.2 Contention for Equipment & Resources

Often times the kitchen must be shared for the production of the patients' food and the cafeteria food. In most cases, the menus are different for the patients and the cafeteria patrons. One of the reasons for this is that the healthier foods that are often prepared for the patients do not sell well in the cafeteria. Therefore, the entrées for the patients and the cafeteria will be different. However, in some cases, resource and equipment constraints determine the other menu items. For instance, some hospital kitchens only have one large vat to make soup in, so both the patients and the cafeteria patrons are offered the same soup (Ovenshire, 2003). When planning the menus for both the patients and the cafeteria patrons, the equipment and resources required for each menu must be taken into account. Fortunately, some of the software packages that determine the patients' menus take into account a balancing of the equipment and resources. In most instances where the patient and cafeteria menus differ, the cafeteria menu feeds off the patient menu, utilizing the other equipment that is available (Ovenshire, 2003). This creates the most effective utilization of the resources and equipment.

3.6 The Use of Simulation

Simulation has been used occasionally in the health care industry for a variety of applications. Simulation certainly has the capability to be used in this industry but has not been used frequently due to several reasons that shall be discussed further in the following sections. Simulation has also been used in foodservice and that too shall be discussed in this section.

3.6.1 Simulation in Health Care

Simulation has been used in health care for a variety of studies and has the potential to be an effective and powerful tool in the health care industry. Simulation is an excellent tool that can be used to design potential changes to a system in the hospital and then test the changes without disrupting the actual system. This approach can minimize any negative effects on the health care system whereas if a new system were to be tested in normal day-to-day operations, it could have dire consequences. Also, "simulation is an extremely useful tool for modeling uncertainty, which is a major characteristic of illness and hence, makes simulation so attractive for modeling health care systems" (Lowry, 1998).

Although research shows that simulation in health care has been around for approximately forty years, simulation has not been used to its fullest extent in this field. There are several reasons why it is difficult to convince health care individuals to use simulation in health care. Many managers seem to prefer a deterministic method of decision-making and therefore lack the incentive to try a new method. It is often times difficult for hospital personnel to buy into the idea of using computer modeling in their health care industry. They are sometimes afraid of time study and treating their patients like objects. They also fear that simulation will attempt to standardize their methods and they argue that is impossible because they must treat each person individually based on his/her needs (Lowry, 1994). In many cases, it is the lack of knowledge of simulation that prevents the hospitals from supporting its use for a project. In order for simulation in health care to be successful, there must be support from the health care personnel, especially the managers to ensure that the improvements are made following the study. Now is an opportune time for the use of simulation in health care because hospitals are increasingly being forced to keep their costs low. Therefore, health care managers

are seeking tools which can aid them in reducing costs but at the same time, maintain a high level of quality care.

Simulation has been used to some extent in the health care industry, however, not usually in the foodservice aspect. The following case study examples will help to illustrate that simulation can be effective in the health care environment. Standridge (1999) presents a tutorial on simulation in health care applications and identifies examples of areas in health care that simulation can be useful and beneficial for solving problems. The areas include public policy, patient treatment procedures, capital expenditure requirements, and provider operating policies. For each example, the languages used to create the simulation models are discussed. These languages include FORTRAN and GASP IV (a precursor of SIMAN and SLAM).

An example of where simulation can be very effective and most useful is in determining staffing schedules for any area of the hospital. Simulation is often used to determine staffing schedules in manufacturing so it makes logical sense that it could also be applied to the health care industry. A specific example of this is a study done at the Emergency Department at the University of Virginia Medical Center (Rossetti, 1999). The motivation for this study of determining the optimal attending physician staffing schedules was to reduce expenses, increase throughput, and improve the overall system performance. The model for this study was created by translating the patient flow process into Arena 3.0 simulation logic. The results of this study concluded that in order to truly understand the system and generate an optimal solution, the staffing schedules of the other medical personnel must be monitored as well.

Simulation has also been used in improving the process at cancer treatment centers. One such example of this is the M.D. Anderson Cancer Center Orlando (Sepulveda, 1999). A similar situation to the one previously discussed, the purpose of this study was to analyze the patient

flow, examine and evaluate alternative floor layouts, test different scheduling options, as well as to analyze the resource and patient flow requirements of a new facility. The plan was to first examine the current situation and determine improvements that could be made to the system. After that was done, the model created was to be examined in the new facility that was currently being designed. The simulation package used for these models was Arena 3.0, but in order to represent the facility layout, a detailed drawing in Visio Technical 5.0 was generated and imported into Arena. The results of this study were that the center should indeed move to the new facility being designed and also increased throughput by altering the scheduling procedures.

Another example of the use of simulation relating to cancer treatment was for the Adjuvant Breast Cancer (ABC) Trial (Baldwin, 1999). In this case, simulation was used as an aid to decision-making. Adjuvant therapy is used for early stages of breast cancer to prolong survival while maintaining a high quality of life. The ABC Trial was a clinical trial to determine if it would be valuable to combine alternative forms of adjuvant therapy for early breast cancer. Simulation was used to test out these theories. The simulation language that was used was actually one that was created specifically for this study and is called ABCSim. The purpose of this language was to aid in the collection of data as well as provide a better understanding of the issues involved in adjuvant breast cancer treatment.

3.6.2 Simulation in Foodservice

Simulation can also be an effective tool in foodservice. Simulation is often used to optimize the entire system so as to maximize profits. This can include many different aspects that are specific to the restaurant being studied. Some of these are the servers' trip times, probability of drink and special requests, probability of ending a meal, number of parties per server, the average table time per party, waiting time, and drink refill statistics (Field, 1997).

Managers use simulation tools to determine the number of resources needed to service the customer demand. Increasing the efficiency of the process will result in increased profits as well as increased patient satisfaction.

4 Design and Analysis of Meal Assembly and Delivery Methods

Hospital foodservice systems have become increasingly complex over time. As the importance of nutrition and its influential role in patient care has become known, foodservice systems have had to change to accommodate nutritional requirements including new and special menus, preparation methods, and health and safety practices. Consequently, foodservice systems in hospitals prepare meals for patients, hospital employees, and visitors who have varying requirements but share many of the same kitchen resources. In general, the foodservice system can be broken down into two primary functions: food preparation and serving.

Since meal preparation methods, including all steps and resources required to convert ingredients into the finished, ready-to-serve dish, are highly dependent on the menu items, meal preparation methods are not the focus of this study. Instead, the scope of this research entails serving methods for patient meals. The objective of this research is to determine the best serving method for the foodservice system based on the performance measures of timeliness, productivity, and patient satisfaction. In particular, this work investigates alternative meal (tray) assembly methods, order/delivery strategies, and menu types for hospitals of various sizes. To accomplish this, a full factorial experiment on these four factors is conducted. Since conducting this experiment on the actual system is not possible, simulation models of the system are constructed to evaluate the performance measures.

By creating a computer simulation model of the current system, industrial engineering tools are used to analyze the systems and compare alternative system configurations based on system performance measures. Simulation models have been chosen as opposed to other models for several reasons, the first of which is that the foodservice system involves a complex interaction of many interdependent variables for which there is currently no closed form

analytical solution that accurately represents the system. Secondly, simulation models do not interrupt the actual system and yet still allow changes to be tested on the model to see the effects. Another reason is that a simulation model is less costly than constructing a physical replication of the system and experimenting with it. A simulation model provides great flexibility to the user in that changes can be made to the model and it can be saved under a different filename so that multiple models of the systems can exist simultaneously.

4.1 System Description

In this section, a general description of the activities involved in serving patient meals is given. In short, the order of events that occur in a typical hospital is the following: a meal card is created for each patient's tray based on their menu selections, the food is prepared, the assembly area is prepared for serving, the trays are assembled, and the trays are delivered to the patients. Each of these events contains several components that are described below in more detail.

The meal card is created for each patient based on his/her selections from the menu. Subsequently, the meal card is reviewed by a dietician to ensure that the patient is provided a meal that conforms to the medical and nutritional requirements prescribed by the physician. The meal card is used in the assembly system to inform the assembly workers which items each patient ordered and should be placed on the meal tray.

Before the trays can be assembled, the prepared food must be set up for serving. This often times involves arranging equipment such as coolers and heated carts, loading the prepared food into the coolers and heated carts, and plugging in the necessary equipment to maintain the temperature of the food including devices such as plate warmers. A typical meal that is served to the patients consists of a hot and/or cold entrée, a vegetable side dish, a cold salad, dessert,

bread, and beverages. For each of these items there are a variety of consistencies to accommodate for the plethora of special diets. For instance, some of the main entrees will be pureed for patients who cannot chew their food while others will contain less sodium than the regular meal. Each of these varieties must be available at the time of tray assembly. Throughout the course of the assembly period, replenishment of the food at the serving stations may be necessary or the preparation of special request items may be required for some patient meals. These exceptions to the basic flow of a tray could cause delays in the tray assembly process (Ovenshire, 2003).

As the trays finish on the assembly portion of the system, they are loaded into delivery carts. Once full, these delivery carts are used to deliver the trays to the patients. The order in which trays are assembled on the line and delivered to the patient may vary based on the delivery method. The trays are loaded into the cart from the assembly system by a first in first out method. Therefore, the trays must be sorted in the order that they will be delivered prior to entering the assembly system. While delivering the trays to the patients, the delivery person may assist the patient in preparing to eat by performing tasks such as opening items on the tray, pouring beverages, or adjusting the patient's bed so that the patient can be in an upright position for eating.

In addition to the operational aspects of the serving methods, there are nutritional and safety requirements that must be met. The dome plate activators used to maintain the temperature of the food will only be effective for forty-five minutes. Therefore, the time from when the tray enters the assembly system until the tray is delivered to the patient should not exceed forty-five minutes. As the temperature of the food decreases, so do the taste and the patient satisfaction.

In general, regardless of the methods used, all of these tasks are performed in order to assemble and deliver meals to the patients in the hospital. The sections that follow discuss specifically the alternative methods that are investigated for efficiently accomplishing meal serving tasks.

4.2 Development of Alternative System Configurations

Many foodservice systems have been designed and are in use in hospitals today that meet the requirements specified in Section 4.1. However, the purpose of this work is to develop and analyze alternative foodservice systems in order to optimize system performance measures such as productivity, timeliness, and patient satisfaction while meeting the medical and nutritional requirements of the system. As a starting point, a base configuration is developed based on an assembly line system with a choice menu and a traditional delivery system that is currently in use by many hospitals including F.F. Thompson Hospital in Canandaigua, NY. Alternative system configurations are developed based on (a) established lean manufacturing methods that result in high productivity in manufacturing settings; and (b) ordering and delivery methods that show promise for maximizing patient satisfaction. Finally, variations of the foodservice system are developed to represent the requirements of small and large hospitals in order to evaluate the robustness of the alternative system configurations on hospitals of various sizes.

4.2.1 Base System Configuration

A common type of hospital foodservice system consists of assembling the trays on an assembly line and delivering the meals to the patients in order by location (by hospital floor or

department). Thus, the system configuration that is referred to as the base system consists of an assembly line for tray preparation, a traditional delivery system, and a choice menu.

The tray assembly line centers around an accumulating conveyor and consists of seven stations including a leadoff station (where basic items such as plate warmers, utensils, condiments, etc. are place on a tray), two cold stations, two hot stations, a check station, and a beverage station. The layout is illustrated in Figure 4.1. Each station is operated by one person. The operator is responsible for placing on the tray any of the items that the patient has requested from that particular station. Because the menu offered to the patients is a choice menu, variety will exist in the number and type of items that each patient orders. Therefore, the cycle times for each station are not constant, but contain a considerable amount of variability. This is one of the reasons that a designated tray checker is on the assembly line. Since the items differ from tray to tray, items may be mistakenly placed on the tray or forgotten. Therefore, a trained nutritionist checks the tray and verifies the tray is assembled correctly.

The system is constrained in that there is a maximum number of trays that can be on the line at any one time. This is to ensure that the temperature of the food on each tray does not decrease too much due to excess time spent on the assembly line. All of the patient menu cards are ready when the assembly line begins so there is no delay between arrivals to the line. The menus are organized in order by delivery location prior to the start of the assembly line. Then, as each tray comes off the assembly line, it is placed in a delivery cart. The cart is filled following a first in first out rule and only contains trays that are delivered to the same location, even if the cart is not quite full. This allows the delivery person to bring the cart to one location and then distribute the trays to the patients from the cart. Therefore, this method minimizes the distance that the delivery person must travel with each delivery cart. The delivery people are also

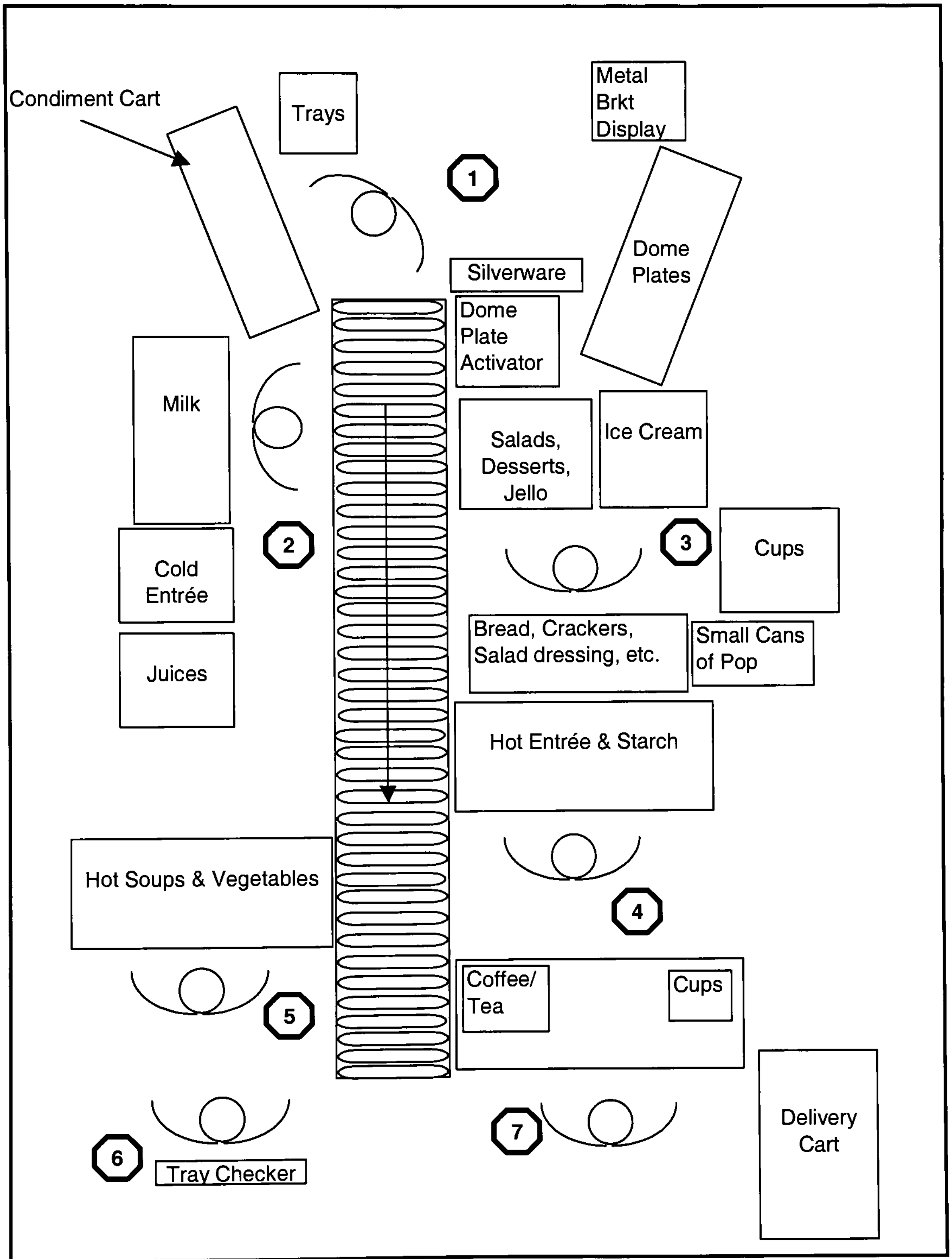

Figure 4.1: Assembly Line Layout for Tray Assembly

responsible for assisting the patients in opening any items and pouring any beverages that may not already be poured.

4.2.2 Alternative System Configurations

In order to determine an optimal solution, alternative systems must be examined. The development of these alternative systems includes the use of industrial engineering concepts including the concept of lean manufacturing. Lean manufacturing techniques are based on the principle of eliminating waste, which includes simplification of the system and the system components and processes wherever possible (Harris, 2002). All of the alternative systems that are developed for this study are conventional systems as opposed to cook-chill systems, both of which are discussed in Chapter 3. The reason being that the conventional system provides the department with flexibility in how they decide to set up their tray assembly and delivery methods. However, the cook-chill system involves an entirely different tray assembly method and delivery system that is generally fixed once a foodservice department chooses to use the cook-chill system. In addition, a conventional system lends itself to lean manufacturing techniques because it can be organized as a just-in-time process.

Cellular manufacturing is a key component of lean manufacturing that utilizes several of the lean manufacturing concepts such as reducing wasted motions, processing steps, and waiting times. The cellular layout uses a one-piece-flow method of assembling a product. The operator works on one piece and moves with it through the series of stations in the cell. Therefore, the number of operators used to run the cell can be less than the number of stations in the cell. In the context of a cellular layout for the tray assembly system, the operator moves through the cell assembling the tray with the all of necessary items required for the entire patient meal. The

operator only stays at each station for the time required to place the items on the tray, then moves to the next station. The flow of trays through the cellular layout is intended to increase the utilization of the workers over the assembly line method where an operator is often waiting for trays to reach his/her station. Also, because one person assembles an entire tray, there is likely to be less error in placing the wrong items on the tray. Furthermore, workers can take ownership for the tray, arranging the items in an appealing fashion. Trays could also be tracked to evaluate employee performance. Consequently, these benefits also eliminate the need for a checker in the cellular assembly systems.

The cell as depicted in Figure 4.2 is configured in a U-Shaped pattern. This unique U-shape of the cell is beneficial in that it minimizes the walking distance of the operator. Yet another benefit is the flexible number of employees based on demand. If there are more or fewer patients in the hospital, thus requiring more or fewer meals, the number of employees running the cell can be increased or decreased. However, there is a limit at which increasing the number of employees working in one cell will no longer be productive and will only result in wait times for the operators.

Lean concepts can also be applied to the type of menu selected for a foodservice system. The hospital can decide to use a fixed menu or a choice menu for their patients. A fixed menu provides only one meal option for each main meal except for modifications based on clinical need. For example, dinner would be the same for all patients except that a diabetic patient would have sugar substitutes and other necessary substitutes. The alternative option is a choice menu in which the patient chooses from a selection of items each meal. From a lean point of view, a fixed menu would be considered as eliminating waste due to variation.

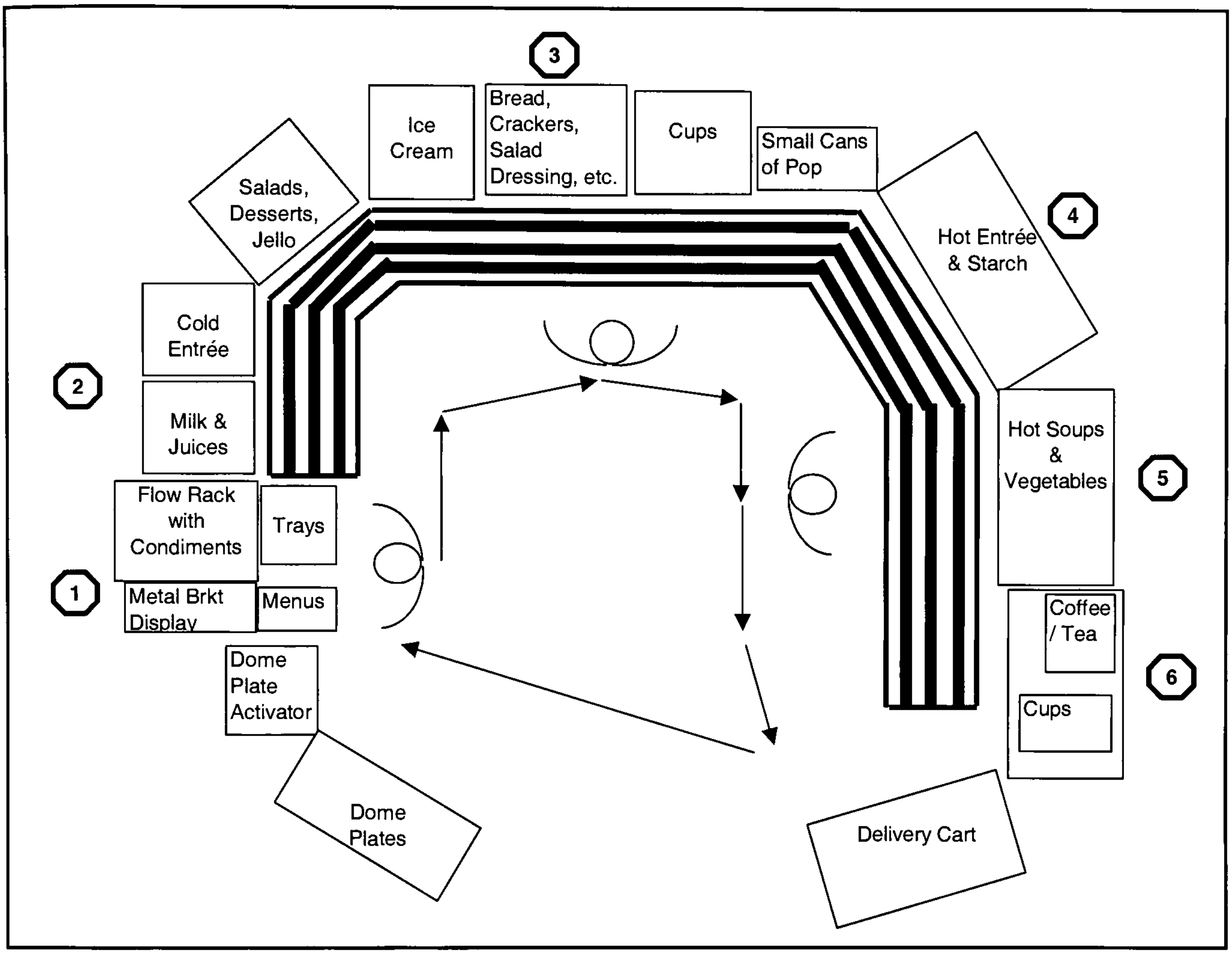

Figure 4.2: Cellular Layout for Tray Assembly

The next aspect, the delivery system, involves the way that the tray is delivered to the patient, and the window of time in which it is delivered. Therefore, the two alternatives related to the delivery system are the traditional system and a room service system. The traditional system involves assembling the trays in order by location so that they can go onto one delivery cart for that location. For the room service system, though, patients request what time they would like their meals delivered similar to the way that a hotel room service system operates. The foodservice system in the hospital would be responsible for setting the window times and while ordering their meal selection, patients would check which time they would like their meal

delivered. For efficiency, the menus could then be put in order by the computer based on the window time as well as the location.

The window times are a defined block of time. A patient could request to receive their meal in a particular window and should receive their meal during that interval. The make-span of the system, the number of trays to be delivered, and a defined interval result in window times. For example, a hospital could set up window times to be fifteen-minute intervals and would like to complete their tray distribution in one and a half hours. Therefore, the system would have six window times, each fifteen minutes long.

4.2.3 Small vs. Large Hospitals

There are a variety of sizes of hospitals in existence and are tracked in the American Hospital Association's publication of national statistics (AHA 2003). The AHA records the number of beds each hospital has and groups the hospitals into categories. The chart in Figure 4.3 is representative of that data (AHA 2003). Given the goal of the study is to find a robust system configuration for hospitals of various sizes, a range of hospital sizes are considered. For the purposes of this study, a hospital serving 200 patient trays per meal is referred to as a small hospital and a hospital serving 600 patient trays per meal is referred to as a large hospital.

The scope of this study is to address hospitals that would use a form of "mass production" for tray assembly of patient meals. For very small hospitals, this may not be the case. That is, the foodservice system may be a type of "short order" system where meals are prepared and placed on trays individually, similar to that of a restaurant. Although 200 patient trays is used to represent small hospitals in this study, the same system configurations may be

applied to smaller hospitals with the only adjustment required being the number of labor personnel.

The requirements of a small hospital and a large hospital not only differ in the number of trays that need to be assembled and delivered, but also in the requirements of labor and equipment. A summary of the equipment and labor requirements for the small and large hospitals is given in Table 4.1.

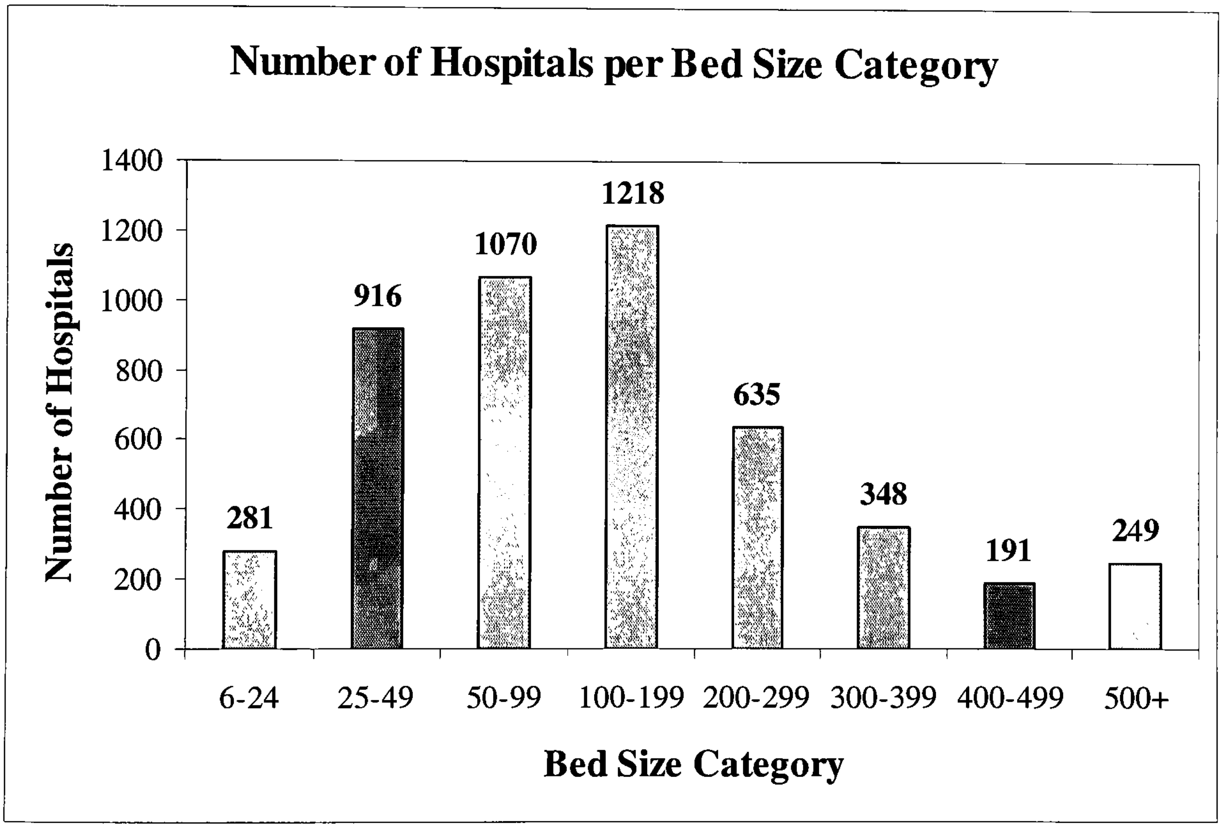

Figure 4.3: Number of Hospitals per Bed Size Category

Table 4.1: Labor Requirements

Worker Description	Hospital Size	
	Small	**Large**
Assembly Workers Assembly Line, Fixed Menu	5	10
Assembly Workers - Assembly Line, Choice Menu	7	14
Assembly Workers - Cell, Fixed Menu	3	8
Assembly Workers - Cell, Choice Menu	4	10
Delivery Workers Traditional	4	8
Delivery Workers Room Service	4	8

For small hospitals, a single assembly line or assembly cell is needed. In order to meet the requirements of the large hospital, the capacity of the assembly system must be doubled to two assembly lines or two assembly cells. In order to do this, the equipment required and the labor needed to run the assembly operations in the large hospital needs to be increased as well over that of the small hospital. Once the trays are finished on the assembly portion of the system, the carts containing the assembled trays are delivered the same way in both small and large hospitals. The delivery person takes the cart to the proper floor and delivers the trays to the patients. However, for a large hospital delivery system, the number of delivery personnel needs to be increased over that of the small hospital.

4.3 Experiment Design

As stated previously, the goal of this thesis is to design optimal foodservice systems with respect to the order/delivery and tray assembly methods relative to some key performance measures. Therefore, the main objective is to determine the best foodservice system for the alternative hospital configurations; in particular, to determine the best tray assembly, ordering, and delivery methods based on hospital size and menu options. Thus, based on the alternative system configurations that have been designed, a four-factor experiment is conducted.

Specifically, the four factors are hospital size, tray assembly method, ordering and delivery method, and menu type. A full factorial experiment is conducted on the four factors each having two levels. Using the full factorial experiment, both the main effects of the factors and their interactions are evaluated. A summary of the factors and the factor levels are restated in Table 4.2. Specifically, these factor levels are small and large hospitals for the hospital sizes, assembly line and cellular layouts for the tray assembly methods, choice and fixed for types of menus, and traditional and room service for the ordering and delivery systems.

Table 4.2: Four-Factor Experiment

Factor	**Factor Levels**	
Hospital Size	Small	Large
Tray Assembly Method	Assembly Line	Cellular
Ordering and Delivery System	Traditional	Room Service
Menu	Fixed	Choice

Consequently, eight different system configurations result and are displayed in Table 4.3. These eight different configurations are examined for both small and large hospitals, resulting in a total of sixteen treatment combinations.

Table 4.3: Tray Assembly and Delivery System Configurations

Configuration 1	**Configuration 2**	**Configuration 3**	**Configuration 4**
Assembly Line Traditional Fixed	Assembly Line Traditional Choice Menu	Assembly Line Room Service Fixed	Assembly Line Room Service Choice Menu
Configuration 5	**Configuration 6**	**Configuration 7**	**Configuration 8**
Cellular Traditional Fixed	Cellular Traditional Choice Menu	Cellular Room Service Fixed	Cellular Room Service Choice Menu

This experiment of the sixteen different systems is performed using computer simulation. Each system is different from the others, thus sixteen different simulation models are created. Some characteristics of the models are similar based on which factor levels they have in common. In order to ensure that the model is an accurate representation of the actual system, verification and validation are performed on each of the models.

Verification is used to check that the model operates the way that it is intended to run, and validation is used to check the accuracy of the model in respect to the actual system. Techniques such as following one entity through the model logic using the trace command and visually observing the running of the model by slowing down the run speed to a reasonable speed so that the animation is visible are used for verification of a model. Validation involves ensuring that the model is an accurate representation of the actual system. To validate a model, the results of the model are examined to determine if the statistics represent results that can be obtained from the actual system. The model and results are examined from a logical perspective to understand if the model is an accurate enough representation of the true system that decisions about the system can be made based upon the results of the simulation model. The base model represents the operation of F.F. Thompson Hospital's existing system. Therefore, cycle times taken from the actual system are input into the model and the layout of the system as well as the stations in the assembly portion are used in the model. The results from the model are used to ensure that the model represents what is actually happening with the existing system. When this is not the case, changes are made to the model to make the model a more accurate representation of the actual system. After verifying and validating the simulation models, the experimental evaluation is conducted. In order to ensure the results of the experiment are representative of the true system and that the results are statistically accurate, each treatment combination is run for

100 replications and the performance measures of all replications for each model are compared. This relatively large number of replications reduces the chance of a slight variation drastically influencing the experimental results. This system is classified as terminating simulation because each replication of the model represents one meal with a fixed beginning and a finite time horizon. Therefore, each replication of the simulation model is run until all the meals are completed in the system (that is, all meals have been delivered to the patients).

Once the experiment is run, an analysis of the results is performed. The analysis involves examining the means of each performance measure that are described in the next section, and comparing how they relate to one another. To compare alternative system configurations, a detailed Analysis of Variance (ANOVA) is performed. The ANOVA is performed on the full factorial experiment to determine if the factors are statistically significant from one another. If a significant interaction is detected between one of the factors, then an ANOVA is run on each of that factor's levels to determine any significant interactions between the levels. Any significant factors and interactions are then analyzed using a Tukey multiple mean comparison test. The Tukey test identifies statistically significant differences among a set or treatment combinations.

4.4 Performance Measures

The main performance measures used in the comparison of alternative systems include the assembly time of a tray, the cycle time of a tray through the entire system, the make-span of the system, the make-span of the tray assembly process, the productivity of the assembly system, and patient satisfaction. The assembly time of a tray is measured by recording the time the tray spends in the tray assembly operation. That is, the time from when the tray assembly begins at the lead-off station until the time the tray is placed on a delivery cart. The overall cycle time is

measured by recording the time the tray enters the assembly portion of the model and recording the time the tray is delivered to the patient. The difference between these two times is the overall cycle time of the tray. The make-span of the system is calculated as the time required to assemble and deliver all of the trays for a given meal. That is, the time from when the first tray enters the system until the time the last tray has been delivered to the patient. Similarly, the make-span of the assembly process is the time required to assemble all of the trays for a given meal. The productivity of the assembly system is defined as the number of trays assembled per hour per worker for a given meal. This is a compound performance measure that takes into account the number of tray assembly workers, the number of trays produced, the make-span of the system, and the utilization of the workers. The formula for the productivity performance measure is

$$\textbf{Productivity} = \frac{\dfrac{\text{Number Trays Produced}}{\text{Assembly Make-Span}}}{\text{Number of Assembly Workers}}$$

The measure of patient satisfaction in this study is based solely on the foodservice system with regard to operational characteristics of the tray assembly, ordering and delivery aspects of the foodservice system. Note that there are many other components that contribute to patient satisfaction with respect to foodservice including the food itself, preparation methods, disposition of the delivery staff, and food choices, to name a few.

The patient satisfaction performance measure is a compound measure that takes into account the following two logical arguments: (1) Food becomes less desirable (and the patient's level of satisfaction decreases) the longer the time between tray assembly and the delivery of the meal to the patient; and (2) The patient's satisfaction decreases the longer the time between the desired dining time of the patient and the actual delivery time of the meal. Therefore, a patient's

satisfaction with the foodservice system would be greatest if the meal were delivered at the desired dining time of the patient immediately after the food is placed on the tray. The first measure is referred to as the "Time In Cart Rank," and the second measure is referred to as the "Delivery Time Rank." The scale for each of these measures is from zero to five with five being the best measurement. Calculating the Delivery Time Rank involves checking which delivery window the patient initially requested, then determining the time window in which the tray is actually delivered, and finally assigning the corresponding rank. The scales and descriptions are outlined in Tables 4.4 and 4.5, respectively. The sum of the ranking measures for the Time In Cart Rank and the Delivery Time Rank is the measure of patient satisfaction with ten being the most desirable or highest level of patient satisfaction.

Table 4.4: Patient Satisfaction Associated With Time In Cart

Satisfaction Rank	Description of Time In Cart Rank
5	Time In Cart < = 10 minutes
4	10 < Time In Cart < = 15 minutes
3	15 < Time In Cart < = 20 minutes
2	20 < Time In Cart < = 25 minutes
1	25 < Time In Cart < = 30 minutes
0	30 < Time In Cart

Table 4.5: Patient Satisfaction Associated With Delivery Time

Satisfaction Rank	Description of Delivery Time Rank
5	Tray delivered in requested window
4	Tray delivered 1 window from patient's desired delivery time
3	Tray delivered 2 windows from patient's desired delivery time
2	Tray delivered 3 windows from patient's desired delivery time
1	Tray delivered 4 windows from patient's desired delivery time
0	Tray delivered 5 windows from patient's desired delivery time

For example, if a patient requests his/her tray to be delivered during window 2, then the tray should be delivered between 25 and 40 minutes after the start of the system. If the tray is finished on the assembly portion of the system, enters the delivery cart at time 35, and is delivered to the patient at time 60, then the time the tray spends in the cart is 25 minutes. Therefore, the satisfaction rank associated with the Time In Cart is 2. Since the delivery occurs at time 60, which is in the fourth window, the tray is delivered 2 windows away from the delivery window requested by the patient. Hence, the satisfaction rank associated with the Delivery Time is 3. The sum of these two satisfaction ranks results in the patient satisfaction of 5 out of a possible 10.

In addition to these measures, the components of the compound measures as well as many other system performance measures are also calculated. For example, the number of trays that are delivered early, late, or on-time is calculated along with the number of windows early or late. A sample of the output performance measures that are collected for each replication are shown in Appendix A.

4.5 Simulation Models

A total of sixteen simulation models are created for the experiment as described in the previous section. ARENA version 5.0 is the simulation language used to create the models. ARENA is a commercially available, general purpose simulation language that can be used to model many different types of systems and applications. The simulation logic for the base model is discussed in the sections that follow as well as the modifications that are required to model the other fifteen system configurations. The ARENA code used is shown in Appendix G.

4.5.1 Base Model

The base model of this experiment is constructed from F.F. Thompson Hospital's existing foodservice system. The layout of the system is the same as F.F. Thompson's as well as the general concept of the system. Some alterations were made from the existing system in order to create a more general system that would be more representative of other hospitals. However, all the necessary cycle times are of the actual system. This system is classified as a small, assembly line, traditional delivery, choice menu system. The assembly portion of the model consists of an accumulating conveyor and seven stations. The stations are the following: Leadoff, Cold Station 1, Cold Station 2, Hot Station 1, Hot Station 2, Check Station, and Beverage Station. The location of the delivery cart is also classified as a station for the model logic. The conveyor is a roller conveyor that the employees push the trays on. Therefore, the conveyor is considered accumulating and is referred to as Tray Line in the context of the model. The conveyor is constructed of segments that are determined by the distance between stations. The actual distances of the existing conveyor are used to accurately portray the travel time. Some of the variables that exist in the model are the number of meals, the maximum WIP that is allowed in the system, the number of trays on the line at one time, and the number of trays allowed on a cart. These variables are represented by NumMeals, MaxWIP, TraysOnLine, and FullCart respectively. The layout of the system is illustrated in Figure 4.1.

The tray, in this case the entity, enters the assembly line at the Leadoff station. The tray is assigned a variety of attributes, including the service times for each station, the time to deliver the tray to the patient, and the patient's desired delivery time. The delivery times have been broken down into fifteen-minute intervals over a period of an hour and a half. Therefore, there are six possible window times in which patients could receive their food, these are indicated in

Table 4.6. Note that the first window time begins ten minutes after the start of the tray assembly system so as to allow time for the trays to be assembled for the first cart. The assignment of each attribute value is based on a discrete distribution with 20% of the meals being of no time preference (represented as 7) and the other delivery times of equal probability of one another. Therefore, the value in the model is: DISC(.133,1,.267,2,.4,3,.533,4,.667,5,0.8,6,1,7) Although this base model does not consider the patient's desired delivery time since it is a Traditional system, this logic is used to track patient satisfaction.

Table 4.6: Time in System Relationship to Window Time

Window	Time In System
1	Minute 10 - Minute 25
2	Minute 25 - Minute 40
3	Minute 40 - Minute 55
4	Minute 55 - Minute 70
5	Minute 70 - Minute 85
6	Minute 85 - Minute 100

A constraint exists that allows only nine trays on the line at any one time. The reason for this is so that the temperature of the food does not decrease too much before being delivered to the patient thus jeopardizing patient satisfaction. This is represented in the model logic in the creation of one batch of MaxWIP size. MaxWIP is a variable that is defined as the number of trays that are allowed on the assembly line at one time. The system first tests to see how many trays are on the line and if more can be added. This is done by using a Scan block to compare TraysOnLine to MaxWIP. If the number of trays on the line is less than the maximum number allowed, another test is run to see if more meals are required to fulfill the demands of the system. If there are more trays that must be assembled, then the entity is duplicated. The original entity continues through the system to be grouped in the delivery cart and then delivered to the patient while the duplicated entity travels to the beginning of the line to create another tray in the

system. The number of meals is defined by a variable named NumMeals. This can easily be changed to represent the size of the hospital. As the original entity continues through the model, the NumMeals variable is decremented by one so as to represent a completed tray. The trays are grouped into the delivery cart in temporary groups of 20, the capacity of the delivery cart.

In order to accurately represent the system and therefore create a valid simulation model, the cycle times of the existing system are used in the model. Since this system utilizes a choice menu, variability exists among trays at each individual station. For instance, a patient could order everything on the menu or only a few items. Therefore, the number of items on each tray will vary and so will the cycle time required to place those items on the tray. For this reason, the cycle times collected for each station were loaded into the Rockwell Software Input Analyzer in order to determine the most accurate distribution to represent the station's cycle time. It was determined that the best fit for each of the cycle times was the Triangular Distribution. The Triangular distribution has been chosen to represent each of the cycle times because it provides variability in the service times at each station, but also limits the cycle times to a particular range representative of the actual data collected. A Triangular distribution also represents the time for a tray to be delivered to a patient. The distributions of the service times at each assembly station are increased by 25% to allow time for material replenishment. Therefore, each cycle time is represented in the model by a Triangular distribution and its low value, mode, and high value. The cycle times for each station in the base model are presented in Table 4.7. These cycle times are also used in the other system configurations that contain a choice menu and an assembly line.

Table 4.7: Cycle Times for Assembly Line, Choice Menu Systems

Station	Cycle Time
LeadOff	(TRIA(10,12.7,19))*1.25
ColdStation1	(TRIA(5,12.2,34))*1.25
ColdStation2	(TRIA(7,11.3,26))*1.25
HotStation1	(TRIA(7,11.2,21))*1.25
HotStation2	(TRIA(8,9.7,25))*1.25
Check Station	(TRIA(5,10,12))*1.25
Beverage Station	(TRIA(4,9.99,21))*1.25

The tray's time in the system officially begins when it is seized by the resource at the LeadOff Station. The tray travels through the entire assembly line stopping at every station and being serviced by a worker defined as a resource in the model. In the system, Cold Station 1 and Cold Station 2 are located across from each other on the Assembly Line so the operators at each station work on the same tray simultaneously. Therefore, the maximum cycle time of the two stations is used to calculate the tray's assembly cycle time. Once the tray reaches the end of the line, it exits the conveyor and the worker at the Beverage Station loads the tray into the Delivery Cart. Once the cart is full, the delivery person transports the cart to its appropriate location and then delivers all 20 trays on the cart to the patients. The delivery person is defined as a transporter that follows a distance map defined in the model. The distance map allows the delivery person to move from the delivery cart to any delivery location and then back from the delivery location to the delivery cart. The delivery person also delivers the tray directly to the patient, but that is accounted for by a delay using a triangular distribution rather then defining the distances to each room. The delivery person always returns to the line after delivering all the trays on the cart so that he/she is ready and waiting for the next full cart to be completed. For this model, there are four delivery people in the system. The distances to each delivery location were obtained from F.F. Thompson's actual system. This is a realistic representation of the

system in that some locations are located further from the delivery cart and others are closer, just as in a real system.

4.5.2 Alternative System Configurations

There are two main types of foodservice systems in use in hospitals today: conventional and cook-chill. For the purposes of this evaluation, however, only the conventional system is considered. The conventional system provides the department with flexibility in how they decide to set up their tray assembly and delivery methods. However, the cook-chill system involves an entirely different tray assembly method and delivery system that is generally fixed once a foodservice department chooses to use the cook-chill system. In addition, a conventional system lends itself to lean manufacturing techniques because it can be understood as a just-in-time process if organized correctly. The cook-chill system, though, follows an older manufacturing concept involving batch processing that creates a great deal of inventory.

The other system configuration models are constructed from the base model. The logic used for the factor levels present in the base model, small hospital, assembly line, traditional delivery system and choice menu, are used in the models that contain those factor levels. The base model, though, only uses four of the eight factor levels. Therefore, logic is developed for the remaining four factor levels: large hospital, cellular assembly, room service delivery system and fixed menu. Some aspects of these factor levels are the same as the base system's factor levels. The aspects that remained the same between the two alternatives for each factor did so to make the factor level's advantages and disadvantages evident in the different system configurations. The only difference was that the cellular layout did not require a Check Station because it was assumed that the one-piece flow method used in the assembly cell would result in

less error in the assembly of the tray. Also, the same cycle time data was used for all systems but for the assembly line, the cycle times were increased by 25% to allow time for replenishment. A Triangular distribution was determined to be the best fit for the distributions. The cycle times for the choice menu are displayed in Table 4.7 in Section 4.5.1 and in Table 4.8. The cycle times for the fixed menu are calculated from the distributions used for the choice menu by reducing the mean by 30%, thus reducing the variability of the system by 51%. These cycle times are presented in Tables 4.9 and 4.10.

Table 4.8: Cycle Times for Cellular Assembly, Choice Menu Systems

Station	**Cycle Time**
LeadOff	TRIA(10,12.7,19)
ColdStation1	TRIA(5,12.2,34)
ColdStation2	TRIA(7,11.3,26)
HotStation1	TRIA(7,11.2,21)
HotStation2	TRIA(8,9.7,25)
Beverage Station	TRIA(4,9.99,21)

Table 4.9: Cycle Times for Assembly Line, Fixed Menu Systems

Station	**Cycle Time**
LeadOff	(TRIA(10,12.7,19))*1.25
ColdStation	(TRIA(4,7.57,14))*1.25
EntreeStation	(TRIA(5,7.1,12))*1.25
HotStation	(TRIA(5.19,5.87,12))*1.25
Check and Beverage	(TRIA(10,10.8,18))*1.25

Table 4.10: Cycle Times for Cellular Assembly, Fixed Menu Systems

Station	Cycle Time
LeadOff	(TRIA(10,12.7,19))
ColdStation	(TRIA(4,7.57,14))
EntreeStation	(TRIA(5,7.1,12))
HotStation	(TRIA(5.19,5.87,12))
Beverage Station	(TRIA(4,9.99,21))

For the cellular layout, because the cell is a unique U-shaped pattern, the distances between the stations can be less. The distances between the stations represents the distance the operator walks even though the tray will be in front of the operator on metal bars that construct a sliding surface for the trays. The layout of the assembly cell is illustrated in Figure 4.2. The cellular assembly accommodates a more flexible number of employees because the cell is a U-shaped layout in which each employee assembles an entire tray, also known as one-piece flow. Therefore, the number of employees in the cell can be increased or decreased according to the tray demand. However, there is a limit at which increasing the number of employees working in one cell will no longer be productive and will only result in wait times for the operators. Once the number of employees in the cell equals the number of stations in the cell, it will no longer be a cellular system, but an assembly line system. Also, if the number of employees is decreased by too much, the cell will not be able to meet the desired demand of trays.

This system also lends itself to some flexibility in terms of the contents of the stations and how they are presented to the worker. With this system, it is entirely possible to create two separate cells to accommodate increased demand. This is illustrated in the cellular models for the large hospitals where two identical cells have been created, thus increasing the capacity of

the system. Also with the cellular assembly system, the dishes of food can be presented to the operator in mass quantities so that they are responsible for dishing up the food for each tray as they are assembling it. This will greatly reduce the preparation time that is required and will also improve the appearance of the tray because the tray will not be cluttered with so many containers and dishes and the operator can arrange the food on the tray in a visually appealing manner. This aspect, though not represented in the model, shows the additional benefits of the cellular system and is recommended for use with the cellular system.

In terms of the model logic for the cellular assembly method, because each operator is responsible for one tray at a time and moving with that tray to each of the stations in the cell, the operators have been represented as transporters. This allows them to move along a path in the cell, which is essentially from one station to the next, while servicing the patient's tray. The number of operators can be increased or decreased to determine the optimal number of operators to meet a desired demand of patient trays. This number was determined to be three for the small, fixed menu systems, four for the small, choice menu systems, eight for the large, fixed menu systems, and ten for the large, choice menu systems. When the tray enters the cell, it requests an available transporter that stays with that tray through the entire cell and is released once the tray is loaded into the delivery cart.

The room service delivery system differs from the traditional delivery system in a few aspects. The most important difference is that the patient requests the time that they would like their tray delivered based on the pre-determined window times discussed previously. In terms of the model logic, then, the trays are created in the model and immediately assigned several attributes including the service times for each station, the time for the delivery person to deliver the tray, the desired delivery time, and the location of the patient. The location of the patient is

assigned so that 20 trays go to each location in the small hospitals and 60 in the large. The trays are also assigned a Desired Delivery Time using a discrete distribution. For a small hospital, the number of windows is six, but for a large hospital, the number of windows is eight. Two extra windows are added to the large models in order to realistically deliver all the trays. Therefore, if the patient has no preference when the meal is delivered, their Desired Delivery Time attribute value becomes seven in a small hospital and nine in a large hospital. These meals are then assigned to a delivery window using a branch system that checks how many meals have been assigned to each window time. The most that can be delivered during each interval is 34 for small hospital systems and 75 for large hospital systems. Therefore, the no preference meals, NPM as they are labeled, are assigned to window times that have fewer than the maximum number of meals to fill in when the delivery demand is less and thus level out the delivery schedule. The trays are then each assigned an attribute Delivery Priority representing the desired window time multiplied by 100 plus the delivery location. Location 1 is station 11, Location 2 is station 12, and so forth until Location 10 is station 20. The trays then enter a queue in which they are ranked by the attribute Delivery Priority with the lowest value first. Therefore, the trays will be delivered in the window time for which they were selected to the location closest to the kitchen first and then proceed from there. Once the trays are sorted in the queue, they can enter the Lead Off Station. For the large hospitals, though, two assembly lines/cells have been created to accommodate the demanded number of meals. Therefore, once the trays are sorted in the queue, a resource named "Fake" is seized to send the trays to one of the two lines. In order to keep the trays in the correct order that they were sorted into, the resource will send ten trays at a time to each cell. The reason for choosing ten trays is that is the capacity of the room service delivery carts. The trays are then assembled on the line/cell and grouped in a cart at the line/cell

at a station that is called a hold station. The full cart contains ten trays with the save criterion representing the attributes of the first tray in the cart. The cart is then routed to the Delivery Cart station where a transporter is requested to deliver all the trays on the cart. This is done using an array and a server attribute that allows the same delivery person to stay with a particular cart the whole time. The transporter moves to the location that the first tray has been assigned to. This is because the trays enter the cart in the sorted order that they were originally placed in at the start of the system. This sorting of the trays by delivery priority will deliver the trays in order of the window times requested, but then within the window time by location so that the transporter is not wasting time moving back and forth between locations. By eliminating this wasted movement, the transporters should be able to better deliver the trays in the appropriate window time. The trays are then delivered to the patient by dropping off one member of the group, splitting the group, re-grouping the remaining trays and then delivering the next tray based on its delivery location attribute.

In order to deliver all the trays in a timely manner, there are four delivery people in the small hospital models and eight in the large hospital models. The delivery people are represented in the model by transporters that move along a defined distance map. This map is the same as the map for the traditional system except that it has an additional station representing the statistics collection. This was done because the delivery person needed a Drop Off location for the tray and since the delivery to the patient is tracked through a delay block using a triangular distribution of delivery times, the statistics collection station was added. One delivery person is responsible for delivering all ten trays on one cart. The delivery person stays with the cart until he/she has delivered all the trays and then returns to the kitchen to deliver another cart.

The third component, menu type, dictates the cycle times in the models. The choice menu is used in the base model, so the alternative menu type is a fixed menu. A choice menu allows the patient to select their food from a menu, whereas a fixed menu would involve only one meal option being offered for each main meal except for modifications based on clinical need. For example, dinner would be the same for all patients except that a diabetic patient would have sugar substitutes and other necessary substitutes. Therefore, the fixed menu consists of the same meal for each patient with the only variety in diet. This greatly reduces the number of different items required in the assembly system, thus decreasing the amount of floor space required. The number of stations will be less than that required for a choice menu and because each patient is receiving the same items, the cycle time of each station will contain less variability than the cycle times used for the choice menu. In the model, the variability of the cycle times at each station has been reduced by 51% and the number of stations for the assembly line and cellular layout has been reduced by two and one, respectively.

As mentioned in previous discussions, the size of the hospital affected the assembly portion of the system in that the capacity had to be increased to accommodate the required demand. The other difference was in the sorting of the trays to assign them to one line/cell or the other.

5 Results and Analysis

The results obtained from the 2^4 full factorial experiment provide a means of comparison among alternative foodservice system configurations. The output performance measures obtained from the experiment are presented including the measures of individual tray cycle time, make-span of the assembly portion and of the entire system, patient satisfaction, and productivity. In addition, the statistical analysis techniques including outcomes of the analysis of variance and Tukey tests are presented. Finally, an interpretation of the results is discussed along with a discussion of how hospitals can use the results of the experiment to determine which system configuration would best meet their needs.

5.1 Results

The experiment consists of sixteen simulation models generated to represent the sixteen system configurations that result from a full factorial experiment of the four factors previously defined and the two levels associated with each factor. For each treatment combination, 100 replications of the associated simulation model are run. The performance measures are recorded in each model replication and the average of all the replications for each system are recorded in the simulation output.

A full range of output performance measures are presented for each configuration including assembly time, the overall cycle time, the assembly make-span, the make-span of the system, patient satisfaction, and productivity. Table 5.1 lists the alternative systems configurations. A summary of the average values of the experimental performance measures appear in Table 5.2 for small hospitals and in Table 5.3 for large hospitals. A complete set of experimental results appear in Appendix A.

Table 5.1: System Configuration Definitions

Config.	Assembly Method	Delivery System	Menu Choice
1	Line	Traditional	Fixed
2	Line	Traditional	Choice
3	Line	Room Service	Fixed
4	Line	Room Service	Choice
5	Cell	Traditional	Fixed
6	Cell	Traditional	Choice
7	Cell	Room Service	Fixed
8	Cell	Room Service	Choice

Table 5.2: Average Performance Measures for System Configurations in Small Hospitals

Config.	Assembly Time (minutes)	Overall Cycle Time (minutes)	Assembly Make-Span (minutes)	Make-Span of System (minutes)	Patient Satisfaction	Productivity (trays/hr/worker)
1	1.15	19.30	56.2	91.6	6.42	42.68
2	3.45	20.19	77.0	106.3	6.62	22.25
3	1.15	19.49	56.2	93.4	7.50	42.67
4	3.45	14.33	77.0	97.7	9.17	22.25
5	1.07	17.76	77.9	103.7	6.67	51.37
6	1.69	18.83	89.5	115.4	6.44	33.51
7	1.07	12.69	77.9	97.2	8.99	51.38
8	1.69	11.62	89.6	104.1	9.36	33.48

Table 5.3: Average Performance Measures for System Configurations in Large Hospitals

Config.	Assembly Time (minutes)	Overall Cycle Time (minutes)	Assembly Make-Span (minutes)	Make-Span of System (minutes)	Patient Satisfaction	Productivity (trays/hr/worker)
1	1.15	21.42	88.15	125.82	5.53	40.84
2	3.47	20.21	121.06	146.95	4.64	21.24
3	1.15	25.19	88.15	136.25	6.81	40.84
4	3.47	15.02	121.20	139.93	8.97	21.22
5	1.07	21.10	87.79	125.32	5.58	51.26
6	1.69	18.01	107.76	133.76	4.80	33.41
7	1.07	25.77	87.77	136.21	6.75	51.27
8	1.69	18.76	107.74	138.40	7.88	33.41

For each of the key performance measures, an analysis of variance is conducted on the full factorial experiment to determine which of the factors, if any, are significant at a significance level of 0.05. The ANOVA table for the full factorial experiment of the performance measure patient satisfaction is presented in Table 5.4. The ANOVA results in p-values of less than 0.001 for all main effects and all of the interaction terms indicating that all of the terms are significant in determining patient satisfaction. In particular, since the analysis indicates significant differences between small and large hospital systems, a three-way ANOVA of the remaining factors is performed and small hospital systems and large hospital systems are analyzed separately.

The three-way ANOVA conducted for small hospitals is shown in Table 5.5. Since, this ANOVA indicates a significant three-way interaction term for assembly method, delivery method, and menu type, a Tukey multiple range test is conducted to determine which of the treatment combinations are significantly different from one another. The results of the Tukey test are shown in Table 5.6. The charts presenting the results of the Tukey tests use vertical lines to illustrate configurations that do not have a statistically different average value for that particular

performance measure. Thus, in Table 5.6, configurations 8,4,7,3,5,2 are significantly different from one another and significantly different than both configurations 6 and 1 at a significance level of 0.05. However, there is no statistically significant difference between configuration 6 and configuration 1 with regard to patient satisfaction. Therefore, from a statistical perspective, one can conclude that for small hospitals configuration 8 will result in the highest level of patient satisfaction. A similar analysis is conducted for the measure of patient satisfaction in large hospitals. The results of the ANOVA are shown in Table 5.7 and the results of the Tukey test are shown in Table 5.8. However, in the case of large hospitals, configuration 4 gives the highest level of patient satisfaction at a significance level of 0.05.

Table 5.4: Full Factorial ANOVA for Performance Measure Patient Satisfaction

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Hospital	1	649.85	649.85	649.85	5.5E+04	0.000
Assembly	1	4.14	4.14	4.14	349.91	0.000
MenuType	1	82.03	82.03	82.03	6941.56	0.000
Delivery	1	2193.19	2193.19	2193.19	1.9E+05	0.000
Hospital*Assembly	1	45.3	45.3	45.3	3832.89	0.000
Hospital*MenuType	1	0.95	0.95	0.95	80.61	0.000
Hospital*Delivery	1	6.21	6.21	6.21	525.38	0.000
Assembly*MenuType	1	43.31	43.31	43.31	3665.06	0.000
Assembly*Delivery	1	0.39	0.39	0.39	33.32	0.000
MenuType*Delivery	1	308.08	308.08	308.08	2.6E+04	0.000
Hospital*Assembly* MenuType	1	3.97	3.97	3.97	336.11	0.000
Hospital*Assembly* Delivery	1	54.4	54.4	54.4	4603.38	0.000
Hospital*MenuType* Delivery	1	52.41	52.41	52.41	4434.87	0.000
Assembly*MenuType* Delivery	1	25.28	25.28	25.28	2139	0.000
Hospital*Assembly* MenuType*Delivery	1	0.52	0.52	0.52	43.74	0.000
Error	1584	18.72	18.72	0.01		
Total	1599	3488.76				

Table 5.5: Three Factor ANOVA of Patient Satisfaction for Foodservice System Configurations in Small Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	38.40	38.40	38.40	3554.430	0.000
Delivery System	1	983.01	983.01	983.01	9.1E+04	0.000
Menu Type	1	50.33	50.33	50.33	4658.790	0.000
Assembly*MenuType	1	32.03	32.03	32.03	2964.300	0.000
Assembly*Delivery	1	36.76	36.76	36.76	3402.37	0.000
MenuType*Delivery	1	53.18	53.18	53.18	4921.970	0.000
Assembly*MenuType*Delivery	1	9.28	9.28	9.28	859.200	0.000
Error	792	8.56	8.56	0.01		
Total	799	1211.54				

Table 5.6: Tukey Multiple Comparison of Average Patient Satisfaction for Foodservice System Configurations in Small Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Patient Satisfaction
8	Cell	Choice	Room Service	9.36
4	Line	Choice	Room Service	9.17
7	Cell	Fixed	Room Service	8.99
3	Line	Fixed	Room Service	7.50
5	Cell	Fixed	Traditional	6.67
2	Line	Choice	Traditional	6.62
6	Cell	Choice	Traditional	6.44
1	Line	Fixed	Traditional	6.42

Table 5.7: Three Factor ANOVA of Patient Satisfaction for Foodservice System Configurations in Large Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	11.04	11.04	11.04	859.57	0.000
Delivery System	1	1216.33	1216.33	1216.33	9.5E+04	0.000
Menu Type	1	32.64	32.64	32.64	2542.61	0.000
Assembly*MenuType	1	22.76	22.76	22.76	1772.88	0.000
Assembly*Delivery	1	10.52	10.52	10.52	819.43	0.000
MenuType*Delivery	1	307.35	307.35	307.35	2.4E+04	0.000
Assembly*MenuType* Delivery	1	16.52	16.52	16.52	1286.74	0.000
Error	792	10.17	10.17	0.01		
Total	799	1627.32				

Table 5.8: Tukey Multiple Comparison of Average Patient Satisfaction for Foodservice System Configurations in Large Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Patient Satisfaction
4	Line	Choice	Room Service	8.97
8	Cell	Choice	Room Service	7.88
3	Line	Fixed	Room Service	6.81
7	Cell	Fixed	Room Service	6.75
5	Cell	Fixed	Traditional	5.58
1	Line	Fixed	Traditional	5.53
6	Cell	Choice	Traditional	4.80
2	Line	Choice	Traditional	4.64

For several performance measures that measure only assembly related activities such as the average assembly time for a tray, the delivery method did not turn out to be a significant main effect nor did delivery method have any significant interactions with other factors. An example of this is illustrated by the full factorial ANOVA on assembly time shown in Table 5.9. Similarly, a three-way ANOVA is conducted on the remaining factors by hospital size. The results of this analysis are shown in Tables 5.10-5.13. Other performance measures exhibited similar behavior including the make-span of assembly, and assembly productivity.

Table 5.9: Full Factorial ANOVA for Performance Measure of Assembly Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hospital	1	0.014	0.014	0.014	13.02	0.000
Assembly	1	340.368	340.368	340.368	3.2E+05	0.000
MenuType	1	859.17	859.17	859.17	8.1E+05	0.000
Delivery	1	0.000	0.000	0.000	0.01	0.943
Hospital*Assembly	1	0.014	0.014	0.014	13.06	0.000
Hospital*MenuType	1	0.007	0.007	0.007	7.07	0.008
Hospital*Delivery	1	0.000	0.000	0.000	0.01	0.938
Assembly*MenuType	1	288.483	288.483	288.483	2.7E+05	0.000
Assembly*Delivery	1	0.000	0.000	0.000	0.01	0.943
MenuType*Delivery	1	0.000	0.000	0.000	0.01	0.943
Hospital*Assembly* MenuType	1	0.007	0.007	0.007	7.02	0.008
Hospital*Assembly* Delivery	1	0.000	0.000	0.000	0.01	0.938
Hospital*MenuType* Delivery	1	0.000	0.000	0.000	0.00	0.985
Assembly*MenuType* Delivery	1	0.000	0.000	0.000	0.01	0.943
Hospital*Assembly* MenuType*Delivery	1	0.000	0.000	0.000	0.00	0.985
Error	1584	1.678	1.678	0.001		
Total	1599	1489.741				

Table 5.10: Three Factor ANOVA of Assembly Time for Foodservice System Configurations in Small Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	168.02	168.02	168.02	1.0E+05	0.000
Menu Type	1	427.05	427.05	427.05	2.6E+05	0.000
Delivery System	1	0.00	0.00	0.00	0.01	0.000
Assembly*MenuType	1	0.00	0.00	0.00	0.01	0.000
Assembly*Delivery	1	142.78	142.78	142.78	8.7E+04	0.000
MenuType*Delivery	1	0.00	0.00	0.00	0.000	0.000
Assembly*MenuType* Delivery	1	0.00	0.00	0.00	0.000	0.000
Error	792	1.30	1.30	0.00		
Total	799	739.15				

Table 5.11: Tukey Multiple Comparison of Average Assembly Time for Foodservice System Configurations in Small Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Assembly Time
5	Cell	Fixed	Traditional	1.07
7	Cell	Fixed	Room Service	1.07
3	Line	Fixed	Room Service	1.15
1	Line	Fixed	Traditional	1.15
6	Cell	Choice	Traditional	1.69
8	Cell	Choice	Room Service	1.69
4	Line	Choice	Room Service	3.45
2	Line	Choice	Traditional	3.45

Table 5.12: Three Factor ANOVA of Assembly Time for Foodservice System Configurations in Large Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	172.36	172.36	172.36	3.6E+05	0.000
Delivery System	1	0.00	0.00	0.00	0.00	0.995
Menu Type	1	432.13	432.13	432.13	9.0E+05	0.000
Assembly*MenuType	1	0.00	0.00	0.00	0.00	0.995
Assembly*Delivery	1	145.71	145.71	145.71	3.0E+05	0.000
MenuType*Delivery	1	0.00	0.00	0.00	0.00	0.956
Assembly*MenuType* Delivery	1	0.00	0.00	0.00	0.00	0.956
Error	792	0.38	0.38	0.00		
Total	799	750.58				

Table 5.13: Tukey Multiple Comparison of Average Assembly Time for Foodservice System Configurations in Large Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Assembly Time
5	Cell	Fixed	Traditional	1.07
7	Cell	Fixed	Room Service	1.07
1	Line	Fixed	Traditional	1.15
3	Line	Fixed	Room Service	1.15
6	Cell	Choice	Traditional	1.69
8	Cell	Choice	Room Service	1.69
4	Line	Choice	Room Service	3.47
2	Line	Choice	Traditional	3.47

A complete set of tables containing the results of the experimental performance evaluation appear in the appendices. Appendix B contains the results of the full factorial ANOVA conducted for each performance measure. Appendix C and Appendix D contain the three-factor ANOVA and Tukey multiple range tests for each of the performance measures conducted for small and large hospitals, respectively. A summary of the rankings of each of the configurations with regard to each key performance measure for small and large hospitals are shown in Table 5.14 and Table 5.15, respectively.

Table 5.14: Summary of Performance Measure Rankings of Configurations for Small Hospitals

Assembly Time	Overall Cycle Time	Assembly Make-Span	Make-Span of System	Patient Satisfaction	Productivity	Time In Cart
5, 7	8	1, 3	1	8	7, 5	8
1, 3	7	2, 4	3	4	1, 3	4
6, 8	4	5, 7	7	7	6, 8	7
2, 4	5	6, 8	4	3	2, 4	2, 5
	6		5, 8	5		6
	1, 3		2	2		1
	2		6	6, 1		3

Table 5.15: Summary of Performance Measure Rankings of Configurations for Large Hospitals

Assembly Time	Overall Cycle Time	Assembly Make-Span	Make-Span of System	Patient Satisfaction	Productivity	Time In Cart
5, 7	4	5, 7	1, 5	4	5, 7	4
1, 3	6	1, 3	6	8	1, 3	8
6, 8	8	6, 8	3, 7	3	6, 8	1, 5
2, 4	2	2, 4	4, 8	7	2, 4	3, 7
	5		2	5		2, 6
	1			1		
	3			6		
	7			2		

In addition to the analysis of the factorial experiments, a single factor comparison is performed. The purpose of this analysis is to determine which factor level is optimal when considered independently from the other factors. Although from the above analysis one can conclude that the interactions effects are very significant, this analysis provides a perspective which individual factor level is best without regard to the levels of the other factors. The results of this analysis for the effect of delivery method on patient satisfaction are shown in Table 5.16. From this ANOVA and by observing the average values of patient satisfaction for each factor level, one can conclude that the room service method results in a significantly better level of patient satisfaction than does the traditional delivery method if no consideration is given to the other factors or the interactions. This information may be beneficial to a hospital that needs to make a decision about one of these factors where the other aspects of the system configuration do not represent the operation of the foodservice system for that particular hospital. The complete set of single factor analyses appears in Appendix E.

Table 5.16: Single Factor Analysis of Delivery System for Patient Satisfaction

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Delivery System	1	983.01	983.01	983.01	3432.46	0.000
Error	798	228.54	228.54	0.290		
Total	799	1211.54				

5.2 Analysis of Results

In order to evaluate how productive a particular system is, one can examine productivity (trays per hour per assembly worker) as well as the utilization of the assembly workers and delivery people. The cycle time of an individual tray is represented by the overall cycle time, however, for a more detailed analysis, one should examine the time the tray spends in the

assembly portion (assembly time) and the time that the tray sits in the cart until it is delivered (time in cart). The make-span of the assembly portion of the system and the entire system are represented by assembly make-span and make-span of the system, respectively. The minimum number of assembly and delivery operators are used in the models so that the make-span times are within a two hour period for the small hospitals and within a two and a half hour period for the large hospitals. Therefore, the means of all the systems' make-span times are reasonable and can accurately be compared to determine the most efficient system. Patient Satisfaction is a calculation in the model that takes into consideration the time that a tray spends in the delivery cart as well as how close the time that the tray is delivered to the patient is to the time that the patient desired the tray to be delivered to them.

The multiple comparison tests reveal that there is a significant difference between the configurations containing the factors of assembly method, menu type, and delivery system. However, the factor hospital size demonstrates the need for a more detailed analysis. Therefore, the experiment is broken down further by separating the analysis of the small and large hospital configurations. The three-way comparison between assembly method, menu type, and delivery system yield the results that are used to compare the two groups of eight systems.

There is more than one interpretation of the results because different performance measures yield different results in terms of an optimal system. This shows the strengths of each system. The key performance measures are productivity, cycle time, make-span of the assembly portion and of the entire system, and patient satisfaction. The measures recorded during the experiment include other items such as the time that a tray spends on the cart, the number of windows a tray was late or early, etc. This information can aid in the decision making process of which system to use. For instance, a hospital may find the number of trays late, early, and on

time interesting because they can use additional techniques to improve this number. An example of this is waiting to deliver trays until a defined lead-time before the delivery window occurs. This could reduce the number of early trays and improve the number of trays delivered on time. The detailed tables for these additional results are presented in Appendix A.

Based on the results of these single factor analyses, several of the performance measures result in robust solutions for the small and large hospitals. The rankings of each system's performance measure mean from the experiments are provided in the appendix. One can conclude that from a productivity perspective, systems 5 (Cell, Fixed, Traditional) and 7 (Cell, Fixed, Room Service) would be the appropriate choice for both small and large hospitals. However, from a patient satisfaction perspective, 8 (Cell, Choice, Room Service) would be the best choice for a small hospital and 4 (Cell, Choice, Traditional) for a large hospital. If considering the factors individually, a cellular assembly method would be recommended, as well as the room service delivery system because they demonstrate the best results. For the menu type, however, it is a matter of productivity versus patient satisfaction. If a hospital focuses on productivity, then the fixed menu would be recommended, but if the hospital focuses on patient satisfaction, the choice menu would be suggested.

5.3 Individual Hospital Application

Since there are over four thousand hospitals in the United States, it seems reasonable that they will not all be using the same foodservice system. It can also be assumed then that one solution will not be the best solution for every hospital. Therefore, the results of this experiment provide multiple solutions based on different performance measures. This allows each hospital

to determine which performance measures are most important to them and examine the results from that perspective.

The two main performance measures that take into consideration some of the other measures are productivity and patient satisfaction. Evaluation of productivity should also include the evaluation of the overall cycle time, assembly time, assembly make-span and make-span of the system. Although most of these measures result in the same optimal system configuration, examination of the actual means may demonstrate that the second best system is not that far off from the first and would better meet the hospital's needs. Patient satisfaction actually takes into consideration the measure of time the tray spends in the cart and the time the tray is delivered relative to the time that the patient requested it. Therefore, one could examine the optimal system based on patient satisfaction and also examine the other top systems to see if there is one that meets some of the other performance measures as well. This could allow a hospital to implement a system that performs fairly well in terms of both productivity and patient satisfaction, but may not be the optimal system for one measure or the other. Chapter 6 presents the recommended system configuration as well as provides an example of how to tailor the results to a specific hospital's needs through the case study.

5.4 Comparison of Resource Requirements

Each system configuration requires a certain number of assembly and delivery people. Therefore, the labor costs will vary among systems. Tables 5.17 and 5.18 illustrate the number of workers required for each system. In addition to labor costs, some equipment costs may be involved with the implementation of a new foodservice tray assembly and delivery system. However, this will vary between individual hospitals. The reason for this is that the equipment

the hospital already possesses may be feasible for the new system or the hospital may need to purchase the proper equipment.

Table 5.17: Amount of Labor Required for Small Hospital Systems

Config.	Number of Workers		
	Assembly	Delivery	Total
1	5	4	9
2	7	4	11
3	5	4	9
4	7	4	11
5	3	4	7
6	4	4	8
7	3	4	7
8	4	4	8

Table 5.18: Amount of Labor Required for Large Hospital Systems

Config.	Number of Workers		
	Assembly	Delivery	Total
1	10	8	18
2	14	8	22
3	10	8	18
4	14	8	22
5	8	8	16
6	10	8	18
7	8	8	16
8	10	8	18

6 Case Study

This case study is of F.F. Thompson Hospital, a hospital that is representative of the operational aspects of a typical hospital with regard to the foodservice system. F.F. Thompson Hospital in Canandaigua, New York, is in the process of building a new kitchen and has eagerly agreed to serve as a case study of an existing foodservice system for the purposes of this thesis work and in return, plans to benefit from the information obtained from the results. One of the main reasons for F.F. Thompson Hospital's renovations is that the kitchen is required to produce 89 percent more meals than the original kitchen design parameters. In addition to serving its acute care patients, the kitchen also provides meals for its continuing care facility and a daycare. By increasing the capacity of the kitchen, the hospital also hopes to participate in serving the outside community in programs such as meals on wheels. The current kitchen and foodservice system are unable handle that additional capacity since the original capacity is already being exceeded and much of the equipment is nearing the end of the equipment's useful life.

While F.F. Thompson Hospital's foodservice system is adequately meeting the nutritional and medical requirements of the hospital as well as providing a relatively high level of satisfaction to patients, the question remains as to the best overall foodservice system that should be implemented to maximize productivity and patient satisfaction. As the hospital is designing the new kitchen, the effect that the additional capacity requirements that the hospital anticipates will have on the tray assembly and delivery portion of the process must be considered. Simply adding labor to the tray assembly line's current process will not result in increased throughput. Therefore, alternative systems must be considered.

For the purposes of this investigation, F.F. Thompson Hospital in Canandaigua, New York, has provided us access to their facility and any information that may be required to

successfully complete this analysis. The examination of the existing foodservice system at F.F. Thompson Hospital provides both a facility for verifying and validating the experiments that have been conducted as well as an opportunity to apply the experimental results in an hospital environment.

The case study provides a description of the current system, the simulation modeling and analysis, as well as recommendations for the configuration of the hospital foodservice system. This section also provides insight for other hospitals in how they can utilize the results of the experiment presented in Chapters 4 and 5 to select the best system configuration for their hospital foodservice system.

6.1 System Description

The system configuration that F.F. Thompson Hospital currently uses consists of an assembly line for the tray assembly, a choice menu, and a type of traditional delivery method. The hospital serves between 240 and 260 patients per meal. The assembly line consists of seven stations and has the same layout as the base system configuration depicted in Figure 4.1. Consequently, there are seven assembly workers in the system. The choice menu contains a large number of items such as a hot entrée, a cold entrée, a vegetable side dish, a salad, dessert, soup, a variety of juices, and a hot beverage, so the line must be equipped with all the choices and diet varieties. The patients place their food order via a paper menu each day for the following day's meals. Thus, the kitchen knows the overall quantities required of each item offered on the menu twenty-four hours in advance so that they can prepare the requested amount of each item. This helps reduce food waste.

The delivery portion of F.F. Thompson Hospital's foodservice system is slightly altered from that of the traditional delivery system defined previously. In F.F. Thompson Hospital's system, a kitchen employee delivers the full cart to each location but does not deliver the trays to the individual patients. This task is the responsibility of the nurses on the floor. However, there are several locations where two other kitchen employees deliver the carts to the floor and then deliver the food to each patient individually. One issue that can arise with the method of delivering the carts to the floors and having the nurses deliver the trays is that the kitchen does not have control over when the trays are actually delivered to the patient. The delivery person may bring the entire cart to the floor as soon as the last tray in the cart has come off the line, but the nurses may not deliver the trays immediately if the nurses are already occupied with other tasks.

6.2 Simulation Modeling and Analysis

For this case study, a simulation model is constructed of the F.F. Thompson Hospital foodservice system. Based on the description, the current foodservice system can be most closely classified as a relatively small hospital that utilizes an assembly line for tray assembly and a choice menu. Although for some locations, the delivery method consists of only delivering the cart and not the individual meals, the system most closely follows the traditional delivery method. The current layout of the assembly line is that depicted in Figure 4.1. Consequently, the simulation model of the current system consists essentially of the base simulation model described in Section 4.5.1 with a few modifications. In particular, the number of trays assembled per meal is increased to 260; the additional 60 trays are distributed equally among three of the ten delivery locations; and the number of delivery personnel is increased by one.

These same modifications are also made to the other seven configurations so that an experiment could be run and the results examined. In addition to those modifications made on the base model, the models containing the room service delivery system required an increase in the number of meals delivered during each window. Since there are six possible delivery windows, the total number of meals is divided by six to determine the number of meals per window, forty-four. This is an increase of ten from the models with 200 meals. Once these alterations are made to the models, each model is run for 100 replications, the same as the experiment for 200 and 600 meals. The results of the performance measures are presented in Tables 6.1 – 6.3. The configurations are then ranked from best to worst within each performance measure. The ranking of the systems within each performance measure are illustrated in Table 6.4. The configurations can easily be compared to the results of the small hospital experiment. These comparisons are illustrated in Table 6.4. Please refer to Appendix F for the full results.

Table 6.1: Definition of System Configurations for F.F. Thompson Hospital

Config.	**Assembly Method**	**Delivery System**	**Menu Choice**
1	Line	Traditional	Fixed
2	Line	Traditional	Choice
3	Line	Room Service	Fixed
4	Line	Room Service	Choice
5	Cell	Traditional	Fixed
6	Cell	Traditional	Choice
7	Cell	Room Service	Fixed
8	Cell	Room Service	Choice

Table 6.2: Summary of the Performance Measure Results for F.F. Thompson Hospital

Config.	Assembly Time (minutes)	Overall Cycle Time (minutes)	Assembly Make-Span (minutes)	Make-Span of System (minutes)
1	1.15	16.74	73.65	101.92
2	3.47	20.06	100.7	130.0
3	1.15	12.80	73.7	95.8
4	3.47	12.63	100.7	118.7
5	1.07	16.61	76.0	101.6
6	1.69	17.84	93.1	118.9
7	1.07	12.98	75.9	96.0
8	1.69	10.91	93.1	107.8

Table 6.3: Summary of the Performance Measure Results for F.F. Thompson Hospital

Config.	Patient Satisfaction	Productivity (trays/hr/worker)	Time In Cart (minutes)
1	6.90	30.61	15.6
2	6.38	17.14	16.6
3	8.91	32.56	11.7
4	9.17	18.78	9.2
5	6.91	38.37	15.5
6	6.61	26.24	16.1
7	8.86	40.61	11.9
8	9.41	28.96	9.2

Table 6.4: Ranking of System Comparisons For Each Performance Measure for F.F. Thompson Hospital

Assembly Time	Overall Cycle Time	Assembly Make-Span	Make-Span of System	Patient Satisfaction	Productivity	Time In Cart
5, 7	8	1, 3	3, 7	8	7	4, 8
1, 3	4	7, 5	5, 1	4	5	3, 7
6, 8	3	6, 8	8	3	3	5, 1
2, 4	7	2, 4	4, 6	7	1	6, 2
	5		2	5	8	
	1			1	6	
	6			6	4	
	2			2	2	

6.3 Recommendation

As the statistics from the experiment indicate, some of the performance measures result in the same system configurations for both a small hospital and F.F. Thompson Hospital. Based on these results, a system can be recommended for F.F Thompson. The system recommended to F.F. Thompson Hospital is configuration 7. Configuration 7 is an assembly cell, fixed menu, with a room service delivery system. The reason this system is recommended is that it yields the best results from a productivity perspective. It is ranked first for both the assembly time and the make-span of the system and is third in terms of patient satisfaction. From an Industrial Engineering perspective, it is important to have an efficient production system. Therefore, system 7 is recommended for F.F. Thompson Hospital.

However, in addition to the system selected for F.F. Thompson, another recommendation is made that takes into consideration F.F Thompson's perception of the weight of the performance measure in terms of importance. F.F. Thompson Hospital's foodservice director has chosen Patient Satisfaction as the most important performance measure (Ovenshire 2003). He chose this not only because it is important to satisfy the hospital's customer, but also since

the Patient Satisfaction measure takes into consideration in its calculation the other measures that F.F. Thompson is often concerned about: the time the tray spends in the cart from the time it finishes on the line until the time it is delivered to the patient and also if the patient is satisfied with the delivery time of their meal. Therefore, since Patient Satisfaction is most important in the consideration of a tray assembly and delivery system, system configuration 8 is recommended to F.F. Thompson Hospital because it has the highest Patient Satisfaction ranking. Configuration 8 is an assembly cell, choice menu, room service delivery system. This system also allows for additional capacity in that it was ranked second in the Large Hospital experiment and analysis. F.F. Thompson currently uses a choice menu system, but the assembly cell and room service delivery system would require some changes to the system. Most of the equipment currently used on the assembly line can be rearranged into the U-shaped cell and the roller conveyor removed. A segmented device would need to be purchased for the tray to slide on through the assembly cell. Adjustments in the number of full time employees required will also need to be made. Since the hospital is currently in the process of building a new kitchen, this is the opportune time for these improvements.

In addition to the equipment and labor changes, there are several lean manufacturing concepts that F.F. Thompson Hospital could implement in their foodservice operations. These concepts can help to reduce wasted motions and time. One recommendation would be for the food to be presented to the operator in mass quantities rather than pre-scooping the items in advance and placing them in individual containers. Not only would this reduce preparation time and floor space, but it could improve on the appearance of the tray because there would be less containers cluttering the tray. The current system uses mass quantities at the hot stations, but pre-scoops the items at the cold stations.

7 Conclusions

The function of a foodservice system in a hospital is a fundamental part of the health care industry. Consequently, the efficiency of the operational aspects of foodservice can significantly impact a hospital's budget and perceived level of satisfaction by the patient. This study has provided an in-depth investigation into alternative foodservice methods for serving patient meals including the assembly method, order and delivery method, and the menu type for hospitals of various sizes. In particular, the experimental results clearly show how alternative system configurations affect key foodservice system performance measures. The construction and execution of a full factorial experiment and the evaluation of the alternative configurations through the use of computer simulation illustrates the positive impact that simulation and other industrial engineering tools can have when applied to operational issues in health care.

The results of the experiment provide a template for hospitals to use to determine improvements that can be made to their system. Furthermore, the results of the experiment can aid in determining the best foodservice system for hospitals of various sizes. The application of the results to an existing system at F.F. Thompson Hospital demonstrate how this method can be applied in a specific hospital environment. Consequently, based on the experimental analysis the conclusion of the case study recommends configuration 7 (an assembly cell, fixed menu, room service delivery system) as the best overall foodservice system for F.F. Thompson Hospital. This decision is made from an industrial engineering perspective, focusing on productivity. However, if a hospital deems other performance measures more important such as patient satisfaction, then the decision can be made based on that particular measure. Finally, the case study demonstrates how the results of the experiment and the overall approach to solving these types of operational problems can be applied to health care systems.

8 Recommendations for Future Research

There are several areas that are recommended for future research. One such area related to this thesis that could be investigated is the modeling and analysis of food preparation and capacity. Another related area is the analysis of the hospital cafeteria foodservice methods. There are also other operations within health care that could be examined such as the optimal allocation of beds within departments, the optimal allocation of private versus semiprivate rooms, and the flow of patients through the hospital. Yet another possible investigation is the study of equipment utilization and capital investment. A concept similar to that is the study of inventory control in terms of medical supplies and small medical utensils. These are several recommendations for future research.

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Appendix A

This appendix presents the results of the experiment run for both small and large hospitals. The eight different system configurations are defined and the results for small and large hospital models indicated. The results include the performance measures as well as additional useful data such as the number of trays early, late and on time.

Table A.1: Definition of System Configurations

Config.	Assembly Method	Delivery System	Menu Choice
1	Line	Traditional	Fixed
2	Line	Traditional	Choice
3	Line	Room Service	Fixed
4	Line	Room Service	Choice
5	Cell	Traditional	Fixed
6	Cell	Traditional	Choice
7	Cell	Room Service	Fixed
8	Cell	Room Service	Choice

Table A.2: Summary of Average Performance Measure Results for Small Hospital Models

Config.	Assembly Time (minutes)	Overall Cycle Time (minutes)	Assembly Make-Span (minutes)	Make-Span of System (minutes)
1	1.15	19.30	56.2	91.6
2	3.45	20.19	77.0	106.3
3	1.15	19.49	56.2	93.4
4	3.45	14.33	77.0	97.7
5	1.07	17.76	77.9	103.7
6	1.69	18.83	89.5	115.4
7	1.07	12.69	77.9	97.2
8	1.69	11.62	89.6	104.1

Table A.3: Summary of Average Performance Measure Results for Large Hospital Models

Config.	Assembly Time (minutes)	Overall Cycle Time (minutes)	Assembly Make-Span (minutes)	Make-Span of System (minutes)
1	1.15	21.42	88.15	125.82
2	3.47	20.21	121.06	146.95
3	1.15	25.19	88.15	136.25
4	3.47	15.02	121.20	139.93
5	1.07	21.10	87.79	125.32
6	1.69	18.01	107.76	133.76
7	1.07	25.77	87.77	136.21
8	1.69	18.76	107.74	138.40

Table A.4: Summary of Average Performance Measure Results for Small Hospital Models

Config.	Patient Satisfaction	Productivity (trays/hr/worker)	Time In Cart (minutes)
1	6.42	42.68	18.2
2	6.62	22.25	16.7
3	7.50	42.67	18.3
4	9.17	22.25	10.9
5	6.67	51.37	16.7
6	6.44	33.51	17.1
7	8.99	51.38	11.6
8	9.36	33.48	9.9

Table A.5: Summary of Average Performance Measure Results for Large Hospital Models

Config.	Patient Satisfaction	Productivity (trays/hr/worker)	Time In Cart (minutes)
1	5.53	40.84	20.27
2	4.64	21.24	47.20
3	6.81	40.84	24.04
4	8.97	21.22	11.54
5	5.58	51.26	20.03
6	4.80	33.41	43.39
7	6.75	51.27	24.69
8	7.88	33.41	17.07

Table A.6: Summary of Average Results for Small Hospital Models

Config.	Number of Trays			Number of "No Preference Meals"
	Early	Late	On Time	
1	79.47	53.53	27.27	39.73
2	61.38	72.85	26.05	39.72
3	60.40	0.08	99.79	39.73
4	23.30	4.70	132.28	39.72
5	26.41	67.50	66.36	39.73
6	55.95	80.07	23.86	40.12
7	32.48	1.79	126.00	39.73
8	6.20	19.79	133.89	40.12

Table A.7: Summary of Average Results for Large Hospital Models

Config.	Number of Trays			Number of "No Preference Meals"
	Early	Late	On Time	
1	232.99	187.30	59.02	120.69
2	182.16	242.79	54.95	120.10
3	70.72	40.70	367.89	120.69
4	14.17	107.21	358.52	120.10
5	235.46	185.04	58.81	120.69
6	209.08	213.02	58.64	119.26
7	64.28	43.45	371.58	120.69
8	29.04	84.33	367.37	119.26

Table A.8: Summary of Average Results for Small Hospital Models

Config.	Windows Early (Number of Trays)				
	1	2	3	4	5 or More
1	26.04	22.68	16.01	10.23	4.51
2	21.68	17.50	12.24	7.45	2.51
3	60.40	0.00	0.00	0.00	0.00
4	23.30	0.00	0.00	0.00	0.00
5	24.14	18.30	12.61	8.04	3.27
6	19.93	15.49	10.93	7.19	2.41
7	32.48	0.00	0.00	0.00	0.00
8	6.20	0.00	0.00	0.00	0.00

Table A.9: Summary of Average Results for Large Hospital Models

Config.	Windows Early (Number of Trays)				
	1	2	3	4	5 or More
1	59.52	49.94	42.48	34.25	46.80
2	47.83	40.69	33.53	26.35	33.76
3	70.72	0.00	0.00	0.00	0.00
4	14.17	0.00	0.00	0.00	0.00
5	59.45	50.60	42.61	34.53	48.27
6	54.19	47.26	37.85	29.63	40.15
7	64.28	0.00	0.00	0.00	0.00
8	29.04	0.00	0.00	0.00	0.00

Table A.10: Summary of Average Results for Small Hospital Models

Config.	**Windows Late (Number of Trays)**				
	1	**2**	**3**	**4**	**5 or More**
1	22.70	15.49	9.88	4.73	0.73
2	25.03	18.22	14.76	9.46	5.38
3	0.08	0.00	0.00	0.00	0.00
4	4.70	0.00	0.00	0.00	0.00
5	24.01	18.23	13.20	8.21	3.85
6	24.46	19.97	15.54	11.28	8.82
7	1.79	0.00	0.00	0.00	0.00
8	19.79	0.00	0.00	0.00	0.00

Table A.11: Summary of Average Results for Large Hospital Models

Config.	**Windows Late (Number of Trays)**				
	1	**2**	**3**	**4**	**5 or More**
1	53.92	44.06	33.64	26.15	29.53
2	56.25	49.87	41.49	34.40	60.78
3	40.70	0.00	0.00	0.00	0.00
4	107.19	0.02	0.00	0.00	0.00
5	53.27	43.89	33.39	25.79	28.71
6	55.19	46.45	38.39	31.34	41.65
7	43.43	0.02	0.00	0.00	0.00
8	84.27	0.06	0.00	0.00	0.00

Table A.12: Summary of Average Results for Small Hospital Models

Config.	Number of Workers			Utilization		
	Assembly	Delivery	Total	Assembly	Delivery	Total
1	5	4	9	0.46	0.73	0.58
2	7	4	11	0.56	0.63	0.59
3	5	4	9	0.46	0.92	0.64
4	7	4	11	0.61	0.83	0.69
5	3	4	7	0.75	0.65	0.69
6	4	4	8	0.77	0.58	0.68
7	3	4	7	0.80	0.84	0.82
8	4	4	8	0.85	0.79	0.82

Table A.13: Summary of Average Results for Large Hospital Models

Config.	Number of Workers			Utilization		
	Assembly	Delivery	Total	Assembly	Delivery	Total
1	10	8	18	0.51	0.80	0.64
2	14	8	22	0.61	0.69	0.64
3	10	8	18	0.47	0.89	0.66
4	14	8	22	0.64	0.87	0.72
5	8	8	16	0.70	0.81	0.75
6	10	8	18	0.80	0.76	0.78
7	8	8	16	0.64	0.90	0.77
8	10	8	18	0.77	0.89	0.82

Table A.14: Summary of Average Results for Small Hospital Models

Config.	Window Requested					
	1	2	3	4	5	6
1	26.06	26.40	26.50	27.13	27.19	26.99
2	27.66	26.59	26.31	26.18	27.01	26.53
3	26.06	26.40	26.50	27.13	27.19	26.99
4	27.66	26.59	26.31	26.18	27.01	26.53
5	26.06	26.40	26.50	27.13	27.19	26.99
6	26.34	26.14	27.16	26.65	26.90	26.69
7	26.06	26.40	26.50	27.13	27.19	26.99
8	26.34	26.14	27.16	26.65	26.90	26.69

Table A.15: Summary of Average Results for Large Hospital Models

Config.	Window Requested							
	1	2	3	4	5	6	7	8
1	59.72	60.18	58.15	59.33	60.21	61.18	60.90	59.64
2	61.42	59.45	60.52	60.19	59.10	60.14	59.69	59.39
3	59.72	60.18	58.15	59.33	60.21	61.18	60.90	59.64
4	61.42	59.45	60.52	60.19	59.10	60.14	59.69	59.39
5	59.72	60.18	58.15	59.33	60.21	61.18	60.90	59.64
6	59.80	59.78	59.79	61.90	59.28	60.81	59.54	59.84
7	59.72	60.18	58.15	59.33	60.21	61.18	60.90	59.64
8	59.80	59.78	59.79	61.90	59.28	60.81	59.54	59.84

Table A.16: Summary of System Configuration Rankings for Performance Measures for Small Hospital Models

Assembly Time	Overall Cycle Time	Assembly Make-Span	Make-Span of System	Patient Satisfaction	Productivity	Time In Cart
5, 7	8	1, 3	1	8	7, 5	8
1, 3	7	2, 4	3	4	1, 3	4
6, 8	4	5, 7	7	7	6, 8	7
2, 4	5	6, 8	4	3	2, 4	2, 5
	6		5, 8	5		6
	1, 3		2	2		1
	2		6	6, 1		3

Table A.17: Summary of System Configuration Rankings for Performance Measures for Large Hospital Models

Assembly Time	Overall Cycle Time	Assembly Make-Span	Make-Span of System	Patient Satisfaction	Productivity	Time In Cart
5, 7	4	5, 7	1, 5	4	5, 7	4
1, 3	6	1, 3	6	8	1, 3	8
6, 8	8	6, 8	3, 7	3	6, 8	1, 5
2, 4	2	2, 4	4, 8	7	2, 4	3, 7
	5		2	5		2, 6
	1			1		
	3			6		
	7			2		

Appendix B

This appendix contains the full factorial ANOVA tables for all of the performance measures. The full factorial analysis contains four factors with two factor levels for each.

Table B.1: Full Factorial ANOVA of Assembly Time for Foodservice System Configurations

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hospital	1	0.014	0.014	0.014	13.02	0.000
Assembly	1	340.368	340.368	340.368	3.2E+05	0.000
MenuType	1	859.17	859.17	859.17	8.1E+05	0.000
Delivery	1	0.000	0.000	0.000	0.01	0.943
Hospital*Assembly	1	0.014	0.014	0.014	13.06	0.000
Hospital*MenuType	1	0.007	0.007	0.007	7.07	0.008
Hospital*Delivery	1	0.000	0.000	0.000	0.01	0.938
Assembly*MenuType	1	288.483	288.483	288.483	2.7E+05	0.000
Assembly*Delivery	1	0.000	0.000	0.000	0.01	0.943
MenuType*Delivery	1	0.000	0.000	0.000	0.01	0.943
Hospital*Assembly*						
MenuType	1	0.007	0.007	0.007	7.02	0.008
Hospital*Assembly*						
Delivery	1	0.000	0.000	0.000	0.01	0.938
Hospital*MenuType*		0.000	0.000			
Delivery	1	0.000	0.000	0.000	0.00	0.985
Assembly*MenuType*		0.000	0.000			
Delivery	1	0.000	0.000	0.000	0.01	0.943
Hospital*Assembly*						
MenuType*Delivery	1	0.000	0.000	0.000	0.00	0.985
Error	1584	1.678	1.678	0.001		
Total	1599	1489.741				

Table B.2: Full Factorial ANOVA of Overall Cycle Time for Foodservice System Configurations

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hospital	1	6110.5	6110.5	6110.5	2.9E+04	0.000
Assembly	1	705	705	705	3400.04	0.000
MenuType	1	4147.7	4147.7	4147.7	2.0E+04	0.000
Delivery	1	1218.9	1218.9	1218.9	5878.44	0.000
Hospital*Assembly	1	1263.6	1263.6	1263.6	6094.19	0.000
Hospital*MenuType	1	1854.5	1854.5	1854.5	8943.92	0.000
Hospital*Delivery	1	3012.2	3012.2	3012.2	1.5E+04	0.000
Assembly*MenuType	1	194.1	194.1	194.1	936.11	0.000
Assembly*Delivery	1	0.3	0.3	0.3	1.66	0.198
MenuType*Delivery	1	2771.1	2771.1	2771.1	1.3E+04	0.000
Hospital*Assembly* MenuType	1	55.8	55.8	55.8	269.06	0.000
Hospital*Assembly* Delivery	1	1127.6	1127.6	1127.6	5437.98	0.000
Hospital*MenuType* Delivery	1	137	137	137	660.68	0.000
Assembly*MenuType* Delivery	1	503.3	503.3	503.3	2427.2	0.000
Hospital*Assembly* MenuType*Delivery	1	8	8	8	38.68	0.000
Error	1584	328.4	328.4	0.2		
Total	1599	23438.1				

Table B.3: Full Factorial ANOVA of the Make-Span of System for Foodservice System Configurations

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hospital	1	466487	466487	466487	2.7E+05	0.000
Assembly	1	1628	1628	1628	932.45	0.000
MenuType	1	33501	33501	33501	1.9E+04	0.000
Delivery	1	204	204	204	116.74	0.000
Hospital*Assembly	1	13603	13603	13603	7792.5	0.000
Hospital*MenuType	1	33	33	33	19.1	0.000
Hospital*Delivery	1	11868	11868	11868	6798.83	0.000
Assembly*MenuType	1	1333	1333	1333	763.92	0.000
Assembly*Delivery	1	7	7	7	4.08	0.044
MenuType*Delivery	1	9426	9426	9426	5400.02	0.000
Hospital*Assembly* MenuType	1	1181	1181	1181	676.35	0.000
Hospital*Assembly* Delivery	1	3360	3360	3360	1925.08	0.000
Hospital*MenuType* Delivery	1	459	459	459	262.72	0.000
Assembly*MenuType* Delivery	1	1782	1782	1782	1020.91	0.000
Hospital*Assembly* MenuType*Delivery	1	191	191	191	109.22	0.000
Error	1584	2765	2765	2		
Total	1599	547828				

Table B.4: Full Factorial ANOVA of the Assembly Make-Span for Foodservice System Configurations

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hospital	1	271057	271057	271057	3.1E+05	0.000
Assembly	1	10398	10398	10398	1.2E+04	0.000
MenuType	1	182612	182612	182612	2.1E+05	0.000
Delivery	1	0.000	0.000	0.000	0.33	0.563
Hospital*Assembly	1	57332	57332	57332	6.6E+04	0.000
Hospital*MenuType	1	10464	10464	10464	1.2E+04	0.000
Hospital*Delivery	1	0.000	0.000	0.000	0.000	0.99
Assembly*MenuType	1	12223	12223	12223	1.4E+04	0.000
Assembly*Delivery	1	0.000	0.000	0.000	0.09	0.758
MenuType*Delivery	1	0.000	0.000	0.000	0.46	0.498
Hospital*Assembly* MenuType	1	382	382	382	443.31	0.000
Hospital*Assembly* Delivery	1	0.000	0.000	0.000	0.39	0.531
Hospital*MenuType* Delivery	1	0.000	0.000	0.000	0.02	0.881
Assembly*MenuType* Delivery	1	0.000	0.000	0.000	0.04	0.847
Hospital*Assembly* MenuType*Delivery	1	0.000	0.000	0.000	0.36	0.549
Error	1584	1366	1366	1		
Total	1599	545835				

Table B.5: Full Factorial ANOVA of the Productivity for Foodservice System Configurations

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hospital	1	236	236	236	2572.73	0.000
Assembly	1	45231	45231	45231	4.9E+05	0.000
MenuType	1	143493	143493	143493	1.6E+06	0.000
Delivery	1	0.000	0.000	0.000	0.15	0.694
Hospital*Assembly	1	178	178	178	1941.14	0.000
Hospital*MenuType	1	17	17	17	188.56	0.000
Hospital*Delivery	1	0.000	0.000	0.000	0.08	0.78
Assembly*MenuType	1	461	461	461	5036.3	0.000
Assembly*Delivery	1	0.000	0.000	0.000	0.02	0.893
MenuType*Delivery	1	0.000	0.000	0.000	0.29	0.588
Hospital*Assembly* MenuType	1	15	15	15	168.31	0.000
Hospital*Assembly* Delivery	1	0.000	0.000	0.000	0.25	0.618
Hospital*MenuType* Delivery	1	0.000	0.000	0.000	0.000	0.983
Assembly*MenuType* Delivery	1	0.000	0.000	0.000	0.01	0.917
Hospital*Assembly* MenuType*Delivery	1	0.000	0.000	0.000	0.21	0.648
Error	1584	145	145	0.000		
Total	1599	189776				

Table B.6: Full Factorial ANOVA of the Patient Satisfaction for Foodservice System Configurations

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hospital	1	649.85	649.85	649.85	5.5E+04	0.000
Assembly	1	4.14	4.14	4.14	349.91	0.000
MenuType	1	82.03	82.03	82.03	6941.56	0.000
Delivery	1	2193.19	2193.19	2193.19	1.9E+05	0.000
Hospital*Assembly	1	45.3	45.3	45.3	3832.89	0.000
Hospital*MenuType	1	0.95	0.95	0.95	80.61	0.000
Hospital*Delivery	1	6.21	6.21	6.21	525.38	0.000
Assembly*MenuType	1	43.31	43.31	43.31	3665.06	0.000
Assembly*Delivery	1	0.39	0.39	0.39	33.32	0.000
MenuType*Delivery	1	308.08	308.08	308.08	2.6E+04	0.000
Hospital*Assembly*MenuType	1	3.97	3.97	3.97	336.11	0.000
Hospital*Assembly*Delivery	1	54.4	54.4	54.4	4603.38	0.000
Hospital*MenuType*Delivery	1	52.41	52.41	52.41	4434.87	0.000
Assembly*MenuType*Delivery	1	25.28	25.28	25.28	2139	0.000
Hospital*Assembly*MenuType*Delivery	1	0.52	0.52	0.52	43.74	0.000
Error	1584	18.72	18.72	0.01		
Total	1599	3488.76				

Table B.7: Full Factorial ANOVA of the Assembly Utilization for Foodservice System Configurations

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hospital	1	0.1343	0.1343	0.1343	4347.11	0.000
Assembly	1	24.0664	24.0664	24.0664	7.8E+05	0.000
MenuType	1	0.0116	0.0116	0.0116	375.1	0.000
Delivery	1	0.000	0.000	0.000	0.55	0.459
Hospital*Assembly	1	0.1033	0.1033	0.1033	3345.64	0.000
Hospital*MenuType	1	0.0004	0.0004	0.0004	12.96	0.000
Hospital*Delivery	1	0.000	0.000	0.000	0.10	0.751
Assembly*MenuType	1	0.0254	0.0254	0.0254	823.96	0.000
Assembly*Delivery	1	0.000	0.000	0.000	0.05	0.83
MenuType*Delivery	1	0.000	0.000	0.000	0.81	0.368
Hospital*Assembly* MenuType	1	0.0003	0.0003	0.0003	8.28	0.004
Hospital*Assembly* Delivery	1	0.000	0.000	0.000	0.71	0.4
Hospital*MenuType* Delivery	1	0.000	0.000	0.000	0.000	0.989
Assembly*MenuType* Delivery	1	0.000	0.000	0.000	0.000	0.975
Hospital*Assembly* MenuType*Delivery	1	0.000	0.000	0.000	0.62	0.431
Error	1584	0.0489	0.0489	0.000		
Total	1599	24.3907				

Table B.8: Full Factorial ANOVA of the Delivery Utilization for Foodservice System Configurations

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hospital	1	2.788	2.788	2.788	3.8E+04	0.000
Assembly	1	0.063	0.063	0.063	862.94	0.000
MenuType	1	1.326	1.326	1.326	1.8E+04	0.000
Delivery	1	9.583	9.583	9.583	1.3E+05	0.000
Hospital*Assembly	1	0.560	0.560	0.560	7723.48	0.000
Hospital*MenuType	1	0.021	0.021	0.021	289.93	0.000
Hospital*Delivery	1	0.427	0.427	0.427	5884.26	0.000
Assembly*MenuType	1	0.062	0.062	0.062	856.5	0.000
Assembly*Delivery	1	0.004	0.004	0.004	59.5	0.000
MenuType*Delivery	1	0.273	0.273	0.273	3764.44	0.000
Hospital*Assembly*MenuType	1	0.016	0.016	0.016	218.2	0.000
Hospital*Assembly*Delivery	1	0.078	0.078	0.078	1070.22	0.000
Hospital*MenuType*Delivery	1	0.018	0.018	0.018	244.72	0.000
Assembly*MenuType*Delivery	1	0.061	0.061	0.061	837.09	0.000
Hospital*Assembly*MenuType*Delivery	1	0.000	0.000	0.000	1.62	0.204
Error	1584	0.115	0.115	0.000		
Total	1599	15.394				

Table B.9: Full Factorial ANOVA of the Total Utilization for Foodservice System Configurations

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hospital	1	0.50304	0.50304	0.50304	1.5E+04	0.000
Assembly	1	5.43925	5.43925	5.43925	1.6E+05	0.000
MenuType	1	0.11542	0.11542	0.11542	3493.7	0.000
Delivery	1	1.96401	1.96401	1.96401	5.9E+04	0.000
Hospital*Assembly	1	0.56134	0.56134	0.56134	1.7E+04	0.000
Hospital*MenuType	1	0.00022	0.00022	0.00022	6.67	0.01
Hospital*Delivery	1	0.13274	0.13274	0.13274	4017.97	0.000
Assembly*MenuType	1	0.01812	0.01812	0.01812	548.46	0.000
Assembly*Delivery	1	0.04479	0.04479	0.04479	1355.91	0.000
MenuType*Delivery	1	0.01143	0.01143	0.01143	346.05	0.000
Hospital*Assembly*MenuType	1	0.00408	0.00408	0.00408	123.44	0.000
Hospital*Assembly*Delivery	1	0.04211	0.04211	0.04211	1274.71	0.000
Hospital*MenuType*Delivery	1	0.00705	0.00705	0.00705	213.51	0.000
Assembly*MenuType*Delivery	1	0.00612	0.00612	0.00612	185.34	0.000
Hospital*Assembly*MenuType*Delivery	1	0.00018	0.00018	0.00018	5.37	0.021
Error	1584	0.05233	0.05233	0.00003		
Total	1599	8.90225				

Table B.10: Full Factorial ANOVA of the Time In Cart for Foodservice System Configurations

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hospital	1	49243	49243	49243	2.1E+05	0.000
Assembly	1	275	275	275	1175.92	0.000
MenuType	1	2514	2514	2514	1.1E+04	0.000
Delivery	1	31957	31957	31957	1.4E+05	0.000
Hospital*Assembly	1	739	739	739	3163.87	0.000
Hospital*MenuType	1	10141	10141	10141	4.3E+04	0.000
Hospital*Delivery	1	7916	7916	7916	3.4E+04	0.000
Assembly*MenuType	1	504	504	504	2155.35	0.000
Assembly*Delivery	1	82	82	82	351.15	0.000
MenuType*Delivery	1	38610	38610	38610	1.7E+05	0.000
Hospital*Assembly* MenuType	1	251	251	251	1076.03	0.000
Hospital*Assembly* Delivery	1	1769	1769	1769	7568.78	0.000
Hospital*MenuType* Delivery	1	24199	24199	24199	1.0E+05	0.000
Assembly*MenuType* Delivery	1	955	955	955	4087.43	0.000
Hospital*Assembly* MenuType*Delivery	1	128	128	128	547.09	0.000
Error	1584	370	370	0.000		
Total	1599	169654				

Table B.11: Full Factorial ANOVA of the Number of Trays On Time for Foodservice System Configurations

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hospital	1	7579422	7579422	7579422	7.9E+04	0.000
Assembly	1	10399	10399	10399	108.84	0.000
MenuType	1	2207	2207	2207	23.1	0.000
Delivery	1	16449311	16449311	16449311	1.7E+05	0.000
Hospital*Assembly	1	479	479	479	5.01	0.025
Hospital*MenuType	1	18516	18516	18516	193.8	0.000
Hospital*Delivery	1	4468679	4468679	4468679	4.7E+04	0.000
Assembly*MenuType	1	1779	1779	1779	18.62	0.000
Assembly*Delivery	1	9965	9965	9965	104.3	0.000
MenuType*Delivery	1	7573	7573	7573	79.27	0.000
Hospital*Assembly*MenuType	1	7652	7652	7652	80.09	0.000
Hospital*Assembly*Delivery	1	2973	2973	2973	31.12	0.000
Hospital*MenuType*Delivery	1	17882	17882	17882	187.17	0.000
Assembly*MenuType*Delivery	1	3028	3028	3028	31.69	0.000
Hospital*Assembly*MenuType*Delivery	1	3761	3761	3761	39.36	0.000
Error	1584	151339	151339	96		
Total	1599	28734964				

Appendix C

This appendix contains the ANOVA tables for a three factor analysis of the performance measures for the small hospital systems. In addition, the Tukey test for each performance measure is presented. In instances where the results of the three factor analysis indicated the need for a more detailed analysis of the performance measure, a two factor and/or single factor analysis is provided. The single factor analyses are also used to determine optimal factor levels when the factors are examined independently of one another.

Table C.1: Three Factor ANOVA of Assembly Time for Foodservice System Configurations in Small Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	168.02	168.02	168.02	1.0E+05	0.000
Menu Type	1	427.05	427.05	427.05	2.6E+05	0.000
Delivery System	1	0.00	0.00	0.00	0.01	0.000
Assembly*MenuType	1	0.00	0.00	0.00	0.01	0.000
Assembly*Delivery	1	142.78	142.78	142.78	8.7E+04	0.000
MenuType*Delivery	1	0.00	0.00	0.00	0.000	0.000
Assembly*MenuType* Delivery	1	0.00	0.00	0.00	0.000	0.000
Error	792	1.30	1.30	0.00		
Total	799	739.15				

Table C.2: Tukey Multiple Comparison of Average Assembly Time for Foodservice System Configurations in Small Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Assembly Time
5	Cell	Fixed	Traditional	1.07
7	Cell	Fixed	Room Service	1.07
3	Line	Fixed	Room Service	1.15
1	Line	Fixed	Traditional	1.15
6	Cell	Choice	Traditional	1.69
8	Cell	Choice	Room Service	1.69
4	Line	Choice	Room Service	3.45
2	Line	Choice	Traditional	3.45

Table C.3: Three Factor ANOVA of Overall Cycle Time for Foodservice System Configurations in Small Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	1928.2	1928.2	1928.2	1.40E+04	0.000
Menu Type	1	227.7	227.7	227.7	1646.08	0.000
Delivery System	1	4031.70	4031.70	4031.70	2.90E+04	0.000
Assembly*MenuType	1	544.30	544.30	544.30	3934.99	0.000
Assembly*Delivery	1	229	229	229	1655.74	0.000
MenuType*Delivery	1	837.90	837.90	837.90	6058.250	0.000
Assembly*MenuType* Delivery	1	192.10	192.10	192.10	1389.010	0.000
Error	792	109.5	109.5	0.1		
Total	799	8100.4				

Table C.4: Tukey Multiple Comparison of Average Overall Cycle Time for Foodservice System Configurations in Small Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Overall Cycle Time
8	Cell	Choice	Room Service	11.62
7	Cell	Fixed	Room Service	12.69
4	Line	Choice	Room Service	14.33
5	Cell	Fixed	Traditional	17.76
6	Cell	Choice	Traditional	18.83
1	Line	Fixed	Traditional	19.30
3	Line	Fixed	Room Service	19.49
2	Line	Choice	Traditional	20.19

Table C.5: Three Factor ANOVA of Make-Span of System for Foodservice System Configurations in Small Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	12320.5	12320.5	12320.5	7556.970	0.000
Delivery System	1	7591.00	7591.00	7591.00	4656.060	0.000
Menu Type	1	17824.2	17824.2	17824.2	1.1E+04	0.000
Assembly*MenuType	1	1529.00	1529.00	1529.00	937.860	0.000
Assembly*Delivery	1	2.3	2.3	2.3	1.43	0.233
MenuType*Delivery	1	2863.30	2863.30	2863.30	1756.220	0.000
Assembly*MenuType* Delivery	1	403.50	403.50	403.50	247.480	0.000
Error	792	1291.2	1291.2	1.6		
Total	799	43825.1				

Table C.6: Tukey Multiple Comparison of Average Make-Span of System for Foodservice System Configurations in Small Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Make-Span of System
1	Line	Fixed	Traditional	91.58
3	Line	Fixed	Room Service	93.39
7	Cell	Fixed	Room Service	97.16
4	Line	Choice	Room Service	97.73
5	Cell	Fixed	Traditional	103.72
8	Cell	Choice	Room Service	104.12
2	Line	Choice	Traditional	106.33
6	Cell	Choice	Traditional	115.41

Table C.7: Three Factor ANOVA of Assembly Make-Span for Foodservice System Configurations in Small Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	58281	58281	58281	6.7E+04	0.000
Delivery System	1	0.00	0.00	0.00	0.170	0.678
Menu Type	1	52825	52825	52825	6.0E+04	0.000
Assembly*MenuType	1	0.00	0.00	0.00	0.050	0.823
Assembly*Delivery	1	4141	4141	4141	4740.15	0.000
MenuType*Delivery	1	0.00	0.00	0.00	0.140	0.711
Assembly*MenuType*Delivery	1	0.00	0.00	0.00	0.080	0.775
Error	792	692	692	1.00		
Total	799	115939				

Table C.8: Tukey Multiple Comparison of Average Assembly Make-Span for Foodservice System Configurations in Small Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Assembly Make-Span
1	Line	Fixed	Traditional	56.23
3	Line	Fixed	Room Service	56.24
2	Line	Choice	Traditional	77.03
4	Line	Choice	Room Service	77.05
7	Cell	Fixed	Room Service	77.86
5	Cell	Fixed	Traditional	77.86
6	Cell	Choice	Traditional	89.52
8	Cell	Choice	Room Service	89.60

Table C.9: Three Factor ANOVA of Productivity for Foodservice System Configurations in Small Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	19869	19869	19869	1.50E+05	0.000
Menu Type	1	73329	73329	73329	5.60E+05	0.000
Delivery System	1	0.00	0.00	0.00	0.16	0.690
Assembly*MenuType	1	0.00	0.00	0.00	0.05	0.829
Assembly*Delivery	1	323	323	323	2477.63	0.000
MenuType*Delivery	1	0.00	0.00	0.00	0.100	0.758
Assembly*MenuType* Delivery	1	0.00	0.00	0.00	0.110	0.740
Error	792	103	103	0.00		
Total	799	93624				

Table C.10: Tukey Multiple Comparison of Average Productivity for Foodservice System Configurations in Small Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Productivity
7	Cell	Fixed	Room Service	51.38
5	Cell	Fixed	Traditional	51.37
1	Line	Fixed	Traditional	42.68
3	Line	Fixed	Room Service	42.67
6	Cell	Choice	Traditional	33.51
8	Cell	Choice	Room Service	33.48
2	Line	Choice	Traditional	22.25
4	Line	Choice	Room Service	22.25

Table C.11: Three Factor ANOVA of Patient Satisfaction for Foodservice System Configurations in Small Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	38.40	38.40	38.40	3554.430	0.000
Delivery System	1	983.01	983.01	983.01	9.1E+04	0.000
Menu Type	1	50.33	50.33	50.33	4658.790	0.000
Assembly*MenuType	1	32.03	32.03	32.03	2964.300	0.000
Assembly*Delivery	1	36.76	36.76	36.76	3402.37	0.000
MenuType*Delivery	1	53.18	53.18	53.18	4921.970	0.000
Assembly*MenuType* Delivery	1	9.28	9.28	9.28	859.200	0.000
Error	792	8.56	8.56	0.01		
Total	799	1211.54				

Table C.12: Tukey Multiple Comparison of Average Patient Satisfaction for Foodservice System Configurations in Small Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Patient Satisfaction
8	Cell	Choice	Room Service	9.36
4	Line	Choice	Room Service	9.17
7	Cell	Fixed	Room Service	8.99
3	Line	Fixed	Room Service	7.50
5	Cell	Fixed	Traditional	6.67
2	Line	Choice	Traditional	6.62
6	Cell	Choice	Traditional	6.44
1	Line	Fixed	Traditional	6.42

Table C.13: Three Factor ANOVA of Assembly Utilization for Foodservice System Configurations in Small Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	10.5079	10.5079	10.5079	2.6E+05	0.000
Delivery System	1	0.0000	0.0000	0.0000	0.430	0.511
Menu Type	1	0.0081	0.0081	0.0081	204.170	0.000
Assembly*MenuType	1	0.0000	0.0000	0.0000	0.150	0.696
Assembly*Delivery	1	0.0154	0.0154	0.0154	386.03	0.000
MenuType*Delivery	1	0.0000	0.0000	0.0000	0.320	0.570
Assembly*MenuType* Delivery	1	0.0000	0.0000	0.0000	0.260	0.611
Error	792	0.0316	0.0316	0.0000		
Total	799	10.5631				

Table C.14: Tukey Multiple Comparison of Average Assembly Utilization for Foodservice System Configurations in Small Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Assembly Utilization
7	Cell	Fixed	Room Service	1.00
5	Cell	Fixed	Traditional	0.99
6	Cell	Choice	Traditional	0.99
8	Cell	Choice	Room Service	0.99
2	Line	Choice	Traditional	0.77
4	Line	Choice	Room Service	0.77
1	Line	Fixed	Traditional	0.76
3	Line	Fixed	Room Service	0.76

Table C.15: Three Factor ANOVA of Average Time In Cart for Foodservice System Configurations in Small Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly	1	957.8	957.8	957.8	6672.45	0.00
MenuType	1	1278.4	1278.4	1278.4	8905.44	0.00
Delivery	1	4031.2	4031.2	4031.2	2.80E+04	0.00
Assembly*MenuType	1	733.4	733.4	733.4	5109.38	0.00
Assembly*Delivery	1	544.4	544.4	544.4	3792.57	0.00
MenuType*Delivery	1	837.8	837.8	837.8	5836.41	0.00
Assembly*MenuType*Delivery	1	192.1	192.1	192.1	1337.94	0.00
Error	792	113.7	113.7	0.1		
Total	799	8688.8				

Table C.16: Tukey Multiple Comparison of Average Time In Cart for Foodservice System Configurations in Small Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Time In Cart
8	Cell	Choice	Room Service	9.93
4	Line	Choice	Room Service	10.87
7	Cell	Fixed	Room Service	11.61
5	Cell	Fixed	Traditional	16.68
2	Line	Choice	Traditional	16.74
6	Cell	Choice	Traditional	17.14
1	Line	Fixed	Traditional	18.16
3	Line	Fixed	Room Service	18.34

Appendix D

This appendix contains the ANOVA tables for a three factor analysis of the performance measures for the large hospital systems. In addition, the Tukey test for each performance measure is presented. In instances where the results of the three factor analysis indicated the need for a more detailed analysis of the performance measure, a two factor and/or single factor analysis is provided. The single factor analyses are also used to determine optimal factor levels when the factors are examined independently of one another.

Table D.1: Three Factor ANOVA of Assembly Time for Foodservice System Configurations in Large Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	172.36	172.36	172.36	3.6E+05	0.000
Delivery System	1	0.00	0.00	0.00	0.00	0.995
Menu Type	1	432.13	432.13	432.13	9.0E+05	0.000
Assembly*MenuType	1	0.00	0.00	0.00	0.00	0.995
Assembly*Delivery	1	145.71	145.71	145.71	3.0E+05	0.000
MenuType*Delivery	1	0.00	0.00	0.00	0.00	0.956
Assembly*MenuType* Delivery	1	0.00	0.00	0.00	0.00	0.956
Error	792	0.38	0.38	0.00		
Total	799	750.58				

Table D.2: Tukey Multiple Comparison of Average Assembly Time for Foodservice System Configurations in Large Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Assembly Time
5	Cell	Fixed	Traditional	1.07
7	Cell	Fixed	Room Service	1.07
1	Line	Fixed	Traditional	1.15
3	Line	Fixed	Room Service	1.15
6	Cell	Choice	Traditional	1.69
8	Cell	Choice	Room Service	1.69
4	Line	Choice	Room Service	3.47
2	Line	Choice	Traditional	3.47

Table D.3: Three Factor ANOVA of Overall Cycle Time for Foodservice System Configurations in Large Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	6090.0	6090.0	6090.0	2.3E+04	0.000
Delivery System	1	7361.5	7361.5	7361.5	2.8E+04	0.000
Menu Type	1	18.6	18.6	18.6	71.15	0.000
Assembly*MenuType	1	2258.0	2258.0	2258.0	8635.69	0.000
Assembly*Delivery	1	4503.4	4503.4	4503.4	1.7E+04	0.000
MenuType*Delivery	1	13730.4	13730.4	13730.4	5.3E+04	0.000
Assembly*MenuType*Delivery	1	8018.0	8018.0	8018.0	3.1E+04	0.000
Error	792	207.1	207.1	0.3		
Total	799	42186.9				

Table D.4: Tukey Multiple Comparison of Average Overall Cycle Time for Foodservice System Configurations in Large Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Overall Cycle Time
4	Line	Choice	Room Service	15.02
6	Cell	Choice	Traditional	18.01
8	Cell	Choice	Room Service	18.76
2	Line	Choice	Traditional	20.21
5	Cell	Fixed	Traditional	21.10
1	Line	Fixed	Traditional	21.42
3	Line	Fixed	Room Service	25.19
7	Cell	Fixed	Room Service	25.77

Table D.5: Three Factor ANOVA of the Make-Span of the System for Foodservice System Configurations in Large Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	2909.7	2909.7	2909.7	1563.67	0.000
Delivery System	1	4480.8	4480.8	4480.8	2407.93	0.000
Menu Type	1	15710.5	15710.5	15710.5	8442.66	0.000
Assembly*MenuType	1	1838.5	1838.5	1838.5	987.99	0.000
Assembly*Delivery	1	2511.8	2511.8	2511.8	1349.82	0.000
MenuType*Delivery	1	7021.6	7021.6	7021.6	3773.35	0.000
Assembly*MenuType* Delivery	1	1569.3	1569.3	1569.3	843.31	0.000
Error	792	1473.8	1473.8	1.9		
Total	799	37515.9				

Table D.6: Tukey Multiple Comparison of Average Make-Span of the System for Foodservice System Configurations in Large Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Make-Span Of System
5	Cell	Fixed	Traditional	125.32
1	Line	Fixed	Traditional	125.82
6	Cell	Choice	Traditional	133.76
7	Cell	Fixed	Room Service	136.21
3	Line	Fixed	Room Service	136.25
8	Cell	Choice	Room Service	138.40
4	Line	Choice	Room Service	139.93
2	Line	Choice	Traditional	146.95

Table D.7: Three Factor ANOVA of Assembly Make-Span for Foodservice System Configurations in Large Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	9449	9449	9449	1.1E+04	0.000
Delivery System	1	0.00	0.00	0.00	0.160	0.687
Menu Type	1	140250	140250	140250	1.6E+05	0.000
Assembly*MenuType	1	0.00	0.00	0.00	0.440	0.506
Assembly*Delivery	1	8464	8464	8464	9944.22	0.000
MenuType*Delivery	1	0.00	0.00	0.00	0.350	0.556
Assembly*MenuType*Delivery	1	0.00	0.00	0.00	0.320	0.573
Error	792	674	674	1		
Total	799	158838				

Table D.8: Tukey Multiple Comparison of Average Assembly Make-Span for Foodservice System Configurations in Large Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Assembly Make-Span
7	Cell	Fixed	Room Service	87.77
5	Cell	Fixed	Traditional	87.79
3	Line	Fixed	Room Service	88.15
1	Line	Fixed	Traditional	88.15
8	Cell	Choice	Room Service	107.74
6	Cell	Choice	Traditional	107.76
2	Line	Choice	Traditional	121.06
4	Line	Choice	Room Service	121.20

Table D.9: Three Factor ANOVA of Productivity for Foodservice System Configurations in Large Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	25540	25540	25540	4.8E+05	0.000
Delivery System	1	0.00	0.00	0.00	0.01	0.915
Menu Type	1	70181	70181	70181	1.3E+06	0.000
Assembly*MenuType	1	0.00	0.00	0.00	0.35	0.556
Assembly*Delivery	1	154	154	154	2908.97	0.000
MenuType*Delivery	1	0.00	0.00	0.00	0.27	0.600
Assembly*MenuType*Delivery	1	0.00	0.00	0.00	0.11	0.743
Error	792	42	42	0		
Total	799	95917				

Table D.10: Tukey Multiple Comparison of Average Productivity for Foodservice System Configurations in Large Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Productivity
7	Cell	Fixed	Room Service	51.27
5	Cell	Fixed	Traditional	51.26
3	Line	Fixed	Room Service	40.84
1	Line	Fixed	Traditional	40.84
8	Cell	Choice	Room Service	33.41
6	Cell	Choice	Traditional	33.41
2	Line	Choice	Traditional	21.24
4	Line	Choice	Room Service	21.22

Table D.11: Three Factor ANOVA of Patient Satisfaction for Foodservice System Configurations in Large Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	11.04	11.04	11.04	859.57	0.000
Delivery System	1	1216.33	1216.33	1216.33	9.5E+04	0.000
Menu Type	1	32.64	32.64	32.64	2542.61	0.000
Assembly*MenuType	1	22.76	22.76	22.76	1772.88	0.000
Assembly*Delivery	1	10.52	10.52	10.52	819.43	0.000
MenuType*Delivery	1	307.35	307.35	307.35	2.4E+04	0.000
Assembly*MenuType* Delivery	1	16.52	16.52	16.52	1286.74	0.000
Error	792	10.17	10.17	0.01		
Total	799	1627.32				

Table D.12: Tukey Multiple Comparison of Average Patient Satisfaction for Foodservice System Configurations in Large Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Patient Satisfaction
4	Line	Choice	Room Service	8.97
8	Cell	Choice	Room Service	7.88
3	Line	Fixed	Room Service	6.81
7	Cell	Fixed	Room Service	6.75
5	Cell	Fixed	Traditional	5.58
1	Line	Fixed	Traditional	5.53
6	Cell	Choice	Traditional	4.80
2	Line	Choice	Traditional	4.64

Table D.13: Three Factor ANOVA of Assembly Utilization for Foodservice System Configurations in Large Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	13.6618	13.6618	13.6618	6.2E+05	0.000
Delivery System	1	0.0000	0.0000	0.0000	0.13	0.722
Menu Type	1	0.0038	0.0038	0.0038	175.54	0.000
Assembly*MenuType	1	0.0000	0.0000	0.0000	0.79	0.375
Assembly*Delivery	1	0.0103	0.0103	0.0103	471.01	0.000
MenuType*Delivery	1	0.0000	0.0000	0.0000	0.56	0.456
Assembly*MenuType* Delivery	1	0.0000	0.0000	0.0000	0.04	0.526
Error	792	0.0173	0.0173	0.0000		
Total	799	13.6933				

Table D.14: Tukey Multiple Comparison of Average Assembly Utilization for Foodservice System Configurations in Large Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Assembly Utilization
7	Cell	Fixed	Room Service	0.99
5	Cell	Fixed	Traditional	0.99
8	Cell	Choice	Room Service	0.99
6	Cell	Choice	Traditional	0.99
2	Line	Choice	Traditional	0.74
4	Line	Choice	Room Service	0.74
3	Line	Fixed	Room Service	0.72
1	Line	Fixed	Traditional	0.72

Table D.15: Three Factor ANOVA of Time In Cart for Foodservice System Configurations in Large Hospitals

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly Method	1	56	56	56	173.95	0.000
Menu Type	1	11377	11377	11377	3.5E+04	0.000
Delivery System	1	35842	35842	35842	1.1E+05	0.000
Assembly*MenuType	1	22.00	22.00	22.00	66.96	0.000
Assembly*Delivery	1	1306	1306	1306	4034.17	0.000
MenuType*Delivery	1	61971	61971	61971	1.9E+05	0.000
Assembly*MenuType*Delivery	1	891	891	891	2751.38	0.000
Error	792	256	256	0		
Total	799	111722				

Table D.16: Tukey Multiple Comparison of Average Time In Cart for Foodservice System Configurations in Large Hospitals

Configuration	Assembly Method	Menu Type	Delivery Method	Time In Cart
4	Line	Choice	Room Service	11.54
8	Cell	Choice	Room Service	17.07
5	Cell	Fixed	Traditional	20.03
1	Line	Fixed	Traditional	20.27
3	Line	Fixed	Room Service	24.04
7	Cell	Fixed	Room Service	24.69
6	Cell	Choice	Traditional	43.39
2	Line	Choice	Traditional	47.20

Appendix E

This appendix contains the single factor ANOVA tables for the performance measures for both small and large hospitals.

Table E.1: Single Factor ANOVA of Assembly Time for Foodservice System Configurations in Small Hospitals – Assembly Method

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly	1	168.02	168.02	168.02	234.76	0.00
Error	798	571.13	571.13	0.72		
Total	799	739.15				

Table E.2: Single Factor ANOVA of Assembly Time for Foodservice System Configurations in Large Hospitals – Assembly Method

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly	1	172.36	172.36	172.36	237.88	0.000
Error	798	578.21	578.21	0.72		
Total	799	750.58				

Table E.3: Single Factor ANOVA of Assembly Time for Foodservice System Configurations in Small Hospitals – Menu Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Menu Type	1	427.1	427.1	427.1	1091.92	0.00
Error	798	312.1	312.1	0.390		
Total	799	739.2				

Table E.4: Single Factor ANOVA of Assembly Time for Foodservice System Configurations in Large Hospitals – Menu Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Menu Type	1	432.13	432.13	432.13	1082.86	0.000
Error	798	318.45	318.45	0.40		
Total	799	750.58				

Table E.5: Single Factor ANOVA of Overall Cycle Time for Foodservice System Configurations in Small Hospitals – Menu Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Menu Type	1	4031.7	4031.7	4031.7	790.74	0.00
Error	798	4068.7	4068.7	5.100		
Total	799	8100.4				

Table E.6: Single Factor ANOVA of Overall Cycle Time for Foodservice System Configurations in Large Hospitals – Delivery System

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Delivery System	1	199.42	199.42	199.42	17.63	0.000
Error	798	9027.9	9027.9	11.31		
Total	799	9227.27				

Table E.7: Single Factor ANOVA of Assembly Make-Span for Foodservice System Configurations in Small Hospitals – Assembly Method

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly	1	58281	58281	58281	806.62	0.00
Error	798	57658	57658	72		
Total	799	115939				

Table E.8: Single Factor ANOVA of Assembly Make-Span for Foodservice System Configurations in Large Hospitals – Assembly Method

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly	1	9448.9	9448.9	9448.9	50.47	0.000
Error	798	149389.3	149389.3	187.2		
Total	799	158838.2				

Table E.9: Single Factor ANOVA of Assembly Make-Span for Foodservice System Configurations in Small Hospitals – Menu Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Menu Type	1	52825	52825	52825	667.91	0.00
Error	798	63114	63114	79		
Total	799	115939				

Table E.10: Single Factor ANOVA of Assembly Make-Span for Foodservice System Configurations in Large Hospitals – Menu Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Menu Type	1	140250	140250	140250	6020.92	0.000
Error	798	18588	18588	23		
Total	799	158838				

Table E.11: Single Factor ANOVA of Make-Span of System for Foodservice System Configurations in Small Hospitals – Delivery System

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Delivery System	1	7591.0	7591.0	7591.0	167.18	0.000
Error	798	36234.1	36234.1	45.400		
Total	799	43825.1				

Table E.12: Single Factor ANOVA of the Make-Span of the System for Foodservice System Configurations in Large Hospitals – Delivery System

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Delivery System	1	4480.8	4480.8	4480.8	108.24	0.000
Error	798	33035.2	33035.2	41.4		
Total	799	37515.9				

Table E.13: Single Factor ANOVA of Productivity for Foodservice System Configurations in Small Hospitals – Assembly Method

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly	1	19869	19869	19869	214.97	0.000
Error	798	73755	73755	92.000		
Total	799	93624				

Table E.14: Single Factor ANOVA of Productivity for Foodservice System Configurations in Large Hospitals – Assembly Method

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly	1	25540	25540	25540	289.59	0.000
Error	798	70377	70377	88		
Total	799	95917				

Table E.15: Single Factor ANOVA of Productivity for Foodservice System Configurations in Small Hospitals – Menu Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Menu Type	1	73329	73329	73329	2883.4	0.000
Error	798	20295	20295	25.000		
Total	799	93624				

Table E.16: Single Factor ANOVA of Productivity for Foodservice System Configurations in Large Hospitals – Menu Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Menu Type	1	70181	70181	70181	2176.15	0.000
Error	798	25736	25736	32		
Total	799	95917				

Table E.17: Single Factor ANOVA of Patient Satisfaction for Foodservice System Configurations in Small Hospitals – Assembly Method

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly	1	38.402	38.402	38.402	26.12	0.000
Error	798	1173.140	1173.140	1.470		
Total	799	1211.542				

Table E.18: Single Factor ANOVA of Patient Satisfaction for Foodservice System Configurations in Large Hospitals – Assembly Method

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly	1	11.030	11.030	11.030	5.45	0.020
Error	798	1616.331	1616.331	2.025		
Total	799	1627.361				

Table E.19: Single Factor ANOVA of Patient Satisfaction for Foodservice System Configurations in Small Hospitals – Menu Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Menu Type	1	50.33	50.33	50.33	34.59	0.000
Error	798	1161.2	1161.2	1.455		
Total	799	1211.5				

Table E.20: Single Factor ANOVA of Patient Satisfaction for Foodservice System Configurations in Large Hospitals – Menu Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Menu Type	1	32.653	32.653	32.653	16.34	0.000
Error	798	1594.707	1594.707	1.998		
Total	799	1627.361				

Table E.21: Single Factor ANOVA of Patient Satisfaction for Foodservice System Configurations in Small Hospitals – Delivery System

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Delivery System	1	983.01	983.01	983.01	3432.46	0.000
Error	798	228.54	228.54	0.290		
Total	799	1211.54				

Table E.22: Single Factor ANOVA of Patient Satisfaction for Foodservice System Configurations in Large Hospitals – Delivery System

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Delivery System	1	1216.4	1216.4	1216.4	2361.93	0.000
Error	798	411.0	411.0	0.5		
Total	799	1627.4				

Table E.23: Single Factor ANOVA of Assembly Utilization for Foodservice System Configurations in Small Hospitals – Assembly Method

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly	1	10.508	10.508	10.508	1.5E+05	0.000
Error	798	0.055	0.055	0.000		
Total	799	10.563				

Table E.24: Single Factor ANOVA of Assembly Utilization for Foodservice System Configurations in Large Hospitals – Assembly Method

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Assembly	1	13.662	13.662	13.662	3.5E+05	0.000
Error	798	0.032	0.032	0.000		
Total	799	13.693				

Table E.25: Single Factor ANOVA of Assembly Utilization for Foodservice System Configurations in Small Hospitals – Menu Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Menu Type	1	0.00815	0.00815	0.00815	0.62000	0.43300
Error	798	10.555	10.555	0.01323		
Total	799	10.563				

Table E.26: Single Factor ANOVA of Assembly Utilization for Foodservice System Configurations in Large Hospitals – Menu Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Menu Type	1	0.00384	0.00384	0.00384	0.22	0.636
Error	798	13.68949	13.68949	0.01715		
Total	799	13.69332				

Table E.27: Single Factor ANOVA of Delivery Utilization for Foodservice System Configurations in Small Hospitals – Delivery System

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Delivery System	1	7.0272	7.0272	7.0272	3556.2	0.000
Error	798	1.5769	1.5769	0.002		
Total	799	8.6041				

Table E.28: Single Factor ANOVA of Delivery Utilization for Foodservice System Configurations in Large Hospitals – Delivery System

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Delivery System	1	2.9825	2.9825	2.9825	2335.49	0.000
Error	798	1.0191	1.0191	0.0013		
Total	799	4.0015				

Table E.29: Single Factor ANOVA of Total Utilization for Foodservice System Configurations in Large Hospitals – Delivery System

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Delivery System	1	0.53779	0.53779	0.53779	88.12	0.000
Error	798	4.8699	4.8699	0.00610		
Total	799	5.40768				

Table E.30: Single Factor ANOVA of Time In Cart for Foodservice System Configurations in Small Hospitals – Delivery System

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Delivery System	1	4031.2	4031.2	4031.2	690.69	0.000
Error	798	4657.6	4657.6	5.800		
Total	799	8688.8				

Table E.31: Single Factor ANOVA of Number of Trays On Time for Foodservice System Configurations in Small Hospitals – Delivery System

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Delivery	1	1885391	1885391	1885391	1.4E+04	0.000
Error	798	108677	108677	136.000		
Total	799	1994067				

Table E.32: Single Factor ANOVA of Number of Trays On Time for Foodservice System Configurations in Large Hospitals – Delivery System

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Delivery System	1	19032599	19032599	19032599	1.2E+05	0.000
Error	798	128875.0	128875.0	161.0		
Total	799	19161474				

Appendix F

This appendix presents the results of the experiment run for F.F Thompson Hospital. The eight different system configurations are defined and the results indicated. The results include the performance measures as well as additional useful data such as the number of trays early, late and on time.

Table F.1: Definition of System Configurations

Config.	Assembly Method	Delivery System	Menu Choice
1	Line	Traditional	Fixed
2	Line	Traditional	Choice
3	Line	Room Service	Fixed
4	Line	Room Service	Choice
5	Cell	Traditional	Fixed
6	Cell	Traditional	Choice
7	Cell	Room Service	Fixed
8	Cell	Room Service	Choice

Table F.2: Summary of Average Performance Results for F.F. Thompson Hospital's Experiment

Config.	Assembly Time (minutes)	Overall Cycle Time (minutes)	Assembly Make-Span (minutes)	Make-Span of System (minutes)
1	1.15	16.74	73.65	101.92
2	3.47	20.06	100.7	130.0
3	1.15	12.80	73.7	95.8
4	3.47	12.63	100.7	118.7
5	1.07	16.61	76.0	101.6
6	1.69	17.84	93.1	118.9
7	1.07	12.98	75.9	96.0
8	1.69	10.91	93.1	107.8

Table F.3: Summary of Average Performance Results for F.F. Thompson Hospital's Experiment

Config.	Patient Satisfaction	Productivity (trays/hr/worker)	Time In Cart (minutes)
1	6.90	30.61	15.6
2	6.38	17.14	16.6
3	8.91	32.56	11.7
4	9.17	18.78	9.2
5	6.91	38.37	15.5
6	6.61	26.24	16.1
7	8.86	40.61	11.9
8	9.41	28.96	9.2

Table F.4: Summary of Average Results for F.F. Thompson Hospital's Experiment

Config.	Number of Trays			Number of "No Preference Meals"
	Early	Late	On Time	
1	89.33	84.44	34.70	51.53
2	61.99	118.72	27.14	52.15
3	51.91	2.55	154.01	51.53
4	0.52	109.16	98.17	52.15
5	90.28	83.66	34.53	51.53
6	71.77	105.36	30.91	51.96
7	53.21	2.26	153.00	51.53
8	5.89	37.08	165.07	51.96

Table F.5: Summary of Average Results for F.F. Thompson Hospital's Experiment

Config.	Windows Early (Number of Trays)				
	1	2	3	4	5 or More
1	30.94	25.40	17.64	10.82	4.53
2	21.88	17.63	12.50	7.47	2.51
3	51.90	0.01	0.00	0.00	0.00
4	0.52	0.00	0.00	0.00	0.00
5	30.98	25.40	17.94	11.12	4.84
6	24.84	19.96	14.20	9.21	3.56
7	53.19	0.02	0.00	0.00	0.00
8	5.89	0.00	0.00	0.00	0.00

Table F.6: Summary of Average Results for F.F. Thompson Hospital's Experiment

Config.	Windows Late (Number of Trays)				
	1	2	3	4	5 or More
1	30.26	23.30	16.56	10.43	3.89
2	30.52	25.99	22.76	16.65	22.80
3	2.55	0.00	0.00	0.00	0.00
4	105.32	3.84	0.00	0.00	0.00
5	29.98	23.36	16.22	10.45	3.65
6	30.94	25.98	20.43	14.32	13.69
7	2.26	0.00	0.00	0.00	0.00
8	37.08	0.00	0.00	0.00	0.00

Table F.7: Summary of Average Results for F.F. Thompson Hospital's Experiment

Config.	Number of Workers			Utilization		
	Assembly	Delivery	Total	Assembly	Delivery	Total
1	5	5	10	0.54	0.68	0.61
2	7	5	12	0.59	0.53	0.57
3	5	5	10	0.58	0.86	0.72
4	7	5	12	0.65	0.69	0.67
5	4	5	9	0.74	0.68	0.71
6	5	5	10	0.78	0.58	0.68
7	4	5	9	0.79	0.86	0.83
8	5	5	10	0.86	0.78	0.82

Table F.8: Summary of Average Results for F.F. Thompson Hospital's Experiment

Config.	Window Requested					
	1	2	3	4	5	6
1	34.15	34.77	34.31	35.56	34.93	34.75
2	35.87	34.83	34.09	33.98	34.99	34.09
3	34.15	34.77	34.31	35.56	34.93	34.75
4	35.87	34.83	34.09	33.98	34.99	34.09
5	34.15	34.77	34.31	35.56	34.93	34.75
6	34.28	34.19	35.05	34.83	35.05	34.64
7	34.15	34.77	34.31	35.56	34.93	34.75
8	34.28	34.19	35.05	34.83	35.05	34.64

Table F.9: Summary of System Configuration Rankings for Performance Measures for F.F. Thompson Hospital's Experiment

Assembly Time	Overall Cycle Time	Assembly Make-Span	Make-Span of System	Patient Satisfaction	Productivity	Time In Cart
5, 7	8	1, 3	3, 7	8	7	4, 8
1, 3	4	7, 5	5, 1	4	5	3, 7
6, 8	3	6, 8	8	3	3	5, 1
2, 4	7	2, 4	4, 6	7	1	6, 2
	5		2	5	8	
	1			1	6	
	6			6	4	
	2			2	2	

Appendix G

This appendix contains the model and experiment code for two of the system configurations from the full factorial experiment. The systems chosen are a small hospital, assembly line, fixed menu, traditional delivery and a large hospital, cellular assembly, choice menu, and room service delivery. Between these two models, all the necessary logic is used. The remaining models are combinations of the logic present within these models. Therefore, the model code and experiment code is provided for each.

Small Hospital, Assembly Line, Fixed Menu, Traditional Delivery System

Model Code

```
2$      STATION,     Cold Station;
32$     QUEUE,       ColdStationQ;
3$      SEIZE,       1,Other:
                 Worker2,1:NEXT(4$);
4$      DELAY:       ColdStationWait,,Other:NEXT(5$);
5$      RELEASE:     Worker2,1;
6$      CONVEY:      TrayLine,Entree Station;
7$      STATION,     Hot Station;
33$     QUEUE,       HotStationQ;
9$      SEIZE,       1,Other:
                 Worker4,1:NEXT(10$);
10$     DELAY:       HotStationWait,,Other:NEXT(11$);
11$     RELEASE:     Worker4,1;
8$      CONVEY:      TrayLine,Check and Beverage Station;
12$     STATION,     Check and Beverage Station;
34$     QUEUE,       CheckandBevStationQ;
13$     SEIZE,       1,Other:
                 Worker5,1:NEXT(14$);
14$     DELAY:       CheckandBevStationWait,,Other:NEXT(15$);
15$     RELEASE:     Worker5,1;
16$     EXIT:        TrayLine,1;
27$     ASSIGN:      TraysOnLine=TraysOnLine - 1:
                 TimeOnLine=TNOW-TimeIn;
17$     TALLY:       TimeOnLineTally,TimeOnLine,1;
28$     COUNT:       NumTraysCompleted,1;
29$     BRANCH,      1:
                 If,NC(NumTraysCompleted) < NumTraysNeeded,26$,Yes:
                 If,NC(NumTraysCompleted) == NumTraysNeeded,37$,Yes:
                 Else,25$,Yes;
26$     SCAN:        TraysOnLine<MaxWIP;
20$     DUPLICATE:   1,BegOfLine:NEXT(25$);
25$     STATION,     DeliveryCart;
18$     GROUP,       ,Temporary:FullCart,First:MARK(EnterCart):NEXT(19$);
19$     ASSIGN:      Picture=2;
40$     ASSIGN:      SA=MOD(Server,4)+1:
                 Server=Server+1;
41$     SCAN:        (NumTraysOnCart(SA)==FullCart)&&(IT(DeliveryPerson,SA)==0);
38$     REQUEST,     5:DeliveryPerson(SA),,DeliveryCart;
```

```
39$      TRANSPORT:   DeliveryPerson,DeliveryLocation;
BegOfLine   STATION,     LeadOff Station;
48$      ASSIGN:     Picture=1:
                LeadOffWait=(TRIA(10,12.7,19))*Al:
                ColdStationWait=(TRIA(4,7.57,14))*Al:
                EntreeStationWait=(TRIA(5,7.1,12))*Al:
                HotStationWait=(TRIA(5.19,5.87,12))*Al:
                CheckandBevStationWait=(TRIA(10,10.8,18))*Al:
                DeliveryToPatientWait=TRIA(45,70,90):
                DesiredDeliveryTime=DISC(.133,1,.267,2,.4,3,.533,4,.667,5,0.8,6,1,7):
                DeliveryLocation=loc+11:
                loctracker=loctracker+1;
35$      BRANCH,     1:
                If,loctracker==20,36$,Yes:
                Else,31$,Yes;
36$      ASSIGN:     loctracker=0:
                loc=loc+1;
31$      QUEUE,      LeadOffQ;
23$      SEIZE,      1,Other:
                Worker1,1:NEXT(30$);
30$      ASSIGN:     TraysOnLine=TraysOnLine + 1:MARK(TimeIn);
1$       DELAY:      LeadOffWait,,Other:NEXT(24$);
24$      RELEASE:    Worker1,1;
22$      ACCESS:     TrayLine,1;
0$       CONVEY:     TrayLine,Cold Station;
37$      TALLY:      MakeSpanOfLine,TNOW,1:NEXT(26$);
21$      CREATE,     1,,Tray:0,MaxWIP:NEXT(BegOfLine);
42$      STATION,    Entree Station;
47$      QUEUE,      EntreeQ;
43$      SEIZE,      1,Other:
                Worker3,1:NEXT(44$);
44$      DELAY:      EntreeStationWait,,Other:NEXT(45$);
45$      RELEASE:    Worker3,1;
46$      CONVEY:     TrayLine,Hot Station;
49$      STATION,    11-20;
62$      COUNT:      M+2,1;
68$      TALLY:      OverallCycleTime,TNOW-TimeIn,1;
52$      ASSIGN:     NumTraysOnCart(SA)=(NumTraysOnCart(SA)) - 1:
                TimeInCart=TNOW-EnterCart:MARK(Eat);
69$      TALLY:      TimeInCartTally,TimeInCart,1;
58$      DELAY:      DeliveryToPatientWait,,Other:NEXT(51$);
51$      BRANCH,     1:
                If,NumTraysOnCart(SA)>0,57$,Yes:
                Else,53$,Yes;
57$      FREE:       DeliveryPerson;
50$      DROPOFF,    1,1:Stats,
                TimeInCart,
                Eat;
55$      SPLIT:      SA,
                M:NEXT(56$);
56$      GROUP,      ,Temporary:NumTraysOnCart(SA),First:NEXT(59$);
59$      REQUEST,    1:DeliveryPerson(SA),,M;
60$      TRANSPORT:  DeliveryPerson,DeliveryLocation;
Stats    STATION,    StatisticsCollection;
70$      BRANCH,     1:
                If,(TimeInCart)<=600,71$,Yes:
                If,(TimeInCart> 600) && (TimeInCart <= 900),72$,Yes:
                If,(TimeInCart> 900) && (TimeInCart <= 1200),73$,Yes:
                If,(TimeInCart > 1200) && (TimeInCart<= 1500),74$,Yes:
                If,(TimeInCart> 1500) && (TimeInCart<= 1800),75$,Yes:
                Else,76$,Yes;
71$      ASSIGN:     TimeInCartRank=5;
78$      BRANCH,     1:
                If,DesiredDeliveryTime==1,80$,Yes:
                If,DesiredDeliveryTime==2,88$,Yes:
                If,DesiredDeliveryTime==3,93$,Yes:
                If,DesiredDeliveryTime==4,98$,Yes:
                If,DesiredDeliveryTime==5,103$,Yes:
                If,DesiredDeliveryTime==6,108$,Yes:
                Else,77$,Yes;
```

```
80$     COUNT:      Window1Requested,1;
79$     BRANCH,     1:
              If,Eat > (WindowTime1),115$,Yes:
              If,Eat==(WindowTime1),84$,Yes:
              If,Eat<(WindowTime1),86$,Yes;
115$    ASSIGN:     LateTrayTime=Eat-WindowTime1;
81$     TALLY:      LateTrayTimeTally,LateTrayTime,1;
83$     COUNT:      TraysLate,1;
127$    ASSIGN:     NumWindowsLate=LateTrayTime / 900:
              NumWindowsAway=NumWindowsLate;
128$    TALLY:      NumWindowsLateTally,NumWindowsLate,1;
129$    BRANCH,     1:
              If,NumWindowsAway <= 1,130$,Yes:
              If,(NumWindowsAway > 1) && (NumWindowsAway<= 2),131$,Yes:
              If,(NumWindowsAway> 2) && (NumWindowsAway<= 3),132$,Yes:
              If,(NumWindowsAway  > 3) && (NumWindowsAway<= 4),133$,Yes:
              Else,134$,Yes;
130$    ASSIGN:     DeliveryTimeRank=4;
140$    COUNT:      OneWindowLate,1;
145$    ASSIGN:     PatientSatisfaction=DeliveryTimeRank + TimeInCartRank;
135$    TALLY:      PatientSatisfactionTally,PatientSatisfaction,1;
138$    COUNT:      DeliveredTrays,1;
137$    BRANCH,     1:
              If,NC(DeliveredTrays) == NumMeals,136$,Yes:
              Else,139$,Yes;
136$    TALLY:      MakeSpanOfSystem,TNOW,1;
139$    COUNT:      FinishedTrays,1;
157$    DISPOSE:    No;
131$    ASSIGN:     DeliveryTimeRank=3;
141$    COUNT:      TwoWindowsLate,1:NEXT(145$);
132$    ASSIGN:     DeliveryTimeRank=2;
142$    COUNT:      ThreeWindowsLate,1:NEXT(145$);
133$    ASSIGN:     DeliveryTimeRank=1;
143$    COUNT:      FourWindowsLate,1:NEXT(145$);
134$    ASSIGN:     DeliveryTimeRank=0;
144$    COUNT:      FiveOrMoreWindowsLate,1:NEXT(145$);
84$     COUNT:      TraysOnTime,1;
113$    ASSIGN:     DeliveryTimeRank=5:NEXT(145$);
86$     BRANCH,     1:
              If,Eat>=(WindowTime1-900),84$,Yes:
              Else,116$,Yes;
116$    ASSIGN:     EarlyTrayTime=(WindowTime1-900)-Eat;
82$     TALLY:      EarlyTrayTimeTally,EarlyTrayTime,1;
85$     COUNT:      TraysEarly,1;
114$    ASSIGN:     NumWindowsEarly=EarlyTrayTime / 900:
              NumWindowsAway=NumWindowsEarly;
112$    TALLY:      NumWindowsEarlyTally,NumWindowsEarly,1;
146$    BRANCH,     1:
              If,NumWindowsAway <= 1,147$,Yes:
              If,(NumWindowsAway > 1) && (NumWindowsAway<= 2),148$,Yes:
              If,(NumWindowsAway> 2) && (NumWindowsAway<= 3),149$,Yes:
              If,(NumWindowsAway  > 3) && (NumWindowsAway<= 4),150$,Yes:
              Else,151$,Yes;
147$    ASSIGN:     DeliveryTimeRank=4;
152$    COUNT:      OneWindowEarly,1:NEXT(145$);
148$    ASSIGN:     DeliveryTimeRank=3;
153$    COUNT:      TwoWindowsEarly,1:NEXT(145$);
149$    ASSIGN:     DeliveryTimeRank=2;
154$    COUNT:      ThreeWindowsEarly,1:NEXT(145$);
150$    ASSIGN:     DeliveryTimeRank=1;
155$    COUNT:      FourWindowsEarly,1:NEXT(145$);
151$    ASSIGN:     DeliveryTimeRank=0;
156$    COUNT:      FiveOrMoreWindowsEarly,1:NEXT(145$);
88$     COUNT:      Window2Requested,1;
87$     BRANCH,     1:
              If,Eat > (WindowTime2),117$,Yes:
              If,Eat==(WindowTime2),84$,Yes:
              If,Eat<(WindowTime2),91$,Yes;
117$    ASSIGN:     LateTrayTime=Eat-WindowTime2;
89$     TALLY:      LateTrayTimeTally,LateTrayTime,1:NEXT(83$);
```

```
91$      BRANCH,     1:
                If,Eat>=(WindowTime2-900),84$,Yes:
                Else,118$,Yes;
118$     ASSIGN:     EarlyTrayTime=(WindowTime2-900)-Eat;
90$      TALLY:      EarlyTrayTimeTally,EarlyTrayTime,1:NEXT(85$);
93$      COUNT:      Window3Requested,1;
92$      BRANCH,     1:
                If,Eat > (WindowTime3),119$,Yes:
                If,Eat==(WindowTime3),84$,Yes:
                If,Eat<(WindowTime3),96$,Yes;
119$     ASSIGN:     LateTrayTime=Eat-WindowTime3;
94$      TALLY:      LateTrayTimeTally,LateTrayTime,1:NEXT(83$);
96$      BRANCH,     1:
                If,Eat>=(WindowTime3-900),84$,Yes:
                Else,120$,Yes;
120$     ASSIGN:     EarlyTrayTime=(WindowTime3-900)-Eat;
95$      TALLY:      EarlyTrayTimeTally,EarlyTrayTime,1:NEXT(85$);
98$      COUNT:      Window4Requested,1;
97$      BRANCH,     1:
                If,Eat > (WindowTime4),121$,Yes:
                If,Eat==(WindowTime4),84$,Yes:
                If,Eat<(WindowTime4),101$,Yes;
121$     ASSIGN:     LateTrayTime=Eat-WindowTime4;
99$      TALLY:      LateTrayTimeTally,LateTrayTime,1:NEXT(83$);
101$     BRANCH,     1:
                If,Eat>=(WindowTime4-900),84$,Yes:
                Else,122$,Yes;
122$     ASSIGN:     EarlyTrayTime=(WindowTime4-900)-Eat;
100$     TALLY:      EarlyTrayTimeTally,EarlyTrayTime,1:NEXT(85$);
103$     COUNT:      Window5Requested,1;
102$     BRANCH,     1:
                If,Eat > (WindowTime5),123$,Yes:
                If,Eat==(WindowTime5),84$,Yes:
                If,Eat<(WindowTime5),106$,Yes;
123$     ASSIGN:     LateTrayTime=Eat-WindowTime5;
104$     TALLY:      LateTrayTimeTally,LateTrayTime,1:NEXT(83$);
106$     BRANCH,     1:
                If,Eat>=(WindowTime5-900),84$,Yes:
                Else,124$,Yes;
124$     ASSIGN:     EarlyTrayTime=(WindowTime5-900)-Eat;
105$     TALLY:      EarlyTrayTimeTally,EarlyTrayTime,1:NEXT(85$);
108$     COUNT:      Window6Requested,1;
107$     BRANCH,     1:
                If,Eat > (WindowTime6),125$,Yes:
                If,Eat==(WindowTime6),84$,Yes:
                If,Eat<(WindowTime6),111$,Yes;
125$     ASSIGN:     LateTrayTime=Eat-WindowTime6;
109$     TALLY:      LateTrayTimeTally,LateTrayTime,1:NEXT(83$);
111$     BRANCH,     1:
                If,Eat>=(WindowTime6-900),84$,Yes:
                Else,126$,Yes;
126$     ASSIGN:     EarlyTrayTime=(WindowTime6-900)-Eat;
110$     TALLY:      EarlyTrayTimeTally,EarlyTrayTime,1:NEXT(85$);
77$      COUNT:      Num NPM,1:NEXT(113$);
72$      ASSIGN:     TimeInCartRank=4:NEXT(78$);
73$      ASSIGN:     TimeInCartRank=3:NEXT(78$);
74$      ASSIGN:     TimeInCartRank=2:NEXT(78$);
75$      ASSIGN:     TimeInCartRank=1:NEXT(78$);
76$      ASSIGN:     TimeInCartRank=0:NEXT(78$);
53$      FREE:       DeliveryPerson;
54$      SPLIT:      SA,
                TimeInCart,
                Eat:NEXT(66$);
66$      DUPLICATE:  1,64$:NEXT(Stats);
64$      ALLOCATE,   10:DeliveryPerson(SA),M;
63$      MOVE:       DeliveryPerson,DeliveryCart;
65$      FREE:       DeliveryPerson;
61$      ASSIGN:     (NumTraysOnCart(SA))=FullCart;
67$      DISPOSE:    No;
```

Experiment Code

```
ATTRIBUTES:  1,LeadOffWait,:
        2,ColdStationWait,:
        3,EntreeStationWait:
        4,HotStationWait,:
        5,CheckandBevStationWait:
        6,DeliveryToPatientWait,:
        7,DesiredDeliveryTime,:
        8,TimeInCartRank:
        9,DeliveryTimeRank:
        10,LastTray:
        11,DeliveryLocation:
        12,SA:
        13,TimeIn:
        14,TimeInCart:
        15,TimeOnLine:
        16,Eat:
        17,PatientSatisfaction:
        18,EnterCart:
        19,NumWindowsEarly:
        20,NumWindowsLate:
        21,NumWindowsAway:
        22,LateTrayTime:
        23,EarlyTrayTime;

VARIABLES:  1,NumMeals,CLEAR(System),CATEGORY("None-None"),200:
        2,FullCart,CLEAR(System),CATEGORY("None-None"),20:
        3,MaxWIP,CLEAR(System),CATEGORY("None-None"),9:
        5,TraysOnLine,CLEAR(System),CATEGORY("None-None"):
        6,WindowTime1,CLEAR(System),CATEGORY("None-None"),1500:
        7,WindowTime2,CLEAR(System),CATEGORY("None-None"),2400:
        8,WindowTime3,CLEAR(System),CATEGORY("None-None"),3300:
        9,WindowTime4,CLEAR(System),CATEGORY("None-None"),4200:
        10,WindowTime5,CLEAR(System),CATEGORY("None-None"),5100:
        11,WindowTime6,CLEAR(System),CATEGORY("None-None"),6000:
        12,NumTraysNeeded,CLEAR(System),CATEGORY("None-None"),191:
        13,loc,CLEAR(System),CATEGORY("None-None"):
        14,loctracker,CLEAR(System),CATEGORY("None-None"):
        15,Server,CLEAR(System),CATEGORY("None-None"):
        16,AI,CLEAR(System),CATEGORY("None-None"),1.25:
        17,NumTraysOnCart(4),CLEAR(System),CATEGORY("None-None"),20,20,20,20;

QUEUES:     1,LeadOffQ,FirstInFirstOut,,AUTOSTATS(Yes,,):
        2,ColdStationQ,FirstInFirstOut,,AUTOSTATS(Yes,,):
        3,EntreeQ,FirstInFirstOut,,AUTOSTATS(Yes,,):
        4,HotStationQ,FirstInFirstOut,,AUTOSTATS(Yes,,):
        5,CheckandBevStationQ,FirstInFirstOut,,AUTOSTATS(Yes,,);

PICTURES:   1,Picture.Tray;

RESOURCES:  1,Worker1,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
        2,Worker2,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
        3,Worker3,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
        4,Worker4,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,):
        5,Worker5,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,);

STATIONS:   1,LeadOff Station:
        2,Cold Station:
        3,Entree Station:
        4,Hot Station:
        5,Check and Beverage Station:
        6,StatisticsCollection:
        8,DeliveryCart:
        11,Location1:
        12,Location2:
        13,Location3:
```

14,Location4:
15,Location5:
16,Location6:
17,Location7:
18,Location8:
19,Location9:
20,Location10;

DISTANCES: Map3,DeliveryCart-Location1-540,Location1-DeliveryCart-540,DeliveryCart-Location2-540,Location2-DeliveryCart-540, DeliveryCart-Location3-563,Location3-DeliveryCart-563,DeliveryCart-Location4-598,Location4-DeliveryCart-598, DeliveryCart-Location5-810,Location5-DeliveryCart-810,DeliveryCart-Location6-841,Location6-DeliveryCart-841, DeliveryCart-Location7-900,Location7-DeliveryCart-900,DeliveryCart-Location8-920,Location8-DeliveryCart-920, DeliveryCart-Location9-1050,Location9-DeliveryCart-1050,DeliveryCart-Location10-1104,Location10-DeliveryCart-1104, Location1-Location2-0,Location2-Location1-0,Location1-Location3-23,Location3-Location1-23,Location1-Location4-58, Location4-Location1-58,Location1-Location5-270,Location5-Location1-270,Location1-Location6-301,Location6-Location1-301,Location1-Location7-360,Location7-Location1-360,Location1-Location8-380,Location8-Location1-380, Location1-Location9-510,Location9-Location1-510,Location1-Location10-564,Location10-Location1-564,Location2-Location3-23,Location3-Location2-23,Location2-Location4-58,Location4-Location2-58,Location2-Location5-270, Location5-Location2-270,Location2-Location6-301,Location6-Location2-301,Location2-Location7-360,Location7-Location2-360,Location2-Location8-380,Location8-Location2-380,Location2-Location9-510,Location9-Location2-510, Location2-Location10-564,Location10-Location2-564,Location3-Location4-35,Location4-Location3-35,Location3-Location5-247,Location5-Location3-247,Location3-Location6-278,Location6-Location3-278,Location3-Location7-337, Location7-Location3-337,Location3-Location8-357,Location8-Location3-357,Location3-Location9-487,Location9-Location3-487,Location3-Location10-541,Location10-Location3-541,Location4-Location5-212,Location5-Location4-212, Location4-Location6-243,Location6-Location4-243,Location4-Location7-302,Location7-Location4-302,Location4-Location8-322,Location8-Location4-322,Location4-Location9-452,Location9-Location4-452,Location4-Location10-506, Location10-Location4-506,Location5-Location6-31,Location6-Location5-31,Location5-Location7-90,Location7-Location5-90,Location5-Location8-110,Location8-Location5-110,Location5-Location9-240,Location9-Location5-240,Location5-Location10-294,Location10-Location5-294,Location6-Location7-59,Location7-Location6-59,Location6-Location8-79, Location8-Location6-79,Location6-Location9-209,Location9-Location6-209,Location6-Location10-263,Location10-Location6-263,Location7-Location8-20,Location8-Location7-20,Location7-Location9-150,Location9-Location7-150, Location7-Location10-204,Location10-Location7-204,Location8-Location9-130,Location9-Location8-130,Location8-Location10-184,Location10-Location8-184,Location9-Location10-54,Location10-Location9-54;

TRANSPORTERS: 1,DeliveryPerson,4,Distance(Map3),6.1---,AUTOSTATS(Yes,,);

SEGMENTS: Conv,LeadOff Station,Cold Station-3,Entree Station-3,Hot Station-3,Check and Beverage Station-3;

CONVEYORS: 1,TrayLine,Conv,1000,1,Active,2,Accumulating,,AUTOSTATS(Yes,,);

COUNTERS: 1,Window1Requested,,Replicate:
2,Window2Requested,,Replicate:
3,Window3Requested,,Replicate:
4,Window4Requested,,Replicate:
5,Window5Requested,,Replicate:
6,Window6Requested,,Replicate:
7,TraysLate,,Replicate:
8,TraysEarly,,Replicate:
9,TraysOnTime,,Replicate:
10,NumTraysCompleted,,Replicate:
11,DeliveredTrays,,Replicate:
12,FinishedTrays,,Replicate:
13,Loc1,,Replicate:
14,Loc2,,Replicate:
15,Loc3,,Replicate:
16,Loc4,,Replicate:
17,Loc5,,Replicate:
18,Loc6,,Replicate:
19,Loc7,,Replicate:
20,Loc8,,Replicate:
21,Loc9,,Replicate:
22,Loc10,,Replicate:
23,OneWindowEarly,,Replicate:
24,TwoWindowsEarly,,Replicate:
25,ThreeWindowsEarly,,Replicate:
26,FourWindowsEarly,,Replicate:
27,FiveOrMoreWindowsEarly,,Replicate:
28,Num NPM,,Replicate:
29,OneWindowLate,,Replicate:
30,TwoWindowsLate,,Replicate:

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        31,ThreeWindowsLate,,Replicate:
        32,FourWindowsLate,,Replicate:
        33,FiveOrMoreWindowsLate,,Replicate;

TALLIES:    1,TimeOnLineTally:
        2,OverallCycleTime:
        3,LateTrayTimeTally:
        4,EarlyTrayTimeTally:
        5,TimeInCartTally:
        6,NumberWindowsAway:
        7,PatientSatisfactionTally:
        8,MakeSpanOfLine:
        9,MakeSpanOfSystem:
        10,NumWindowsEarlyTally:
        11,NumWindowsLateTally;

OUTPUTS:    1,DAVG(Worker1.Utilization)+DAVG(Worker2.Utilization)+DAVG(Worker3.Utilization),,Line1:
        2,DAVG(Worker4.Utilization) + DAVG(Worker5.Utilization),,Line2:
        3,(OVALUE(Line1) + OVALUE(Line2)) / 5,"AssyWorkerUtil.dat",Assy Worker Util:
        4,DAVG(DeliveryPerson.Utilization),"DeliveryUtil.dat",Delivery Util:
        5,5,"NumAssyWorkers.dat",Num Assy Workers:
        6,MT(DeliveryPerson),"NumDeliveryPeople.dat",Num Delivery People:
        7,MT(DeliveryPerson) + 5,"TotalNumWorkers.dat",Total Num Workers:
        8,
        ((OVALUE(Assy Worker Util)*5)+(DAVG(DeliveryPerson.Utilization) * MT(DeliveryPerson)) )/ OVALUE(Total Num Workers),
        "TotalUtil.dat",Total Util:
        9,(TAVG(TimeOnLineTally))/60,"TimeOnLine.dat",TimeOnLine:
        10,(TAVG(OverallCycleTime))/60,"OverallCycleTime.dat",OverallCycleTime:
        11,(TAVG(MakeSpanOfLine))/60,"MakeSpanOfLine.dat",MakeSpanOfLine:
        12,(TAVG(MakeSpanOfSystem))/60,"MakeSpanOfSystem.dat",MakeSpanOfSystem:
        13,(TAVG(TimeInCartTally))/60,"TimeInCart.dat",TimeInCart:
        14,TAVG(NumWindowsLateTally),"NumWindowsLate.dat",NumWindowsLate:
        15,TAVG(NumWindowsEarlyTally),"NumWindowsEarly.dat",NumWindowsEarly:
        16,TAVG(PatientSatisfactionTally),"PatientSatisfaction.dat",PatientSatisfaction:
        17,NC(TraysLate),"TraysLate.dat",TraysLate:
        18,NC(TraysEarly),"TraysEarly.dat",TraysEarly:
        19,NC(TraysOnTime),"TraysOnTime.dat",TraysOnTime:
        20,NC(OneWindowEarly),"OneWindowEarly.dat",OneWindowEarly:
        21,NC(TwoWindowsEarly),"TwoWindowsEarly.dat",TwoWindowsEarly:
        22,NC(ThreeWindowsEarly),"ThreeWindowsEarly.dat",ThreeWindowsEarly:
        23,NC(FourWindowsEarly),"FourWindowsEarly.dat",FourWindowsEarly:
        24,NC(FiveOrMoreWindowsEarly),"FiveOrMoreWindowsEarly.dat",FiveOrMoreWindowsEarly:
        25,NC(OneWindowLate),"OneWindowLate.dat",OneWindowLate:
        26,NC(TwoWindowsLate),"TwoWindowsLate.dat",TwoWindowsLate:
        27,NC(ThreeWindowsLate),"ThreeWindowsLate.dat",ThreeWindowsLate:
        28,NC(FourWindowsLate),"FourWindowsLate.dat",FourWindowsLate:
        29,NC(FiveOrMoreWindowsLate),"FiveOrMoreWindowsLate.dat",FiveOrMoreWindowsLate:
        30,NC(Num NPM),"NumNPM.dat",Num NPM:
        31,NC(Window1Requested),"Window1Req.dat",Window1Requested:
        32,NC(Window2Requested),"Window2Requested.dat",Window2Requested:
        33,NC(Window3Requested),"Window3Requested.dat",Window3Requested:
        34,NC(Window4Requested),"Window4Requested.dat",Window4Requested:
        35,NC(Window5Requested),"Window5Requested.dat",Window5Requested:
        36,NC(Window6Requested),"Window6Requested.dat",Window6Requested;

REPLICATE,  100,,HoursToBaseTime(24),Yes,Yes,,NC(FinishedTrays)==200,,24,Seconds,No,No;

ENTITIES:   Tray,,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,);
```

Model Output

Summary for Replication 1 of 1

Project: Configuration1 Run execution date : 8/12/2003
Analyst:Emily Olney Model revision date: 8/12/2003

Replication ended at time : 5404.6852

TALLY VARIABLES

Identifier	Average	Half-Width	Minimum	Maximum	Observations
TimeOnLineTally	67.936	(Insuf)	54.626	83.183	200
OverallCycleTime	1145.7	(Insuf)	482.06	2016.7	200
LateTrayTimeTally	1546.0	(Insuf)	19.267	3825.0	54
EarlyTrayTimeTally	1595.1	(Insuf)	17.556	3825.4	79
TimeInCartTally	1077.7	(Insuf)	413.54	1957.3	200
NumberWindowsAway	--	--	--	--	0
PatientSatisfactionTal	6.4050	(Insuf)	.00000	10.000	200
MakeSpanOfLine	3385.6	(Insuf)	3385.6	3385.6	1
MakeSpanOfSystem	5404.6	(Insuf)	5404.6	5404.6	1
NumWindowsEarlyTally	1.7723	(Insuf)	.01951	4.2505	79
NumWindowsLateTally	1.7177	(Insuf)	.02141	4.2500	54

DISCRETE-CHANGE VARIABLES

Identifier	Average	Half-Width	Minimum	Maximum	Observations
Tray.WIP	51.426	(Corr)	0	83	1
Worker1.NumberBusy	0.64917	(Insuf)	0	1	0
Worker1.NumberSchedule	1	(Insuf)	1	1	1
Worker1.Utilization	0.64917	(Insuf)	0	1	0
Worker2.NumberBusy	0.38977	(Corr)	0	1	0
Worker2.NumberSchedule	1	(Insuf)	1	1	1
Worker2.Utilization	0.38977	(Corr)	0	1	0
Worker3.NumberBusy	0.36074	(Corr)	0	1	0
Worker3.NumberSchedule	1	(Insuf)	1	1	1
Worker3.Utilization	0.36074	(Corr)	0	1	0
Worker4.NumberBusy	0.35885	(Corr)	0	1	0
Worker4.NumberSchedule	1	(Insuf)	1	1	1
Worker4.Utilization	0.35885	(Corr)	0	1	0
Worker5.NumberBusy	0.59674	(Corr)	0	1	0
Worker5.NumberSchedule	1	(Insuf)	1	1	1
Worker5.Utilization	0.59674	(Corr)	0	1	0
DeliveryPerson.NumberB	2.9693	(Insuf)	0	4	1
DeliveryPerson.NumberS	4	(Insuf)	4	4	4
DeliveryPerson.Utiliza	0.74233	(Insuf)	0	1	0.25

COUNTERS

Identifier	Count	Limit
Window1Requested	34	Infinite
Window2Requested	26	Infinite
Window3Requested	20	Infinite

Window4Requested	18	Infinite
Window5Requested	35	Infinite
Window6Requested	27	Infinite
TraysLate	54	Infinite
TraysEarly	79	Infinite
TraysOnTime	27	Infinite
NumTraysCompleted	200	Infinite
DeliveredTrays	200	Infinite
FinishedTrays	200	Infinite
Loc1	20	Infinite
Loc2	20	Infinite
Loc3	20	Infinite
Loc4	20	Infinite
Loc5	20	Infinite
Loc6	20	Infinite
Loc7	20	Infinite
Loc8	20	Infinite
Loc9	20	Infinite
Loc10	20	Infinite
OneWindowEarly	29	Infinite
TwoWindowsEarly	16	Infinite
ThreeWindowsEarly	19	Infinite
FourWindowsEarly	13	Infinite
FiveOrMoreWindowsEarly	2	Infinite
Num NPM	40	Infinite
OneWindowLate	21	Infinite
TwoWindowsLate	12	Infinite
ThreeWindowsLate	12	Infinite
FourWindowsLate	6	Infinite

OUTPUTS

Identifier	Value
Assy Worker Util	0.47105
Delivery Util	0.74233
Num Assy Workers	5
Num Delivery People	4
Total Num Workers	9
Total Util	0.59162
TimeOnLine	1.1322
OverallCycleTime	19.095
MakeSpanOfLine	56.426
MakeSpanOfSystem	90.078
TimeInCart	17.963
NumWindowsLate	1.7177
NumWindowsEarly	1.7723
PatientSatisfaction	6.405
TraysLate	54

TraysEarly	79
TraysOnTime	27
OneWindowEarly	29
TwoWindowsEarly	16
ThreeWindowsEarly	19
FourWindowsEarly	13
FiveOrMoreWindowsEarly	2
OneWindowLate	21
TwoWindowsLate	12
ThreeWindowsLate	12
FourWindowsLate	6
FiveOrMoreWindowsLate	3
Num NPM	40
Window1Requested	34
Window2Requested	26
Window3Requested	20
Window4Requested	18
Window5Requested	35
Window6Requested	27
Worker1.TimesUsed	200
Worker1.ScheduledUtiliz	0.64917
Worker2.TimesUsed	200
Worker2.ScheduledUtiliz	0.38977
Worker3.TimesUsed	200
Worker3.ScheduledUtiliz	0.36074
Worker4.TimesUsed	200
Worker4.ScheduledUtiliz	0.35885
Worker5.TimesUsed	200
Worker5.ScheduledUtiliz	0.59674

Large Hospital, Cellular Assembly, Choice Menu, Room Service Delivery System

Model Code

```
0$      STATION,    2-6;
1$      DELAY:      A(M),,Other:NEXT(2$);
2$      TRANSPORT:  Worker,M+1;
4$      STATION,    7;
3$      FREE:       Worker;
73$     ASSIGN:     TimeInCell=TNOW-TimeIn;
5$      TALLY:      TimeInCellTally,TimeInCell,1;
13$     COUNT:      NumTraysCompleted,1;
14$     BRANCH,     1:
            If,NC(NumTraysCompleted) == NumMeals,15$,Yes:
            Else,11$,Yes;
15$     TALLY:      MakeSpanOfCell,TNOW,1;
11$     GROUP,      ,Temporary:FullCart,First:MARK(EnterCart):NEXT(12$);
12$     ASSIGN:     Picture=2;
28$     ROUTE:      0.0,DeliveryCart;
6$      STATION,    LeadOff Station;
16$     QUEUE,      LeadOffQ;
7$      REQUEST,    1:Worker(CYC),,LeadOff Station;
10$     ASSIGN:     Picture=2:MARK(TimeIn);
8$      DELAY:      LeadOffWait,,Other:NEXT(9$);
9$      TRANSPORT:  Worker,2;
17$     STATION,    23-27;
18$     DELAY:      A(M-21),,Other:NEXT(19$);
19$     TRANSPORT:  Cell2Worker,M+1;
21$     STATION,    28;
20$     FREE:       Cell2Worker;
72$     ASSIGN:     TimeInCell=TNOW-TimeIn;
29$     TALLY:      TimeInCellTally,TimeInCell,1;
32$     COUNT:      NumTraysCompleted,1;
33$     BRANCH,     1:
            If,NC(NumTraysCompleted) == NumMeals,34$,Yes:
            Else,30$,Yes;
34$     TALLY:      MakeSpanOfCell,TNOW,1;
30$     GROUP,      ,Temporary:FullCart,First:MARK(EnterCart):NEXT(31$);
31$     ASSIGN:     Picture=2;
35$     ROUTE:      0.0,DeliveryCart;
22$     STATION,    LeadOff Cell2;
27$     QUEUE,      LeadOff Cell2Q;
23$     REQUEST,    1:Cell2Worker(CYC),,LeadOff Cell2;
26$     ASSIGN:     Picture=2:MARK(TimeIn);
24$     DELAY:      LeadOffWait,,Other:NEXT(25$);
25$     TRANSPORT:  Cell2Worker,23;
38$     STATION,    DeliveryCart;
39$     ASSIGN:     SA=MOD(Server,8)+1:
            Server=Server+1;
40$     SCAN:       (NumTraysOnCart(SA)==FullCart)&&(IT(DeliveryPerson,SA)==0);
36$     REQUEST,    5:DeliveryPerson(SA),,DeliveryCart;
37$     TRANSPORT:  DeliveryPerson,DeliveryLocation;
45$     CREATE,     NumMeals,,Tray:0,1:NEXT(95$);
95$     ASSIGN:     Picture=1:
            LeadOffWait=(TRIA(10,12.7,19))*AI:
            ColdStation1Wait=(TRIA(5,12.2,34))*AI:
            ColdStation2Wait=(TRIA(7,11.3,26))*AI:
            HotStation1Wait=(TRIA(7,11.2,21))*AI:
            HotStation2Wait=(TRIA(8,9.7,25))*AI:
            BeverageStationWait=(TRIA(4,9.99,21))*AI:
            DeliveryToPatientWait=TRIA(45,70,90):
            DesiredDeliveryTime=DISC(0.1,1,0.2,2,0.3,3,0.4,4,0.5,5,0.6,6,0.7,7,0.8,8,1,9):
            DeliveryLocation=loc+11:
            loctracker=loctracker+1;
50$     BRANCH,     1:
            If,loctracker==60,51$,Yes:
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          Else,62$,Yes;
51$     ASSIGN:     loctracker=0:
          loc=loc+1;
62$     BRANCH,     1:
          If,DesiredDeliveryTime <= 8,61$,Yes:
          Else,64$,Yes;
61$     ASSIGN:     DW(DesiredDeliveryTime)=DW(DesiredDeliveryTime)+1;
46$     ASSIGN:     DeliveryPriority=(DesiredDeliveryTime * 100) + DeliveryLocation;
44$     QUEUE,      ArrivalQ:DETACH;
64$     ASSIGN:     NPM=1;
63$     QUEUE,      NPMQ:DETACH;
53$     CREATE,     1,,Dummy:0,1:NEXT(54$);
54$     SCAN:       NQ(ArrivalQ)+NQ(NPMQ) ==NumMeals;
55$     BRANCH,     1:
          If,NQ(NPMQ)==0,57$,Yes:
          If,DW(NPMindex)>=75,200$,Yes:
          Else,58$,Yes;
57$     DISPOSE:    No;
200$    DELAY:      .0000001,,Other:NEXT(56$);
56$     ASSIGN:     NPMindex=NPMindex+1:NEXT(55$);
58$     REMOVE:     1,NPMQ,60$;
59$     ASSIGN:     DW(NPMindex)=DW(NPMindex)+1:NEXT(55$);
60$     ASSIGN:     DesiredDeliveryTime=NPMindex:NEXT(46$);
65$     STATION,    SortedTrays Station;
66$     QUEUE,      SortedTraysQ;
47$     SEIZE,      1,Other:
          Fake,1:NEXT(52$);
52$     ASSIGN:     traynumber=traynumber+1;
41$     BRANCH,     1:
          If,MOD(traynumber,20)>=10,48$,Yes:
          Else,49$,Yes;
48$     RELEASE:    Fake,1;
42$     ROUTE:      0.0,LeadOff Cell2;
49$     RELEASE:    Fake,1;
43$     ROUTE:      0.0,LeadOff Station;
67$     CREATE,     1,,Dummy2:0,1:NEXT(68$);
68$     SCAN:       NQ(ArrivalQ)==NumMeals;
69$     BRANCH,     1:
          If,NQ(ArrivalQ)==0,71$,Yes:
          Else,70$,Yes;
71$     DISPOSE:    No;
70$     REMOVE:     1,ArrivalQ,66$:NEXT(69$);
74$     STATION,    11-20;
87$     COUNT:      M+2,1;
93$     TALLY:      OverallCycleTime,TNOW-TimeIn,1;
77$     ASSIGN:     NumTraysOnCart(SA)=(NumTraysOnCart(SA)) - 1:
          TimeInCart=TNOW-EnterCart:MARK(Eat);
94$     TALLY:      TimeInCartTally,TimeInCart,1;
83$     DELAY:      DeliveryToPatientWait,,Other:NEXT(76$);
76$     BRANCH,     1:
          If,NumTraysOnCart(SA)>0,82$,Yes:
          Else,78$,Yes;
82$     FREE:       DeliveryPerson;
75$     DROPOFF,    1,1:Stats,
          NPM,
          TimeInCart,
          Eat;
80$     SPLIT:      SA,
          M:NEXT(81$);
81$     GROUP,      ,Temporary:NumTraysOnCart(SA),First:NEXT(84$);
84$     REQUEST,    1:DeliveryPerson(SA),,M;
85$     TRANSPORT:  DeliveryPerson,DeliveryLocation;
Stats   STATION,    StatisticsCollection;
96$     BRANCH,     1:
          If,(TimeInCart)<=600,97$,Yes:
          If,(TimeInCart> 600) && (TimeInCart <= 900),98$,Yes:
          If,(TimeInCart> 900) && (TimeInCart <= 1200),99$,Yes:
          If,(TimeInCart > 1200) && (TimeInCart<= 1500),100$,Yes:
          If,(TimeInCart> 1500) && (TimeInCart<= 1800),101$,Yes:
          Else,102$,Yes;
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97$        ASSIGN:      TimeInCartRank=5;
103$       BRANCH,      1:
                 If,NPM == 1,104$,No:
                 Else,105$,Yes;
104$       COUNT:       Num NPM,1;
140$       ASSIGN:      DeliveryTimeRank=5;
172$       ASSIGN:      PatientSatisfaction=DeliveryTimeRank + TimeInCartRank;
162$       TALLY:       PatientSatisfactionTally,PatientSatisfaction,1;
165$       COUNT:       DeliveredTrays,1;
164$       BRANCH,      1:
                 If,NC(DeliveredTrays) == NumMeals,163$,Yes:
                 Else,166$,Yes;
163$       TALLY:       MakeSpanOfSystem,TNOW,1;
166$       COUNT:       FinishedTrays,1;
199$       WRITE,       TraysOut:
                 DesiredDeliveryTime,
                 DeliveryLocation,
                 AINT(1+(Eat-600)/900),
                 Eat/60;
184$       DISPOSE:     No;
105$       BRANCH,      1:
                 If,DesiredDeliveryTime==1,107$,Yes:
                 If,DesiredDeliveryTime==2,115$,Yes:
                 If,DesiredDeliveryTime==3,120$,Yes:
                 If,DesiredDeliveryTime==4,125$,Yes:
                 If,DesiredDeliveryTime==5,130$,Yes:
                 If,DesiredDeliveryTime==6,135$,Yes:
                 If,DesiredDeliveryTime==7,186$,Yes:
                 If,DesiredDeliveryTime==8,193$,Yes;
107$       COUNT:       Window1Requested,1;
106$       BRANCH,      1:
                 If,Eat > (WindowTime1),142$,Yes:
                 If,Eat==(WindowTime1),111$,Yes:
                 If,Eat<(WindowTime1),113$,Yes;
142$       ASSIGN:      LateTrayTime=Eat-WindowTime1;
108$       TALLY:       LateTrayTimeTally,LateTrayTime,1;
110$       COUNT:       TraysLate,1;
154$       ASSIGN:      NumWindowsLate=LateTrayTime / 900:
                 NumWindowsAway=NumWindowsLate;
155$       TALLY:       NumWindowsLateTally,NumWindowsLate,1;
156$       BRANCH,      1:
                 If,NumWindowsAway <= 1,157$,Yes:
                 If,(NumWindowsAway > 1) && (NumWindowsAway<= 2),158$,Yes:
                 If,(NumWindowsAway> 2) && (NumWindowsAway<= 3),159$,Yes:
                 If,(NumWindowsAway  > 3) && (NumWindowsAway<= 4),160$,Yes:
                 Else,161$,Yes;
157$       ASSIGN:      DeliveryTimeRank=4;
167$       COUNT:       OneWindowLate,1:NEXT(172$);
158$       ASSIGN:      DeliveryTimeRank=3;
168$       COUNT:       TwoWindowsLate,1:NEXT(172$);
159$       ASSIGN:      DeliveryTimeRank=2;
169$       COUNT:       ThreeWindowsLate,1:NEXT(172$);
160$       ASSIGN:      DeliveryTimeRank=1;
170$       COUNT:       FourWindowsLate,1:NEXT(172$);
161$       ASSIGN:      DeliveryTimeRank=0;
171$       COUNT:       FiveOrMoreWindowsLate,1:NEXT(172$);
111$       COUNT:       TraysOnTime,1:NEXT(140$);
113$       BRANCH,      1:
                 If,Eat>=(WindowTime1-900),111$,Yes:
                 Else,143$,Yes;
143$       ASSIGN:      EarlyTrayTime=(WindowTime1-900)-Eat;
109$       TALLY:       EarlyTrayTimeTally,EarlyTrayTime,1;
112$       COUNT:       TraysEarly,1;
141$       ASSIGN:      NumWindowsEarly=EarlyTrayTime / 900:
                 NumWindowsAway=NumWindowsEarly;
139$       TALLY:       NumWindowsEarlyTally,NumWindowsEarly,1;
173$       BRANCH,      1:
                 If,NumWindowsAway <= 1,174$,Yes:
                 If,(NumWindowsAway > 1) && (NumWindowsAway<= 2),175$,Yes:
                 If,(NumWindowsAway> 2) && (NumWindowsAway<= 3),176$,Yes:
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                If,(NumWindowsAway > 3) && (NumWindowsAway<= 4),177$,Yes:
                Else,178$,Yes;
174$     ASSIGN:     DeliveryTimeRank=4;
179$     COUNT:      OneWindowEarly,1:NEXT(172$);
175$     ASSIGN:     DeliveryTimeRank=3;
180$     COUNT:      TwoWindowsEarly,1:NEXT(172$);
176$     ASSIGN:     DeliveryTimeRank=2;
181$     COUNT:      ThreeWindowsEarly,1:NEXT(172$);
177$     ASSIGN:     DeliveryTimeRank=1;
182$     COUNT:      FourWindowsEarly,1:NEXT(172$);
178$     ASSIGN:     DeliveryTimeRank=0;
183$     COUNT:      FiveOrMoreWindowsEarly,1:NEXT(172$);
115$     COUNT:      Window2Requested,1;
114$     BRANCH,     1:
                If,Eat > (WindowTime2),144$,Yes:
                If,Eat==(WindowTime2),111$,Yes:
                If,Eat<(WindowTime2),118$,Yes;
144$     ASSIGN:     LateTrayTime=Eat-WindowTime2;
116$     TALLY:      LateTrayTimeTally,LateTrayTime,1:NEXT(110$);
118$     BRANCH,     1:
                If,Eat>=(WindowTime2-900),111$,Yes:
                Else,145$,Yes;
145$     ASSIGN:     EarlyTrayTime=(WindowTime2-900)-Eat;
117$     TALLY:      EarlyTrayTimeTally,EarlyTrayTime,1:NEXT(112$);

120$     COUNT:      Window3Requested,1;
119$     BRANCH,     1:
                If,Eat > (WindowTime3),146$,Yes:
                If,Eat==(WindowTime3),111$,Yes:
                If,Eat<(WindowTime3),123$,Yes;
146$     ASSIGN:     LateTrayTime=Eat-WindowTime3;
121$     TALLY:      LateTrayTimeTally,LateTrayTime,1:NEXT(110$);
123$     BRANCH,     1:
                If,Eat>=(WindowTime3-900),111$,Yes:
                Else,147$,Yes;
147$     ASSIGN:     EarlyTrayTime=(WindowTime3-900)-Eat;
122$     TALLY:      EarlyTrayTimeTally,EarlyTrayTime,1:NEXT(112$);
125$     COUNT:      Window4Requested,1;
124$     BRANCH,     1:
                If,Eat > (WindowTime4),148$,Yes:
                If,Eat==(WindowTime4),111$,Yes:
                If,Eat<(WindowTime4),128$,Yes;
148$     ASSIGN:     LateTrayTime=Eat-WindowTime4;
126$     TALLY:      LateTrayTimeTally,LateTrayTime,1:NEXT(110$);
128$     BRANCH,     1:
                If,Eat>=(WindowTime4-900),111$,Yes:
                Else,149$,Yes;
149$     ASSIGN:     EarlyTrayTime=(WindowTime4-900)-Eat;
127$     TALLY:      EarlyTrayTimeTally,EarlyTrayTime,1:NEXT(112$);
130$     COUNT:      Window5Requested,1;
129$     BRANCH,     1:
                If,Eat > (WindowTime5),150$,Yes:
                If,Eat==(WindowTime5),111$,Yes:
                If,Eat<(WindowTime5),133$,Yes;
150$     ASSIGN:     LateTrayTime=Eat-WindowTime5;
131$     TALLY:      LateTrayTimeTally,LateTrayTime,1:NEXT(110$);
133$     BRANCH,     1:
                If,Eat>=(WindowTime5-900),111$,Yes:
                Else,151$,Yes;
151$     ASSIGN:     EarlyTrayTime=(WindowTime5-900)-Eat;
132$     TALLY:      EarlyTrayTimeTally,EarlyTrayTime,1:NEXT(112$);
135$     COUNT:      Window6Requested,1;
134$     BRANCH,     1:
                If,Eat > (WindowTime6),152$,Yes:
                If,Eat==(WindowTime6),111$,Yes:
                If,Eat<(WindowTime6),138$,Yes;
152$     ASSIGN:     LateTrayTime=Eat-WindowTime6;
136$     TALLY:      LateTrayTimeTally,LateTrayTime,1:NEXT(110$);
138$     BRANCH,     1:
                If,Eat>=(WindowTime6-900),111$,Yes:
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            Else,153$,Yes;
153$    ASSIGN:     EarlyTrayTime=(WindowTime6-900)-Eat;
137$    TALLY:      EarlyTrayTimeTally,EarlyTrayTime,1:NEXT(112$);
186$    COUNT:      Window7Requested,1;
185$    BRANCH,     1:
            If,Eat > (WindowTime7),190$,Yes:
            If,Eat==(WindowTime7),111$,Yes:
            If,Eat<(WindowTime7),189$,Yes;
190$    ASSIGN:     LateTrayTime=Eat-WindowTime7;
187$    TALLY:      LateTrayTimeTally,LateTrayTime,1:NEXT(110$);
189$    BRANCH,     1:
            If,Eat>=(WindowTime7-900),111$,Yes:
            Else,191$,Yes;
191$    ASSIGN:     EarlyTrayTime=(WindowTime7-900)-Eat;
188$    TALLY:      EarlyTrayTimeTally,EarlyTrayTime,1:NEXT(112$);
193$    COUNT:      Window8Requested,1;
192$    BRANCH,     1:
            If,Eat > (WindowTime8),197$,Yes:
            If,Eat==(WindowTime8),111$,Yes:
            If,Eat<(WindowTime8),196$,Yes;
197$    ASSIGN:     LateTrayTime=Eat-WindowTime8;
194$    TALLY:      LateTrayTimeTally,LateTrayTime,1:NEXT(110$);
196$    BRANCH,     1:
            If,Eat>=(WindowTime8-900),111$,Yes:
            Else,198$,Yes;
198$    ASSIGN:     EarlyTrayTime=(WindowTime8-900)-Eat;
195$    TALLY:      EarlyTrayTimeTally,EarlyTrayTime,1:NEXT(112$);
98$     ASSIGN:     TimeInCartRank=4:NEXT(103$);
99$     ASSIGN:     TimeInCartRank=3:NEXT(103$);
100$    ASSIGN:     TimeInCartRank=2:NEXT(103$);
101$    ASSIGN:     TimeInCartRank=1:NEXT(103$);
102$    ASSIGN:     TimeInCartRank=0:NEXT(103$);
78$     FREE:       DeliveryPerson;
79$     SPLIT:      SA,
            NPM,
            TimeInCart,
            Eat:NEXT(91$);
91$     DUPLICATE:  1,89$:NEXT(Stats);
89$     ALLOCATE,   10:DeliveryPerson(SA),M;
88$     MOVE:       DeliveryPerson,DeliveryCart;
90$     FREE:       DeliveryPerson;
86$     ASSIGN:     (NumTraysOnCart(SA))=FullCart;
92$     DISPOSE:    No;
```

Experiment Code

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ATTRIBUTES:  1,LeadOffWait,:
        2,ColdStation1Wait,:
        3,ColdStation2Wait,:
        4,HotStation1Wait,:
        5,HotStation2Wait,:
        6,BeverageStationWait,:
        8,DeliveryToPatientWait,:
        9,TimeIn:
        10,DesiredDeliveryTime,:
        11,TimeInCartRank,:
        12,DeliveryTimeRank,:
        13,DeliveryLocation:
        14,DeliveryPriority:
        15,LastTray:
        16,SA:
        17,NPM:
        18,Eat:
        19,TimeInCart:
        20,TimeInCell:
        21,PatientSatisfaction:
        22,EnterCart:
        23,NumWindowsEarly:
        24,NumWindowsLate:
        25,NumWindowsAway:
        26,EarlyTrayTime:
        27,LateTrayTime;

FILES:      1,EatTime,"EatTime.txt",Sequential(),Free Format,Error,No,Hold:
        2,TraysOut,"TraysOut.txt",Sequential(),Free Format,Error,No,Hold;

VARIABLES:  1,NumMeals,CLEAR(System),CATEGORY("None-None"),600:
        2,FullCart,CLEAR(System),CATEGORY("None-None"),10:
        3,WindowTime1,CLEAR(System),CATEGORY("None-None"),1500:
        4,WindowTime2,CLEAR(System),CATEGORY("None-None"),2400:
        5,WindowTime3,CLEAR(System),CATEGORY("None-None"),3300:
        6,WindowTime4,CLEAR(System),CATEGORY("None-None"),4200:
        7,WindowTime5,CLEAR(System),CATEGORY("None-None"),5100:
        8,WindowTime6,CLEAR(System),CATEGORY("None-None"),6000:
        9,WindowTime7,CLEAR(System),CATEGORY("None-None"),6900:
        10,WindowTime8,CLEAR(System),CATEGORY("None-None"),7800:
        11,traynumber,CLEAR(System),CATEGORY("None-None"):
        12,Server,CLEAR(System),CATEGORY("None-None"):
        13,NPMindex,CLEAR(System),CATEGORY("None-None"),1:
        14,AI,CLEAR(System),CATEGORY("None-None"),1:
        15,loc,CLEAR(System),CATEGORY("None-None"):
        16,loctracker,CLEAR(System),CATEGORY("None-None"):
        20,DW(8),CLEAR(System),CATEGORY("None-None"),0,0,0,0,0,0,0,0:
        45,NumTraysOnCart(8),CLEAR(System),CATEGORY("None-None"),10,10,10,10,10,10,10,10;

QUEUES:     1,LeadOffQ,FirstInFirstOut,,AUTOSTATS(Yes,,):
        2,LeadOff Cell2Q,FirstInFirstOut,,AUTOSTATS(Yes,,):
        3,ArrivalQ,HighValueFirst(DeliveryPriority),,AUTOSTATS(Yes,,):
        4,NPMQ,FirstInFirstOut,,AUTOSTATS(Yes,,):
        5,SortedTraysQ,FirstInFirstOut,,AUTOSTATS(Yes,,);

PICTURES:   1,Picture.Tray;

RESOURCES:  1,Fake,Capacity(1),,Stationary,COST(0.0,0.0,0.0),,AUTOSTATS(Yes,,);

STATIONS:   1,LeadOff Station:
        2,Cold Station 1:
        3,Cold Station 2:
        4,Hot Station 1:
        5,Hot Station 2:
        6,Beverage Station:
        7,HoldStation Cell1:
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8,DeliveryCart:
11,Location1:
12,Location2:
13,Location3:
14,Location4:
15,Location5:
16,Location6:
17,Location7:
18,Location8:
19,Location9:
20,Location10:
21,StatisticsCollection:
22,LeadOff Cell2:
23,ColdStation1 Cell2:
24,ColdStation2 Cell2:
25,HotStation1 Cell2:
26,HotStation2 Cell2:
27,BeverageStation Cell2:
28,HoldStation Cell2:
29,SortedTrays Station;

DISTANCES: Map1,LeadOff Station-Cold Station 1-5,Cold Station 1-Cold Station 2-4,Cold Station 2-Hot Station 1-5,
Hot Station 1-Hot Station 2-4,Hot Station 2-Beverage Station-5,Beverage Station-HoldStation Cell1-2,
HoldStation Cell1-LeadOff Station-8:
Map3,DeliveryCart-Location1-540,Location1-DeliveryCart-540,DeliveryCart-Location2-540,Location2-DeliveryCart-540,
DeliveryCart-Location3-563,Location3-DeliveryCart-563,DeliveryCart-Location4-598,Location4-DeliveryCart-598,
DeliveryCart-Location5-810,Location5-DeliveryCart-810,DeliveryCart-Location6-841,Location6-DeliveryCart-841,
DeliveryCart-Location7-900,Location7-DeliveryCart-900,DeliveryCart-Location8-920,Location8-DeliveryCart-920,
DeliveryCart-Location9-1050,Location9-DeliveryCart-1050,DeliveryCart-Location10-1104,Location10-DeliveryCart-1104,
Location1-Location2-0,Location2-Location1-0,Location1-Location3-23,Location3-Location1-23,Location1-Location4-58,
Location4-Location1-58,Location1-Location5-270,Location5-Location1-270,Location1-Location6-301,Location6-
Location1-301,Location1-Location7-360,Location7-Location1-360,Location1-Location8-380,Location8-Location1-380,
Location1-Location9-510,Location9-Location1-510,Location1-Location10-564,Location10-Location1-564,Location2-
Location3-23,Location3-Location2-23,Location2-Location4-58,Location4-Location2-58,Location2-Location5-270,
Location5-Location2-270,Location2-Location6-301,Location6-Location2-301,Location2-Location7-360,Location7-
Location2-360,Location2-Location8-380,Location8-Location2-380,Location2-Location9-510,Location9-Location2-510,
Location2-Location10-564,Location10-Location2-564,Location3-Location4-35,Location4-Location3-35,Location3-
Location5-247,Location5-Location3-247,Location3-Location6-278,Location6-Location3-278,Location3-Location7-337,
Location7-Location3-337,Location3-Location8-357,Location8-Location3-357,Location3-Location9-487,Location9-
Location3-487,Location3-Location10-541,Location10-Location3-541,Location4-Location5-212,Location5-Location4-212,
Location4-Location6-243,Location6-Location4-243,Location4-Location7-302,Location7-Location4-302,Location4-
Location8-322,Location8-Location4-322,Location4-Location9-452,Location9-Location4-452,Location4-Location10-506,
Location10-Location4-506,Location5-Location6-31,Location6-Location5-31,Location5-Location7-90,Location7-Location5-
90,Location5-Location8-110,Location8-Location5-110,Location5-Location9-240,Location9-Location5-240,Location5-
Location10-294,Location10-Location5-294,Location6-Location7-59,Location7-Location6-59,Location6-Location8-79,
Location8-Location6-79,Location6-Location9-209,Location9-Location6-209,Location6-Location10-263,Location10-
Location6-263,Location7-Location8-20,Location8-Location7-20,Location7-Location9-150,Location9-Location7-150,
Location7-Location10-204,Location10-Location7-204,Location8-Location9-130,Location9-Location8-130,Location8-
Location10-184,Location10-Location8-184,Location9-Location10-54,Location10-Location9-54:
Map5,LeadOff Cell2-ColdStation1 Cell2-5,ColdStation1 Cell2-ColdStation2 Cell2-4,ColdStation2 Cell2-
HotStation1 Cell2-5,HotStation1 Cell2-HotStation2 Cell2-4,HotStation2 Cell2-BeverageStation Cell2-5,
BeverageStation Cell2-HoldStation Cell2-2,HoldStation Cell2-LeadOff Cell2-8;

TRANSPORTERS: 1,Worker,5,Distance(Map1),1.5---,AUTOSTATS(Yes,,):
2,DeliveryPerson,8,Distance(Map3),6.1---,AUTOSTATS(Yes,,):
3,Cell2Worker,5,Distance(Map5),1.5---,AUTOSTATS(Yes,,);

COUNTERS: 1,Window1Requested,,Replicate:
2,Window2Requested,,Replicate:
3,Window3Requested,,Replicate:
4,Window4Requested,,Replicate:
5,Window5Requested,,Replicate:
6,Window6Requested,,Replicate:
7,Window7Requested,,Replicate:
8,Window8Requested,,Replicate:
10,NumTraysCompleted,,Replicate:
11,DeliveredTrays,,Replicate:
12,FinishedTrays,,Replicate:
13,Loc1,,Replicate:
14,Loc2,,Replicate:

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        15,Loc3,,Replicate:
        16,Loc4,,Replicate:
        17,Loc5,,Replicate:
        18,Loc6,,Replicate:
        19,Loc7,,Replicate:
        20,Loc8,,Replicate:
        21,Loc9,,Replicate:
        22,Loc10,,Replicate:
        23,OneWindowEarly,,Replicate:
        24,TwoWindowsEarly,,Replicate:
        25,ThreeWindowsEarly,,Replicate:
        26,FourWindowsEarly,,Replicate:
        27,FiveOrMoreWindowsEarly,,Replicate:
        28,Num NPM,,Replicate:
        29,OneWindowLate,,Replicate:
        30,TwoWindowsLate,,Replicate:
        31,ThreeWindowsLate,,Replicate:
        32,FourWindowsLate,,Replicate:
        33,FiveOrMoreWindowsLate,,Replicate:
        34,TraysLate,,Replicate:
        35,TraysEarly,,Replicate:
        36,TraysOnTime,,Replicate;

TALLIES:    1,TimeInCellTally:
        2,OverallCycleTime:
        3,LateTrayTimeTally:
        4,EarlyTrayTimeTally:
        5,TimeInCartTally:
        7,PatientSatisfactionTally:
        8,MakeSpanOfCell:
        9,MakeSpanOfSystem:
        10,NumWindowsEarlyTally:
        11,NumWindowsLateTally;

OUTPUTS:    1,((DAVG(Cell2Worker.Utilization)*MT(Cell2Worker))+(DAVG(Worker.Utilization)*MT(Worker)))/OVALUE(Num Assy
Workers),
        "AssyWorkerUtil.dat",Assy Worker Util:
        2,DAVG(DeliveryPerson.Utilization),"DeliveryUtil.dat",Delivery Util:
        3,MT(Cell2Worker) + MT(Worker),"NumAssyWorkers.dat",Num Assy Workers:
        4,MT(DeliveryPerson),"NumDeliveryPeople.dat",Num Delivery People:
        5,MT(Cell2Worker) + MT(DeliveryPerson) + MT(Worker),"TotalNumWorkers.dat",Total Num Workers:
        6,
        ((OVALUE(Assy Worker Util)*OVALUE(Num Assy Workers))+(OVALUE(Delivery Util)*MT(DeliveryPerson)))/OVALUE(Total
Num Workers),
        "TotalUtil.dat",Total Util:
        9,(TAVG(TimeInCellTally))/60,"TimeInCell.dat",TimeInCell:
        10,(TAVG(OverallCycleTime))/60,"OverallCycleTime.dat",OverallCycleTime:
        11,(TAVG(MakeSpanOfCell))/60,"MakeSpanOfCell.dat",MakeSpanOfCell:
        12,(TAVG(MakeSpanOfSystem))/60,"MakeSpanOfSystem.dat",MakeSpanOfSystem:
        13,(TAVG(TimeInCartTally))/60,"TimeInCart.dat",TimeInCart:
        14,TAVG(NumWindowsLateTally),"NumWindowsLate.dat",NumWindowsLate:
        15,TAVG(NumWindowsEarlyTally),"NumWindowsEarly.dat",NumWindowsEarly:
        16,TAVG(PatientSatisfactionTally),"PatientSatisfaction.dat",PatientSatisfaction:
        17,NC(TraysLate),"TraysLate.dat",TraysLate:
        18,NC(TraysEarly),"TraysEarly.dat",TraysEarly:
        19,NC(TraysOnTime),"TraysOnTime.dat",TraysOnTime:
        20,NC(OneWindowEarly),"OneWindowEarly.dat",OneWindowEarly:
        21,NC(TwoWindowsEarly),"TwoWindowsEarly.dat",TwoWindowsEarly:
        22,NC(ThreeWindowsEarly),"ThreeWindowsEarly.dat",ThreeWindowsEarly:
        23,NC(FourWindowsEarly),"FourWindowsEarly.dat",FourWindowsEarly:
        24,NC(FiveOrMoreWindowsEarly),"FiveOrMoreWindowsEarly.dat",FiveOrMoreWindowsEarly:
        25,NC(OneWindowLate),"OneWindowLate.dat",OneWindowLate:
        26,NC(TwoWindowsLate),"TwoWindowsLate.dat",TwoWindowsLate:
        27,NC(ThreeWindowsLate),"ThreeWindowsLate.dat",ThreeWindowsLate:
        28,NC(FourWindowsLate),"FourWindowsLate.dat",FourWindowsLate:
        29,NC(FiveOrMoreWindowsLate),"FiveOrMoreWindowsLate.dat",FiveOrMoreWindowsLate:
        30,NC(Num NPM),"NumNPM.dat",Num NPM:
        31,NC(Window1Requested),"Window1Req.dat",Window1Requested:
        32,NC(Window2Requested),"Window2Requested.dat",Window2Requested:
        33,NC(Window3Requested),"Window3Requested.dat",Window3Requested:
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        34,NC(Window4Requested),"Window4Requested.dat",Window4Requested:
        35,NC(Window5Requested),"Window5Requested.dat",Window5Requested:
        36,NC(Window6Requested),"Window6Requested.dat",Window6Requested:
        37,NC(Window7Requested),"Window7Requested.dat",Window7Requested:
        38,NC(Window8Requested),"Window8Requested.dat",Window8Requested;

REPLICATE,   100,,,Yes,Yes,,NC(FinishedTrays)==600,,24,Seconds,No,No;

ENTITIES:   Dummy,,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
        Dummy2,,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
        Tray,,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,);
```

Model Output

Summary for Replication 1 of 1

Project: Configuration8 Run execution date : 8/12/2003
Analyst:ISE Department Model revision date: 8/12/2003

Replication ended at time : 8136.7439

TALLY VARIABLES

Identifier	Average	Half-Width	Minimum	Maximum	Observations
TimeInCellTally	100.98	0.73845	77.168	132.08	600
OverallCycleTime	1078.3	(Corr)	300.44	2041.2	600
LateTrayTimeTally	162.21	(Insuf)	6.5449	537.6	61
EarlyTrayTimeTally	98.971	(Insuf)	4.7084	336.62	27
TimeInCartTally	977.38	(Corr)	213.56	1934.7	600
PatientSatisfactionTal	8.07	(Corr)	4	10	600
MakeSpanOfCell	6422.2	(Insuf)	6422.2	6422.2	1
MakeSpanOfSystem	8136.7	(Insuf)	8136.7	8136.7	1
NumWindowsEarlyTally	0.10997	(Insuf)	0.00523	0.37403	27
NumWindowsLateTally	0.18024	(Insuf)	0.00727	0.59733	61

DISCRETE-CHANGE VARIABLES

Identifier	Average	Half-Width	Minimum	Maximum	Final Value
Dummy.WIP	8.603E-11	(Insuf)	0	1	0
Dummy2.WIP	8.603E-11	(Insuf)	0	1	0
Tray.WIP	326.15	(Corr)	0	603	2
Fake.NumberBusy	0	(Insuf)	0	1	0
Fake.NumberScheduled	1	(Insuf)	1	1	1
Fake.Utilization	0	(Insuf)	0	1	0
Worker.NumberBusy	3.9163	(Insuf)	0	5	0
Worker.NumberScheduled	5	(Insuf)	5	5	5
Worker.Utilization	0.78326	(Insuf)	0	1	0
DeliveryPerson.NumberB	7.1866	(Corr)	0	8	2
DeliveryPerson.NumberS	8	(Insuf)	8	8	8
DeliveryPerson.Utiliza	0.89833	(Insuf)	0	1	0.25
Cell2Worker.NumberBusy	3.9166	(Insuf)	0	5	0
Cell2Worker.NumberSche	5	(Insuf)	5	5	5
Cell2Worker.Utilizatio	0.78333	(Insuf)	0	1	0

COUNTERS

Identifier	Count	Limit
Window1Requested	58	Infinite

Window2Requested	54	Infinite
Window3Requested	62	Infinite
Window4Requested	72	Infinite
Window5Requested	50	Infinite
Window6Requested	63	Infinite
Window7Requested	59	Infinite
Window8Requested	61	Infinite
NumTraysCompleted	600	Infinite
DeliveredTrays	600	Infinite
FinishedTrays	600	Infinite
Loc1	60	Infinite
Loc2	60	Infinite
Loc3	60	Infinite
Loc4	60	Infinite
Loc5	60	Infinite
Loc6	60	Infinite
Loc7	60	Infinite
Loc8	60	Infinite
Loc9	60	Infinite
Loc10	60	Infinite
OneWindowEarly	27	Infinite
TwoWindowsEarly	0	Infinite
ThreeWindowsEarly	0	Infinite
FourWindowsEarly	0	Infinite
FiveOrMoreWindowsEarly	0	Infinite
Num NPM	121	Infinite
OneWindowLate	61	Infinite
TwoWindowsLate	0	Infinite
ThreeWindowsLate	0	Infinite
FourWindowsLate	0	Infinite
FiveOrMoreWindowsLate	0	Infinite
TraysLate	61	Infinite
TraysEarly	27	Infinite
TraysOnTime	391	Infinite

OUTPUTS

Identifier	Value
Assy Worker Util	0.7833
Delivery Util	0.89833
Num Assy Workers	10
Num Delivery People	8
Total Num Workers	18
Total Util	0.83442
TimeInCell	1.683
OverallCycleTime	17.972
MakeSpanOfCell	107.03

MakeSpanOfSystem	135.61
TimeInCart	16.289
NumWindowsLate	0.18024
NumWindowsEarly	0.10997
PatientSatisfaction	8.07
TraysLate	61
TraysEarly	27
TraysOnTime	391
OneWindowEarly	27
TwoWindowsEarly	0
ThreeWindowsEarly	0
FourWindowsEarly	0
FiveOrMoreWindowsEarly	0
OneWindowLate	61
TwoWindowsLate	0
ThreeWindowsLate	0
FourWindowsLate	0
FiveOrMoreWindowsLate	0
Num NPM	121
Window1Requested	58
Window2Requested	54
Window3Requested	62
Window4Requested	72
Window5Requested	50
Window6Requested	63
Window7Requested	59
Window8Requested	61