How Can the Structure of a Maternity Ward Be Amended to Increase the Number of Patients Moving Through the Ward?

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Systems Dynamics Modeling 1-2

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Introduction

Hospitals all over the country struggle to regulate the fullness of their maternity wards. Unlike the admittance to other parts of the hospital, admittance to the maternity wards is not usually scheduled. Therefore it is difficult to determine how many beds are available at any given time in the future. The purpose of this model is to model the patient inflow to and outflow from the maternity ward at Providence Hospital in Portland, Oregon. The model should give an idea of which contributing factors may stabilize the number of patients in the ward. Another purpose of the model is to find an alternate solution to the overcrowding of the ward than building new maternity rooms.

The Process of Model Building

The first model had only one stock, one inflow, and one outflow. The stock represented the number of patients in the maternity ward at any time. Therefore, the inflow was the patients being admitted to the ward pre-delivery, and the outflow was the patients being discharged after delivery. This model was based on a 24-hour counter, which means that the inflow was built for a twenty-four hour time period. This twenty-four hour data was repeated over and over again thereafter. To build the inflow, certain information was taken into account. First, some patients that are admitted to the maternity ward spend longer before and/or after delivery than others. So the patient pool was divided into four different groups. The first group was the "Primip C-Section" group. These patients opted to have a cesarean section delivery, and the delivery was their first. The second group was the "Multip C-Section" group. These patients also opted to have a cesarean section delivery, however the delivery was not their first. The third group was the "Primip Vaginal" group. These patients opted to have a vaginal delivery, and the delivery was their first. The last group was the "Multip Vaginal" group. These patients opted for a vaginal delivery, which was not their first. Note that there is also a group of patients that are admitted to the ward, but do not deliver. Although these "Procedure" patients do not deliver, they each still take up a room. For the purpose of this model the Procedure patients were divided evenly between the other four groups. It was assumed that during any given hour of the day, the ratio of admittance between the four groups was constant. The data for total patients admitted per hour (over a 24-hour time period) was input via a graphical function (that was also a 24-hour counter). So that the breakdown of input per patient group could be monitored, four converters were created (one for each group) that calculated the number of patients admitted per hour in each group based on the total patients admitted per hour and the fraction of patients that were in each group. The total input was a sum of these four converters, as shown in Figure 1.
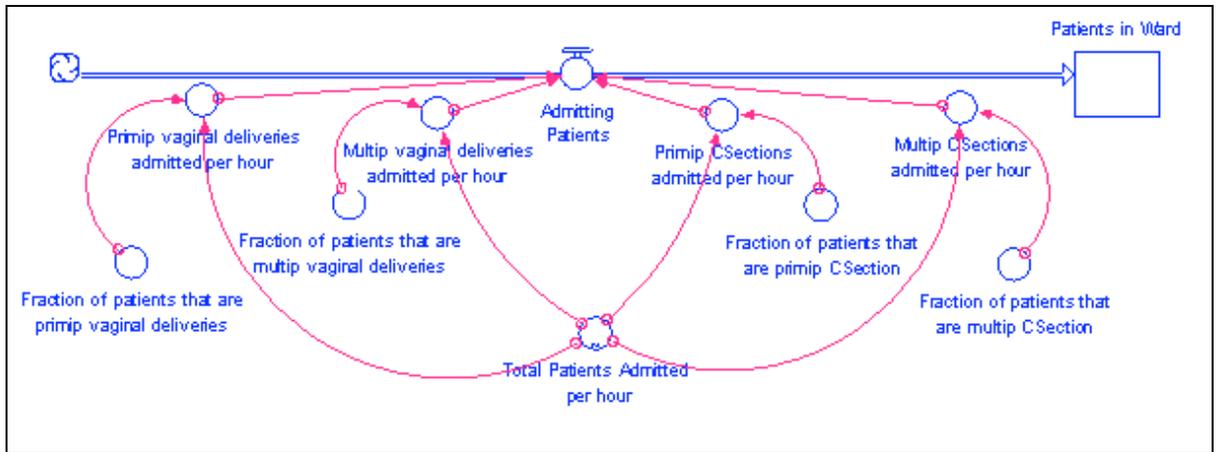
Figure 1: This diagram shows the inflow for the first model, which is a sum of four converters, each based on the same graphical function and varying ratios.

The idea of feedback was soon introduced to the model. It was deduced that as the maternity ward filled up, the staff would be increasingly careful about admitting patients. When the ward reached its capacity no patients would be admitted (they might be sent to another ward or even to another hospital). The graphical function shown in Figure 2, based upon the total number of patients in the ward and the total number of beds in the ward, was added to the model, affecting the inflow.
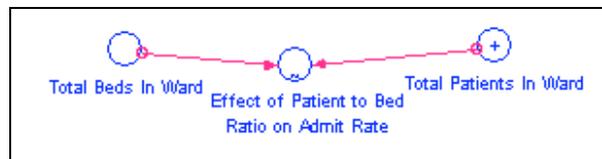

Figure 2: The ratio of patients to beds (fullness of ward) affects the admittance (inflow). As the ratio approaches one, the effect on the inflow approaches zero.

A later model recognized the necessity to monitor each of the four patient groups separately. A revised model included four different stocks, one for each of the groups. New information was taken into account, showing that although the admittance patterns for each of the groups shared some similarities, they were enough different that each should have its own admittance rate. So in the new model, each stock had its own inflow, dependent on its own admittance rate (still a graphical function on a 24-hour counter). Each inflow was still affected equally by the already established feedback loop.

The final addition to the inflows was a random function that varied the exact admittance rate from one 24-hour period to the next, based on a normal curve. The idea behind this is that the number of patients admitted each day is not exactly the same. The random function produces an unpredictable inflow within

given boundaries, similar to what the hospital actually experiences. This idea will be explained in greater detail in the next section.

The outflow from each stock has undergone one large alteration. At first, the outflow for each group was based on an average dwell time, as shown in Figure 3. This delay time was based on the average amount of time spent at the hospital for each patient group. With this type of outflow, the percentage of patients being discharged each hour (within a specific group) was constant for every hour. However, this was not realistic. In reality there is a much higher percentage of patients discharged at prime time (early to late afternoon) than in the middle of the night, for instance. Therefore, a converter specific to each group called "Effect of Time of Day on Discharge" was added to each outflow. This idea will also be explained in greater detail in the section immediately following.
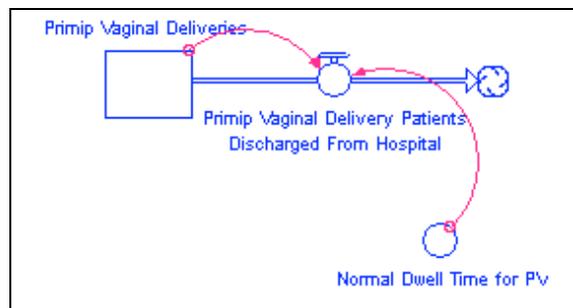

Figure 3: The preliminary outflows were determined by the normal hospital
dwell times for each group (the delay time), and the number of patients
in each group at any given time. This diagram shows the outflow
for only one group, the Primip Vaginal group.

The Finished Model and How It Works

The final model monitors the admittance to and discharge from the maternity ward of the four different patient groups: Primip C-Section, Multip C-Section, Primip Vaginal, and Multip Vaginal. There are four different stocks that each keep track of the amount of patients from one patient group in the maternity ward.

The inflows into each of the stocks are affected mainly by an average admittance rate as well as a random function that causes the inflow to vary each day. The structure of the inflows is shown in Figure 4. One converter, named "Normal Entry Rate," is a graphical function in which is entered the average number of patients (in the specific patient group) that are admitted during a given hour. The equation for the graphical function is a 24-hour Counter. This means that the number of patients admitted each hour is entered for a 24-hour time period, and then the converter automatically reuses the same values for an infinite number of 24-hour time periods. The "Normal Entry Rate" converter is connected to another converter called "Actual Entry Rate." This new converter is controlled by a (random) Normal function. The converter looks at the values coming in from the first converter, and then randomly chooses values for the actual admittance rate.

The criteria for the actual admittance rates is that they must fall within a normal curve (bell-shaped curve) for which the average entry rate is at the peak of the curve and the standard deviation is one fourth of the average entry rate. The Normal function allows for a more realistic entry rate pattern. The entry rate should vary daily, but linger around an average value. The Normal function allows for this behavior. The "Actual Entry Rate" is connected to the inflow.

One last converter, the "Women Multip," affects the inflow. This one converter will affect all four of the inflows equally. Most of the time the "Women Multip" will have a value of one ninetieth in it. The data that is in the normal entry rate for each group is the cumulative number of patients in the specific group admitted during a certain hour of the day over a period of ninety days. Making the "Women Multip" one ninetieth makes the inflows for each hour the correct average from the ninety-day data. If the rate of admittance (of all the patient groups in general) changes drastically, this converter can be altered to reflect that change. This is a more efficient way of documenting a general change in maternity ward admittance rate than changing the "Normal Entry Rate" of each group individually.
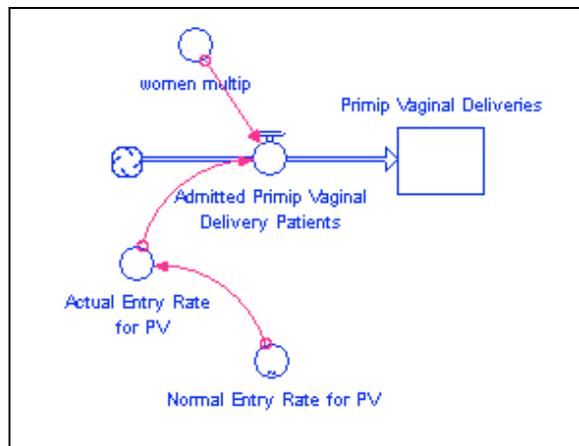

Figure 4: This shows the inflow structure for the Primip Vaginal group.
The inflow is controlled specifically by the Actual Entry Rate
and the Women Multip. The Actual Entry Rate is determined
by the product of a random function and a normal function based on the Normal
Entry Rate.

The final outflow is determined by three different factors: the number of patients (in one patient group) in the ward, the normal dwell time (average length of stay in the hospital) for that group, and the effect of the time of day on the number of discharges. The final structure is shown in Figure 5. The average length of stay for each group was calculated from data from Portland Providence Hospital. With this information the concept of delay was utilized. If a patient usually stays four days in the ward, then every day one fourth of the patients in the ward are discharged. So by dividing the stock for each patient group by their average length of stay, a rough discharge rate is created. Then the effect of the time of

day is added to the equation. Very rarely are patients discharged during the night. The majority of patients from all patient groups are usually discharged sometime between 9:00 AM and 4:00 PM. A large number of patients are also discharged between 4:00 PM and 10:00 PM. Therefore, it would not make sense to discharge the same number of patients each hour. Each patient group has its own converter adding the effect of time of day specific to that patient group. The converter is a graphical function that is also a 24-hour counter. The converter takes into account what fraction of the total daily discharges occurs during each hour.
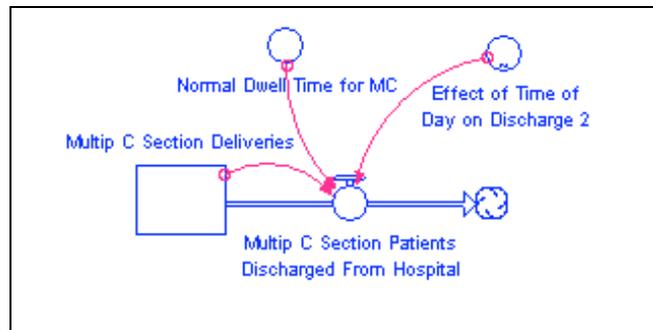

Figure 5: This is the model of the outflow for the Multip C-Section patient group. The outflow depends on three factors: the number of patients in the group that are currently in the ward, the normal time spent in the hospital for a patient in the group, and the effect of the time of day on the number of discharges.

In Figure 6 is a graph of the total patients in the ward over a ten-day time period, and a line showing the total number of maternity beds in the ward.

Refer to the appendix for the completed model.

The Model Feedback & Loop Story

Feedback is a very important concept to analyze in all dynamic systems models. Feedback analysis usually describes the internal relationships in the model that affect its behavior. Feedback means that output information from one aspect of the model "loops" back around to effect the input of another part of the model. These effects are based solely on internal actions of the model, not on external inputs, therefore describing endogenous behavior.

The four stocks in this model are connected by one graphical function called "Effect of Patient to Bed Ratio on Admit Rate." This converter calculates the ratio of patients to beds at any given time. When the ratio is low, the converter is programmed to have no effect on the inflows. However, as the ratio gets larger, the converter causes the inflow of each stock to decrease. When the ratio is one, the converter makes the inflow of each stock zero. Therefore, as the sum of the stocks increases or decreases (caused by an increase or decrease in the inflows), the converter causes the inflow to either decrease or increase respectively. This kind of feedback is called balancing feedback because as one factor increases, the
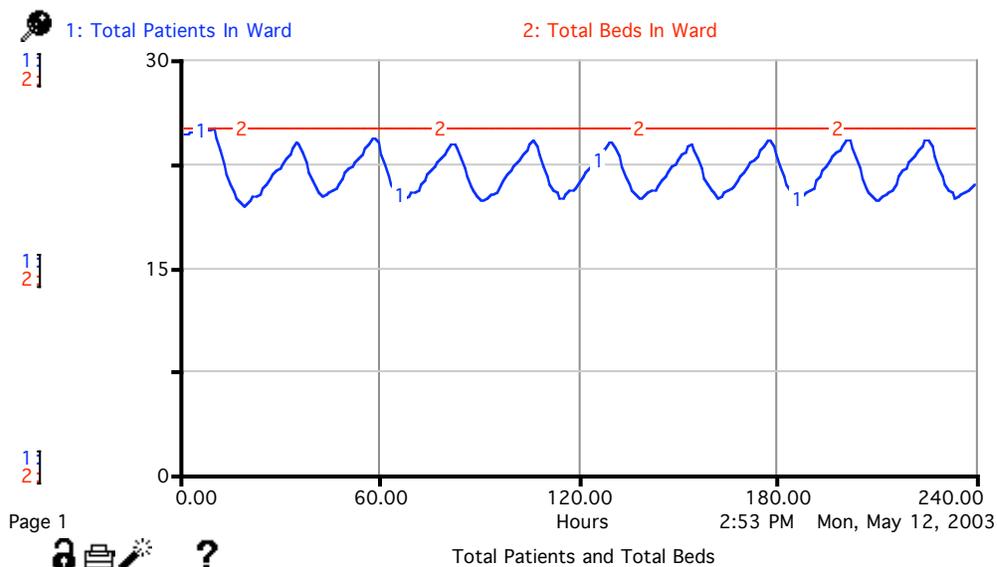
Figure 6: This graph shows the total patients in the maternity ward and the total beds in the ward over the 10-day testing period. As demonstrated by the graph, there is a distinct cycle that the number of patients in the ward follows each day. Although the number of patients begins rather "full" the cycle eventually reaches equilibrium after a couple of days.

result is a decrease in another component of the model, or vise-versa, therefore counterbalancing the instigating fluctuation. This accommodates specifically for a situation in which the maternity ward is full (the ratio of patients to beds is one) and no more patients are able to enter. Thanks to this converter, the total number of patients in the ward at any time is capped at the total number of beds in the ward. Other patients who want to come into the ward may be sent to another section of the hospital, or even in some cases referred to another hospital. It also accounts for a situation in which the ward is dangerously close to being full, in which case it starts to decrease the inflow in anticipation. Refer to Figure 2 for the converter's structure in the model, and see Figure 7 for the feedback loop.

The Model Boundaries

Major Assumptions

There were several assumptions made in order to make the model usable. First, it was assumed that all 25 beds in the maternity ward are usable at all times. Also, it was assumed that within each patient type, the admittance per hour is relatively stable and the patients have a similar length of stay. Because of these assumptions, a normal function acting on a data set was used for the input and an average length of stay was used for the output in the model. In addition, it was

assumed that each patient group is treated consistently when it comes to turning patients away. And so the patient to bed ratio affects the four inflows equally.
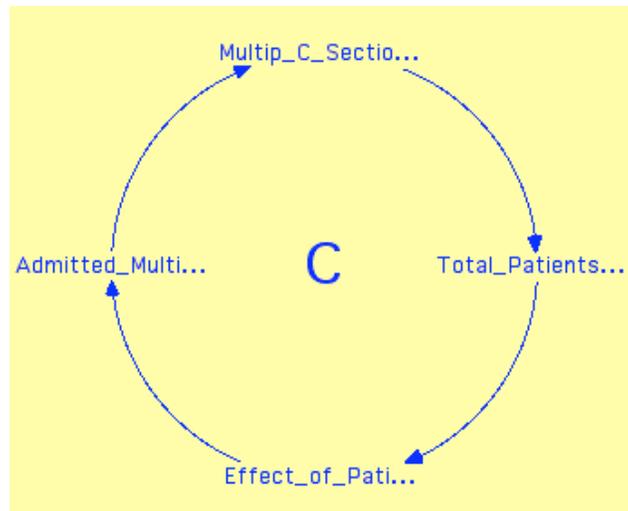

Figure 7: This is a "counterbalancing" or balancing feedback loop, indicated by the "C." This loop is for the C-Section patients that are Multips. However, the feedback loop is similar for all four patient type groups.

Finally, it was assumed that the "procedure patients," patients who come into the ward thinking they are going into labor and then actually leave without giving labor, are divided equally between the four groups. This way a separate stock for those patients was not needed.

Choice of Time

For this model, the DT, or interval of time between recalculations, is one hour. This DT was chosen because all of the data is given in terms of hourly increments. Also, this model is a discrete model rather than a continuous model, which deals with whole people and data calculated over 24-hour periods, rather than continuously. Euler's Method was used to make the calculations. These two settings combined created a good system to deal with the discrete model. Finally, the simulation time is 240 hours, or ten days. For simplicity reasons, the beginning simulation time is zero and the ending simulation time is 240. A run-time of ten days was chosen so that both trends over one day's time and trends over longer periods of time (differences from one day to the next) could be observed.

Model Testing

The model was tested by two methods. First, the total number of beds in the ward was altered and the model was tested using different values in that converter. Second, a converter named "Discharge Factor" was added to the outflows from

the stocks for the two multips patient groups, and the model was tested using different values in this converter.

The model was tested and the total number of patients in the ward in each simulation was compared for four different total numbers of beds in the ward: 15, 20, 25, and 30 beds. The graph of the four different outcomes is shown in Figure 8 below. As shown in the graph, the total number of patients in the ward follows the total number of beds. For instance, if there are more beds in the ward, there are more patients. This flexibility is evidence that the model is working correctly because the hospital wants to fill however many beds they have, but not admit more patients than there are room for, no matter how many beds there are. The reason the graph of the number of patients does not come as close to reaching 30 when there are 30 beds is that the "Effect of Patient to Bed Ratio" is only set to double the inflow at the most. This ratio would have to be altered to create a greater inflow in order to fully take advantage of the addition of beds to the ward. The reason the graph is greater than 15 when there are 15 beds is that there are 24 patients in the ward when the simulation begins. This starting value is not realistic, and because of that the number of patients in the ward can not decrease to less than 15.

Total Patients In Ward: 1 - 2 - 3 - 4 -

Page 1
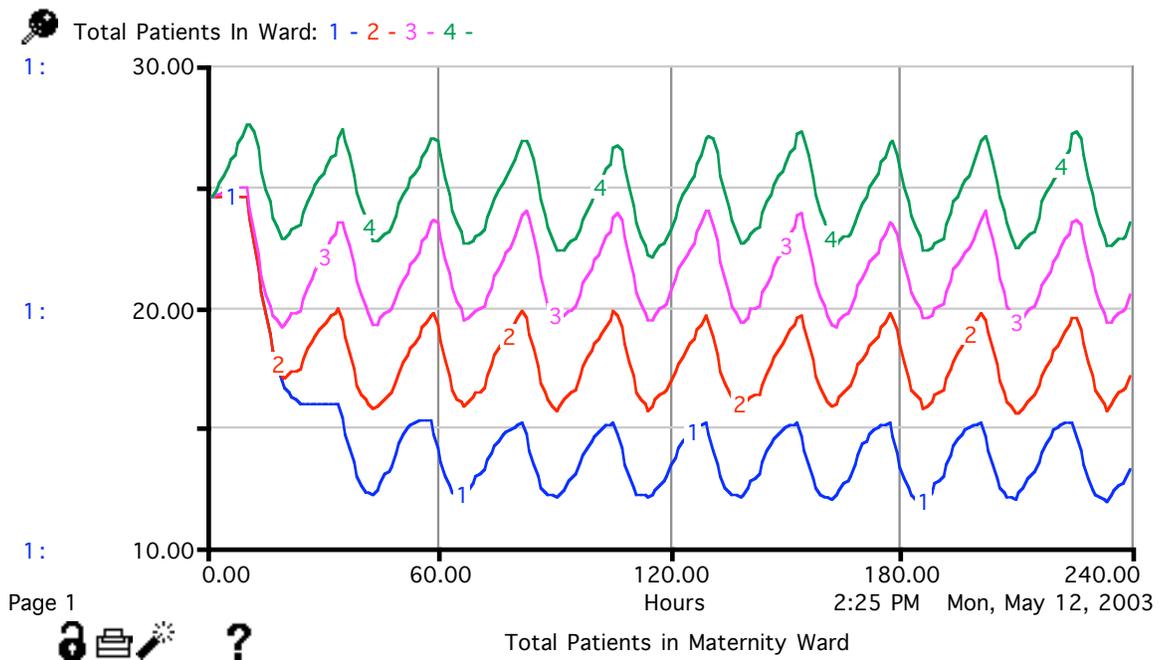
Total Patients in Maternity Ward

Figure 8: Graphs 1, 2, 3, and 4 show the total number of patients in the ward
         when there are 15, 20, 25, and 30 beds in the ward, respectively. The
         tendency of the number of patients to follow the number of beds is
         evidence that the model is working correctly.

The model was also tested by changing the values in a new converter, called the "Discharge Factor." The "Discharge Factor" was created to alter the time each woman spends in the hospital after she gives birth. For instance, to create better efficiency in the flow of patients through the ward, the "Discharge Factor" could be less than one, therefore reducing the waiting time after birth and before discharge, and increasing the flow of women through the ward. The "Discharge Factor" only affects the Multip Vaginal and Multip C-Section patient groups. Multip patients are more likely to agree to a shorter stay in the ward than primip patients are. The model was tested for three different values in the "Discharge Factor" converter: 8/10, 1, and 12/10. Changing the value of the "Discharge Factor" did not make a big difference in either the number of patients in the ward or the amount of patients admitted per hour, both of which suggesting that changing the "Discharge Factor" does not affect the efficiency of moving patients through the ward. This could be a problem with the model because changing the amount of time a woman stays in the ward after giving birth should affect the number of patients moving through the ward. The total number of patients in the ward during the 10-day period for each value in the "Discharge Factor" is shown in Figure 9 below.
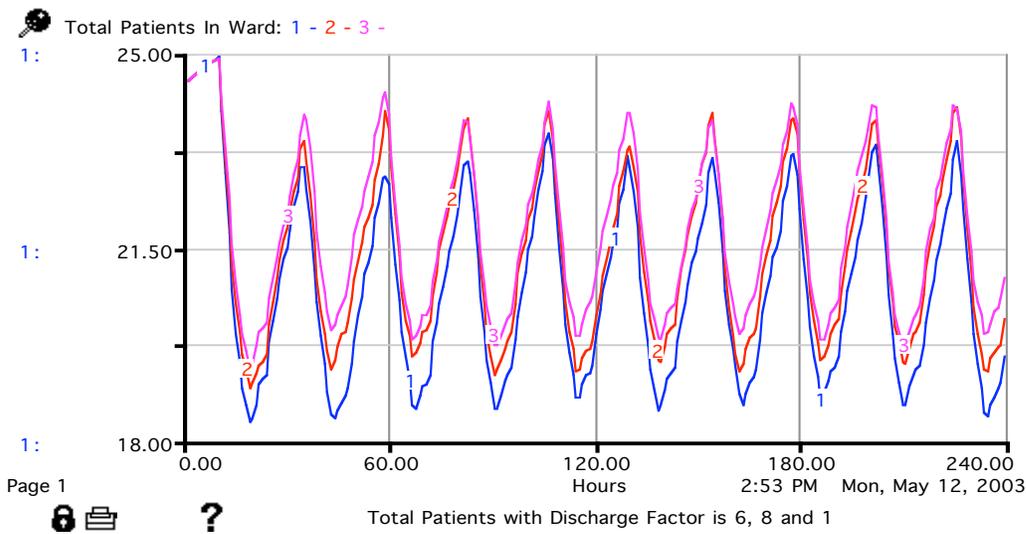

Total Patients In Ward: 1 - 2 - 3 -

Page 1

Total Patients with Discharge Factor is 6, 8 and 1

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Figure 9: Graphs 1, 2, and 3 show the total number of
         patients in the ward when the "Discharge Factor"
         was .6, 8, and 1 respectively.

The Results of Modeling and Thinking

The Results

From studying the model and graphs of the maternity ward, much can be deduced about the pattern of women moving in and out of the ward. The preliminary graphs of the final model show that the women of all patient groups are admitted in waves during "prime" periods of the day. The women are also discharged during a "prime" time period in the early afternoon. The discharge "prime" period is even more concentrated than the "prime" admittance periods. Therefore, the number of women in the ward fluctuates daily, growing in the morning to a peak at about 9:00, then decreasing until the early evening when it starts to grow again until the next day.

This same curve is seen for each day making the graph of the number of patients in the ward over a long period of time a wave. If the graph does not start in equilibrium, the curve is slightly modified each day, even though it still keeps the same general shape and pattern, until the number of patients entering and leaving the ward reaches equilibrium.

Finally, one objective of using the model may be to predict when the ward will become dangerously full in the future. Other than the knowledge that there is a peak number of people in the ward shown on the graph each day, the model will predictably reach equilibrium as long as the factors contributing to the model stay constant. However, once a drastic change has occurred, such as a sudden increase in the amount of women coming to the ward, the change can be documented in the model, and the time until the graph will reach equilibrium can be predicted.

The Key Learning from the Modeling Process

Many different things were learned about the maternity ward problem through the making of the model:

- The maternity ward problem is a discrete, not continuous, problem, which makes it very different from other dynamic systems models.

- The number of patients coming into and going out of the ward reaches an equilibrium unless contributing factors fluctuate.

- There is a specific daily pattern for the number of patients in the ward.

- The number of patients in the ward reflects the number of beds available.

- Changing the amount of time "Multip" patient groups stay in the ward

after delivery by a factor of 20% does not have a significant effect on the overall efficiency of the flow of patients through the ward.
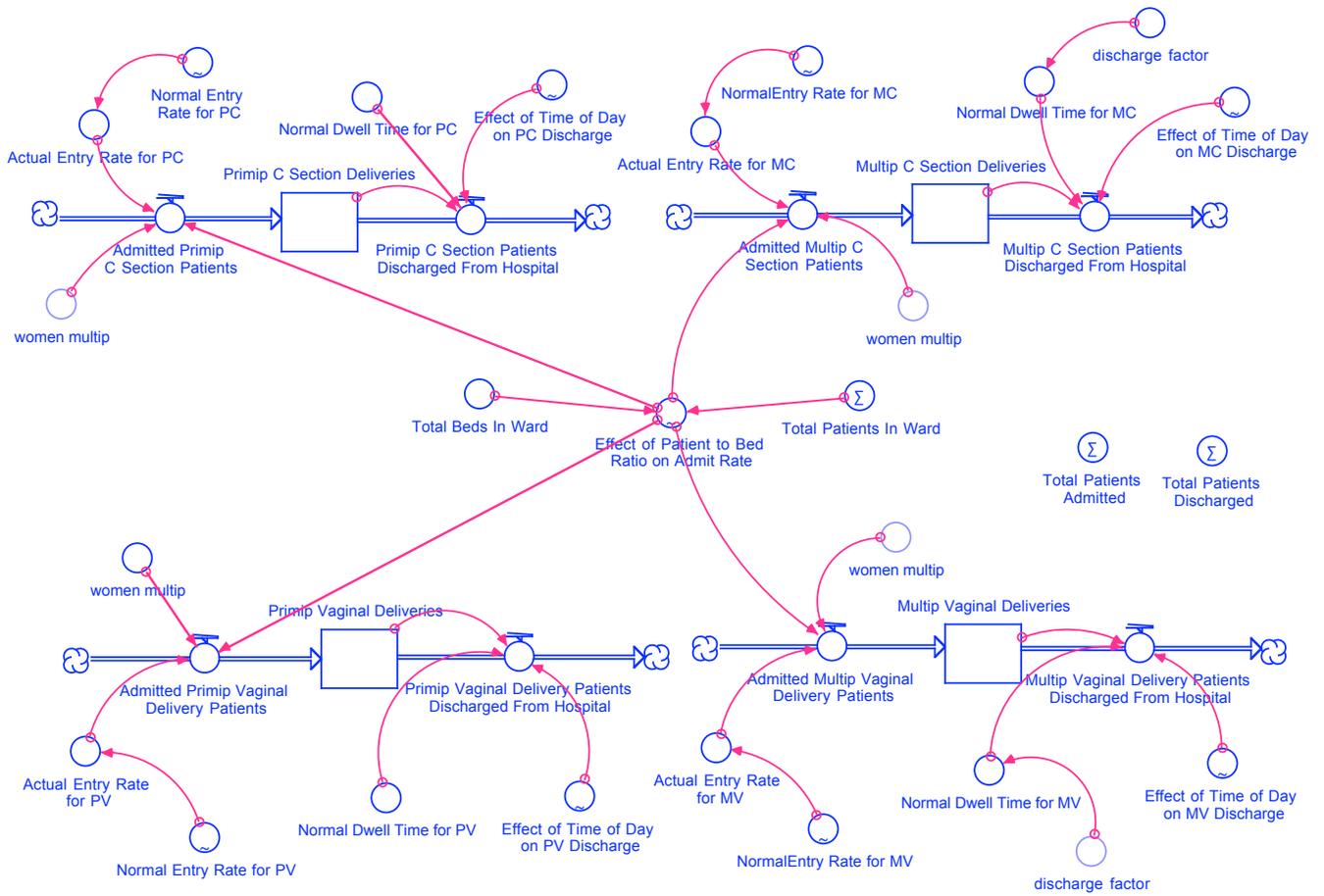
- The maternity ward takes advantage of balancing feedback, meaning that as the ward becomes full fewer patients are admitted, and when the ward is emptier more patients are admitted.

The title of this paper poses a question: "how can the structure of a maternity ward be amended to increase the number of patients moving through the ward?" By examining this model, the conclusion has been reached that the only way to increase the number of patients moving through the ward is to increase the number of beds in the room. Other methods, such as shortening each patient's stay or eliminating the "prime" admittance and discharge periods, do not have significant effects on the efficiency of the ward.

The model could be amended in the future to take into account procedures that must be followed and other delays after delivery, such as baby pictures, circumcision, transportation problems, and doctor visits. Then, the alteration of some of these procedures would be tested to see what effects they have on the efficiency of the ward.

Appendix

Full Model Diagram

Equations

Omitted