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SIMULATION OF LABOR: A STUDY OF THE RELATIONSHIP BETWEEN CESAREAN SECTION RATES AND THE TIME SPENT IN LABOR

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ABSTRACT

Cesarean delivery is the most common major abdominal surgery in many parts of the world. As of October 2012, the cesarean section rate in the United States was reported to be 32.8% in 2011, rising from 4.5% in 1970. Cesarean sections are associated with an increased risk of neonatal respiratory morbidity, increased risk of a hysterectomy and can cause major complications in subsequent pregnancies, such as uterine rupture. To evaluate the current cesarean delivery rate due to a “failure to progress” diagnosis, our goal was to replicate the delivery process for women undergoing a trial of labor. In this simulation we evaluate the Friedman Curve and other labor progression rules to identify circumstances in which the cesarean rate can be decreased through the analysis of the total length of time a woman spends in labor as well as the duration of time a woman remains in a cervical dilation stage.

1 INTRODUCTION

In October of 2012, it was reported that the cesarean section rate in the United States was 32.8% in 2011, rising from 4.5% in 1970 (Martin et al. 2013, Cesario 2014). In addition to the risks of short-term surgical complications, cesarean delivery is associated with an increased risk of neonatal respiratory morbidity and an increased risk of major complications in subsequent pregnancies, such as uterine rupture, placenta previa, and placenta accreta (Zanardo et al. 2004, Getahun et al. 2006; Miller, Chollet, and Goodwin 1997, Usta et al. 2005). Since cesarean sections increase the risk of many short-term complications, increase maternal time in the hospital, may interfere with early maternal-infant bonding, and increase the overall costs of care, there is a general consensus that current cesarean rates are too high (Caughey et al. 2014). We aim to understand the policy surrounding the need for a cesarean section in singleton pregnancies for nulliparous women (women giving birth for the first time) with no prior indications, such as preeclampsia or breech presentation.

The goals of this study are to (1) model the natural progression of labor in absence of cesarean deliveries, (2) determine the underlying rules responsible for the current rate of cesarean deliveries due to a "failure to progress" diagnosis, and (3) develop ways to reduce unnecessary cesarean deliveries while also reducing the rate of complications.

For many years the guidelines surrounding the amount of time spent in labor were governed by the Friedman Curve which was established in 1954 by Emanuel Friedman (Pitkin 2003). Friedman described abnormal labor progression as cervical dilation of less than 1.2 cm per hour for nulliparous women and cervical dilation less than 1.5 cm per hour for multiparous women. Friedman further defined no change in dilation for more than two hours as labor arrest. In years prior to Friedman Curve utilization, fetal assessment techniques used to determine the fetal oxygenation and general well-being of the fetus during labor were nonexistent. During this time period labors were considered to be long and often ended in negative outcomes related to hypoxic injury and birth trauma (Cesario 2014). The Friedman Curve was established to set a standard for performing a cesarean delivery in order to avoid some of the harmful outcomes of prolonging labor. The goal of the Friedman Curve was to provide guidance regarding an appropriate delivery time frame that would result in the best outcomes. A cesarean section was performed if the woman was not able to deliver the baby vaginally within the established time frame.

Due to changes in the delivery process and changes in the demographics of laboring women, a re-evaluation of the use of the Friedman Curve guidelines is needed. In early 2014, the American College of Obstetricians and Gynecologists (ACOG) and the Society for Maternal-Fetal Medicine (SMFM) jointly issued new recommendations targeted at reducing the cesarean rate by taking measures to prevent the first cesarean delivery in particular. By avoiding the first cesarean section, it is believed that the cesarean section rate will decrease due to the reduction in repeat cesareans, which make up a large proportion of the cesarean section rate. The series developed by the obstetrics and gynecology groups mention the length of time a woman should be allowed to labor as one of the contributing factors to the growing cesarean rate for nulliparous women (Caughey et al. 2014). Dr. Aaron B. Caughey who helped develop the guidelines said in a statement, "Evidence now shows that labor actually progresses slower than we thought in the past, so many women might just need a little more time to labor and deliver vaginally instead of moving to a cesarean delivery."

Zhang et al. (2010) performed a retrospective study using labor and delivery information from electronic medical records in 19 hospitals across the United States (Consortium on Safe Labor). The goal of the study was to examine current labor patterns. In this study, they discovered that labor progression for a cervical dilation of 4 to 5 cm could take as long as 6 hours and more than 3 hours to progress from 5 to 6 cm, which differs greatly from rules established by the Friedman Curve. They summarized their results by noting that allowing labor to continue for an extended period of time for cervical dilations 6 cm and under, would aid in reducing the rate of intrapartum cesarean deliveries (Zhang, Landy et al. 2010).

An evaluation of the most appropriate time to perform a cesarean section is a combination of many elements. In particular, the status of the fetus and mother is consistently checked to ensure the health of both patients. Cheng et al. (2009) developed a study that looked at the association between the length of labor, mode of delivery, and perinatal outcomes. This study showed that the risk of birth trauma, neonatal complications, and neonatal intensive care unit (NICU) admissions tended to increase as the length of labor increased (Cheng et al. 2009).

The decision models in this area focus widely on risk predictors for cesarean delivery and the appropriate epidemiologic characteristics that can be used for effective delivery mode prediction (Harlow et al. 1995). These methods vary from risk scores, scales and nomograms that use logistic regression (Zhang, Troendle et al. 2010) to decision trees and machine learning (Grobman et al. 2007, Sims et al. 1997; Hill et al. 2008; Dugas et al. 2012; Caruana et al. 2003; Dahan and Dahan 2005; Analysis et al. 2010; A. A. Montgomery et al. 2007; Labib et al. 2007; Emmett et al. 2007; Smith et al. 2004; Mankuta 2003) which are based on the probability of various risks and utility of certain health outcomes. Sims et al. (2000) summarized the use of decision tree models in predicting cesarean delivery as compared to a logistic regression method using historical data for women who delivered live-born singleton neonates during the period of 1995 to 1997 (a total of 22,157 births) (Sims et al. 1997). In the study they determined decision trees can be used to predict cesarean delivery and suggested decision trees are small enough to be intelligible to physicians and handle missing values more easily than logistic regression methods. In the study developed by Xu et al. (2010), a decision tree was used to determine the best mode of delivery by evaluating the cost-effectiveness of different health interventions considering pelvic floor consequences (Patel et al. 2006). Emmett et al. (2007) used a decision tree in a study to predict mode of delivery for women who have had a previous cesarean delivery based on utility assessments gathered through two types of computer-based decision aids (A. A. Montgomery et al. 2007; Emmett et al. 2007). According to our knowledge a decision model that uses computer simulation has not been done.

The simulation model presented here extends these research studies by determining, for each cervical dilation state, the appropriate length of labor to reduce the rate of cesarean deliveries and increase the likelihood of health outcomes for both mother and child. In particular, we introduce two simulation models that model labor progression. The first model (Figure 1) characterizes the natural progression of labor. This model seeks to understand the length of time a woman may labor if no interventions or a cesarean section are introduced. The second model (Figure 2) is similar to the first model; however upon completion of each dilation state, the total time in that dilation state is evaluated to determine whether the patient should be given a cesarean section or not based on a defined stopping criterion. That is, if a two hour rule is used and a patient requires 3.6 hours to dilate from 4 cm to 5 cm, then she would be given a cesarean section at 4 cm. If she had completed state 4 cm within two hours, she would continue to labor and proceed to 5 cm.

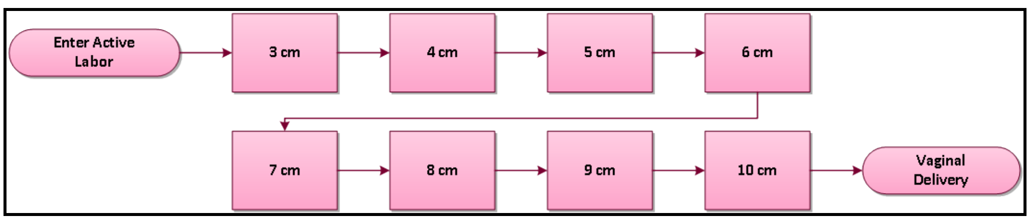


Figure 1: Flowchart to depict the simulation of labor in absence of interventions and cesarean sections.

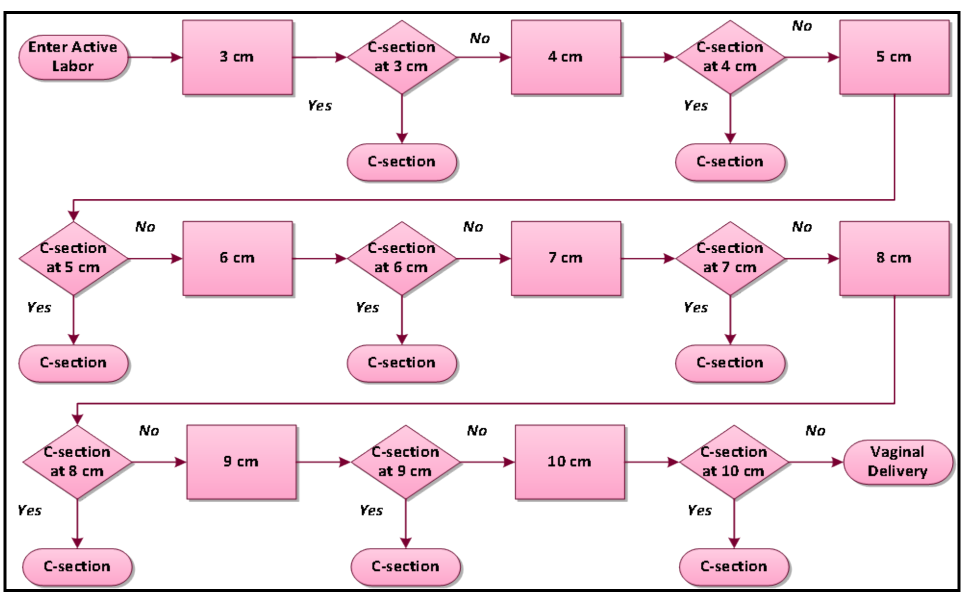


Figure 2. Flowchart to depict the simulation model for which cesarean deliveries are allowed.

2 MODEL FORMULATION

To evaluate the current cesarean delivery rate, our goal was to simulate the delivery process for women undergoing a trial of labor. In this simulation we evaluate the Friedman Curve and other labor progression rules to identify circumstances in which the cesarean rate can be decreased by analyzing the length of time a woman spends in labor and more specifically the duration of time a woman remains at one particular cervical dilation. We only seek to identify cesarean deliveries that are performed after a trial of labor has started and only consider "failure to progress" as the indication for a cesarean delivery for singleton nulliparous deliveries with no prior indications for cesarean delivery. Other indications for cesarean delivery may include fetal distress, uterine rupture, and cephalopelvic disproportion (CPD), but are not considered in this study.

2.1 Data Description

Data for the model were derived from four main sources: (1) *Contemporary cesarean delivery practice in the United States*, (Zhang, Troendle et al. 2010), (2) *Contemporary Patterns of Spontaneous Labor with Normal Neonatal Outcomes* (Zhang, Landy et al. 2010), (3) *Normal Progress of Induced Labor* (Harper et al. 2012), and (4) *Second-stage labor duration in nulliparous women: relationship to maternal and perinatal outcomes* (Rouse et al. 2009). The studies conducted by Zhang et al (2010) used data from the Consortium on Safe Labor which consisted of labor and delivery information from electronic medical records in 19 hospitals across the United States. Data from Harper et al. (2012) was taken from a four-year retrospective cohort study of deliveries at Washington University Medical Center in St. Louis, Missouri. Each data source evaluated current labor progression patterns. In particular, these studies used an interval censored regression to estimate the median time to progress 1 cm in cervical dilation. Rouse et al. (2009) conducted analysis of fetal pulse oximetry at 14 clinical centers of the National Institute of Child Health and Human Development Maternal Fetal Medicine Units Network to assess trends in the duration of the second stage of labor and maternal and perinatal outcomes.

2.2 Patient Types

We model three different types of patients: (1) patients who had an induction of labor, (2) patients who had an augmented labor and (3) patients who had a spontaneous labor as described in Harper et al. (2012). Harper et al. (2012) sought to compare normal labor progress for women whose labor was induced versus labor progression for those women who labored spontaneously. Those patients in the spontaneous labor category are women who received no augmentation with oxytocin nor underwent artificial rupture of the membranes. Augmented labors were defined for women who were diagnosed as having a spontaneous labor but subsequently received oxytocin augmentation. There were 5,388 women included in the Harper et al. (2012) study, 2,021 of which were spontaneous labors, 1,720 were augmented labors, and 1,647 were induced labors accounting for 37.5%, 31.9%, and 30.6% of the study population, respectively. We used these percentages to assign identities to the entities (patients) in the simulation. All women included in the study delivered in the second stage of labor. Therefore if a cesarean section was given it was done after a cervical dilation of 10 cm (Harper et al. 2012).

2.3 Probability Distributions for Labor Duration by Cervical Dilation

Harper et al. (2012) provided a median, 5^{th} percentile and 95^{th} percentile of the duration of labor for each dilation state. This information was used to model the duration of labor for each cervical dilation state using a Beta-PERT distribution where we estimated the mode by using the median, minimum by using the 5^{th} percentile and maximum by using the 95^{th} percentile. The density function for the Beta distribution is

$$f(x) = \begin{cases} \dfrac{x^{v-1}(1-x)^{w-1}}{B(v,w)} & 0 \leq x \leq 1, \\ 0 & \text{otherwise.} \end{cases}$$

For the Beta distribution, the minimum and maximum values and two shape parameters, v and w, are required. The Beta-PERT distribution uses the mode to generate the shape parameters, v and w. There is an additional scale parameter, λ, which is the height of the distribution and is estimated to be 4 (Vose 2000).

For the Beta-PERT distribution, the mean, μ, is calculated as

$$\mu = \frac{x_{min} + x_{max} + \lambda x_{mode}}{(\lambda + 2)}$$

and the v and w are calculated by

$$v = \frac{(\mu - x_{min})(2x_{mode} - x_{min} - x_{max})}{(x_{mode} - \mu)(x_{max} - x_{min})}$$

$$w = \frac{v(x_{max} - \mu)}{(\mu - x_{min})}$$

The duration of labor data presented in Zhang, Troendle et al. (2010), Zhang, Landy et al. (2010), and Rouse et al. (2009) were used to supplement Harper et al. (2012) by providing better estimates of time in labor. The information from the Consortium on Safe Labor, provided the median and 95th percentile of the duration of labor for nulliparous women. To get a better sense of the maximum amount of time a woman may spend in one particular cervical dilation state, we averaged the median values from Harper et al. (2012) and the Consortium on Safe Labor to get a more precise estimate of the mode. The information presented in Rouse et al. (2009) provided more insight into the duration of the second stage of labor. We were able to use the minimum and maximum times provided in this study as the lower and upper bounds for the second stage servers (Srv2ndStage_epidural and Srv2ndStage_no_epidural), respectively. Using this information we were able to derive the distributions for nulliparous women in the induction, augmented, and spontaneous labor groups as presented in Table 1.

Table 1. The 5th, median, and 95th percentile (minimum, mode, and maximum) duration of labor times in hours used in creating the distribution for each cervical dilation state for nulliparous women given in hours (Harper et al. 2012; Zhang, Troendle et al. 2010; Zhang, Landy et al. 2010; Rouse et al. 2009).

	Induced Labor					**Augmented Labor**					**Spontaneous Labor**				
	Min.	*Mode*	*Max.*	*Parameters*		*Min.*	*Mode*	*Max.*	*Parameters*		*Min.*	*Mode*	*Max.*	*Parameters*	
Dilation				v	w				v	w				v	w
3	0.2	1.4	8.1	1.61	4.39	0.2	1.5	8.1	1.66	4.34	0.1	0.4	2.3	1.55	4.45
4	0.2	1.3	6.8	1.67	4.33	0.3	1.35	7.6	1.58	4.42	0.1	0.5	2.7	1.62	4.38
5	0.2	0.6	4.3	1.39	4.61	0.1	0.75	4.9	1.54	4.46	0.06	0.4	2.7	1.52	4.48
6	0.05	0.4	2.8	1.51	4.49	0.06	0.55	3.9	1.51	4.49	0.03	0.3	2.1	1.52	4.48
7	0.02	0.2	1.5	1.31	4.69	0.05	0.4	2.8	1.51	4.49	0.04	0.3	1.7	1.63	4.37
8	0.03	0.2	1.3	1.26	4.74	0.05	0.4	3	1.47	4.53	0.03	0.2	1.3	1.54	4.46
9	0.04	0.3	1.9	1.46	4.54	0.05	0.4	2.2	1.65	4.35	0.04	0.3	1.8	1.59	4.41
10 (epidural)	0.4	1.1	5	1.61	4.39	0.2	1.1	5	1.75	4.25	0.4	1.1	5	1.61	4.39
10 (no epidural)	0.4	0.6	5	1.17	4.83	0.2	0.6	5	1.33	4.67	0.4	0.6	5	1.17	4.83

2.4 Model 1: Simulation for Natural Progression of Labor

Labor is often described in three stages: (1) early and active labor, (2) delivery of baby, and (3) delivery of the placenta. In the first stage (the primary focus of our study) there are three phases (early labor phase, active labor phase, and transition phase) that begin at the onset of labor until the cervix is fully dilated to 10 cm (American Pregnancy 2007). A Simio® model is developed to simulate labor to understand the duration of labor in absence of any stopping rules or interventions. In this model the patients (i.e., the entities) enter "active" labor starting at cervical dilation of 3 cm and we model the progression of cervical dilation to 10 cm. Once the cervix is dilated to 10 cm the patient then moves into the second stage of labor (known as the pushing phase).

We divide the cervical dilation of active labor, starting at 3 cm, into states. Figure 3 shows the Simio® model of the natural progression of labor. Patients enter the labor server (SrcLabor) at an exponential rate of 1 hour and proceed through each dilation server (Srv*j*cm) until they reach the vaginal delivery sink (SnkVD). We assumed a percentage (50%) of women receives epidural analgesia prior to SnkVD. In this model we do not allow cesarean sections because we want to understand how long active labor can last given the probability distributions derived from the data sources described above.

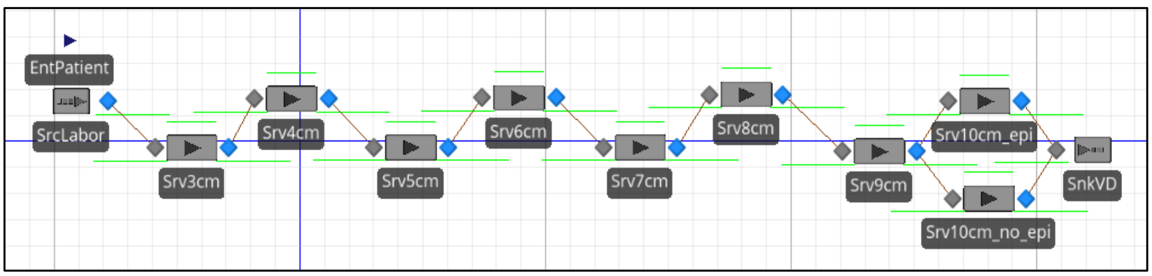


Figure 3. Screenshot of Simio® simulation Model 1 of labor progression from 3 cm to 10 cm in absence of any cesarean deliveries.

2.5 Model 2: Simulation of Labor Progress for Various Rules

In the second simulation, women progress through labor according to the distributions defined in Table 1 similar to Model 1. After the patient has finished processing through a dilation state, it is decided whether the patient should continue to the next dilation state or be transferred to a cesarean delivery at that particular dilation. This decision is based on the processing time (i.e., how long the patient remains at a particular dilation). If this time is greater than the established cutoff time, then the patient is given a cesarean section due to a "failure to progress" diagnosis. We use this model (Figure 4) to simulate the current cesarean delivery rate and to experiment with various stopping rules.

2.5.1 Simulation to Achieve Current Cesarean Delivery Rate for Failed to Progress Diagnosis

The Consortium on Safe Labor data (Zhang, Troendle et al. 2010), found that 2% of pre-labor cesarean deliveries and 47.1% of intrapartum cesarean deliveries are attributed to failure to progress or CPD (occurs when a baby's head or body is too large to fit through the mother's pelvis). They estimated that the total cesarean rate was 30.5%. In order to identify the decision rule used to achieve a cesarean rate of 14.9755% (i.e., $30.5\% \times 49.1\% = 14.9755$) for a failure to progress/CPD diagnosis, we simulated 200 scenarios with differing stopping rules. For each dilation state we allowed the stopping rule to vary from 1 to 8 hours for 3 cm, 1 to 7 hours for 4 cm, 1 to 4 hours for 5 cm, 1 to 3 hours for states 6 cm through 9 cm, and 1 to 7 hours for 10 cm by an increment of 0.1 hours and calculated the cesarean delivery rate as well as the absolute value of the difference between the rate and the target rate of 0.149755.

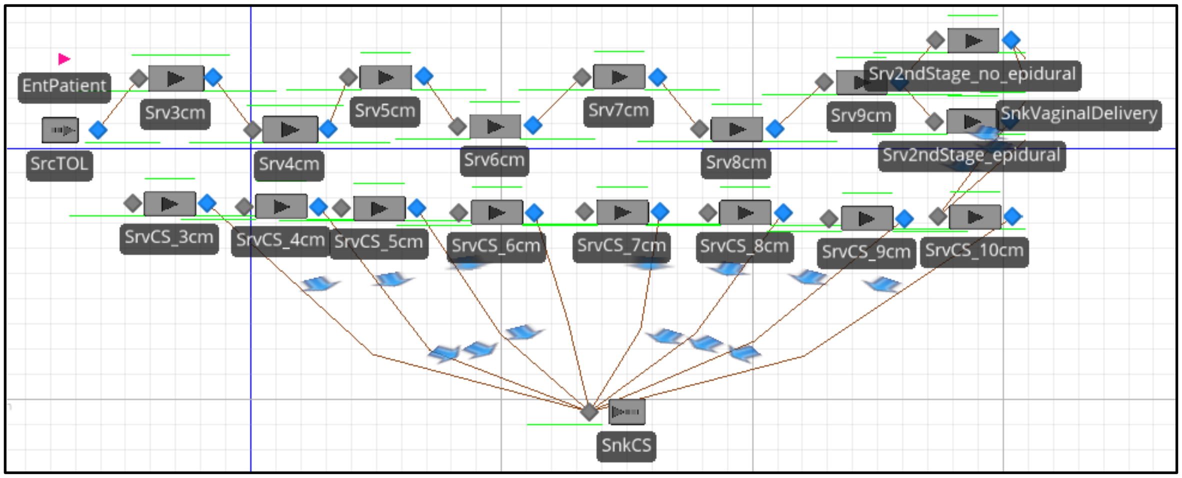


Figure 4. Screenshot of Simio® simulation Model 2 where patients (EntPatient) enter the system (SrcLabor) at a rate of exponential(1) hour and progress through each server which is represented by Srv$j$cm for each cervical dilation j. Once the patient completes each cervical dilation state, a decision is made of whether to perform a cesarean section given the length of time she was in that particular dilation. If the length of time exceeds the stabled cutoff time, she delivers through cesarean. Here the simulation ends with each patient delivering either through cesarean or vaginally.

2.5.2 Experiments with Various Stopping Rules

To gain insight regarding the effects of allowing women to labor longer before deciding to deliver by cesarean, we experimented with different stopping rules to estimate the resulting cesarean section rate and the corresponding number of complications. We used probability estimates from Cheng et al. (2009) who estimated the rate of complications for labors lasting 0-12 hours, 12-18 hours, 18-24 hours, and greater than 24 hours to calculate the number of complications. The complications we included were birth trauma, NICU admissions, and a neonatal composite variable which includes 5-min Apgar <7, shoulder dystocia, and birth trauma. By adding the probability of the complications mentioned for each time interval, we calculated an expected number of complications that occurred from labor durations of 0-12 hours (0.059), 12-18 hours (0.061), 18-24 hours (0.066), and greater than 24 hours (0.101). We were able to calculate the expected number of complications for each simulation run as

$$\begin{aligned} &Expected(Number\ of\ Compliations) \\ &\qquad = .059 * \mathrm{NumberComplications0\_12} + .061 * \mathrm{NumberComplications12\_18} \\ &\qquad + .066 * \mathrm{NumberComplications18\_24} + .101 * \mathrm{NumberComplications24}. \end{aligned}$$

We estimated the cesarean section rate and number of complications using a stopping criterion of 2 hours, 3 hours, 4 hours, 5 hours, 6 hours, and 7 hours.

3 RESULTS

3.1 Natural Progression of Labor

Simulation Model 1 was run for 52 weeks with 10 replications, we had approximately 8,692 total patients where 2,662 (30.62 ± 0.0016%) were induced labors, 2,762 (31.78 ± 0.0034%) were augmented labors and 3,268 (37.60 ± 0.0032%) were spontaneous labors. The average time in system, which we define as the length of the active labor from 3 cm to vaginal delivery, was 8.3093 ± 0.0231 hours. The minimum and maximum times were 2.3816 ± 0.1179 hours and 20.9249 ± 0.4204 hours, respectively. From the results of this simulation we created an upper bound on the length of active labor. Given the data used, we see it would not take longer than 21 hours to reach delivery. Figure 5 shows the min, average, and max duration of labor for each dilation state.

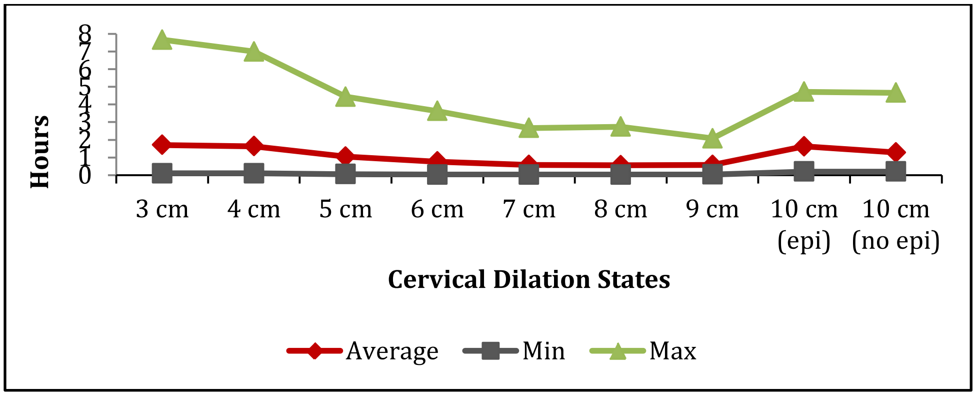


Figure 5. The min, average, and max amount of time a woman remains in one particular dilation state according to the simulation.

3.2 Estimate of Current Cesarean Section Rate due to Failure to Progress

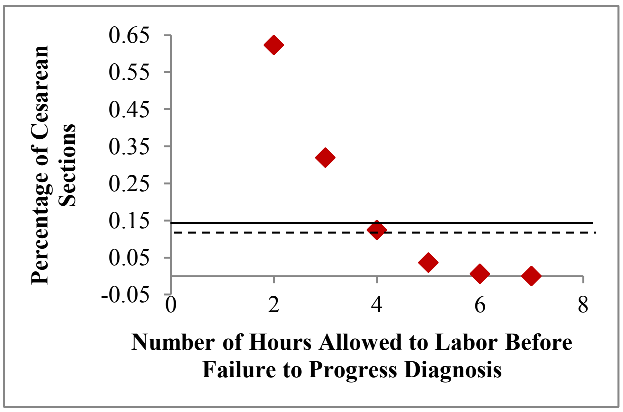
We were able to identify three scenarios that resulted in a cesarean section percentage close to 0.149755, presented in Table 2. It is our assumption that one of the rules identified or a similar decision criteria may have been used in the 19 hospitals observed by Zhang et al. (2010). We see that the stopping criterion was above two hours in many states, which differs from the labor progression rules suggested by the Friedman Curve. Scenario 2 seems to agree with results from Zhang, Landy et al. (2010) who determined that women should be allowed to labor longer in the first stage of labor for cervical dilation at and below 6 cm. The results for Scenario 1 and 3 differ slightly. Here we see that these scenarios show women should be allowed to labor longer up to 8 cm and 7 cm, respectively. Thus providing evidence that allowing women to have a longer first stage of labor can aid in reducing the rate of cesarean deliveries. These results suggest Scenario 2 gives better insight into the labor rules physicians used for the Consortium on Safe Labor.

Table 2: Display of duration of labor (in hours) to achieve current rate of 14.9755%.

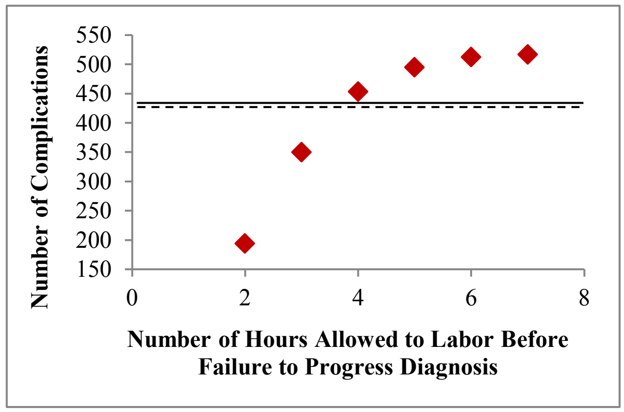
	Scenario 1*	**Scenario 2**	**Scenario 3**
Duration of Labor 3 cm	6.3	4.5	5.5
Duration of Labor 4 cm	3.3	4	5.7
Duration of Labor 5 cm	2	2.5	2.3
Duration of Labor 6 cm	2.3	2	2.8
Duration of Labor 7 cm	2.5	2	2.8
Duration of Labor 8 cm	2.3	2	1.8
Duration of Labor 9 cm	1.3	2	1.2
Duration of Labor 10 cm	4.5	4	3.3
Difference from 0.149755	0.0043	0.0098	0.0101
Cesarean Section Percentage	0.1469 ± 0.0047	0.1399 ± 0.0035	0.1598 ± 0.0042
Number Complications	436.352 ± 5.3577	443.17 ± 5.4794	431.189 ± 4.7531
Percentage of Complications	0.0505 ± 0.0003	0.0532 ± 0.0002	0.0502± 0.0002
Total Amount of Births	8668.2 ± 90.7094	8732.4 ± 92.9873	8697.2 ± 80.5021

3.3 Effect of Different Stopping Rules

To understand the effect of waiting before deciding a patient has failed to progress and a cesarean section is necessary, we estimated the cesarean section rate and number of complications using a stopping criterion of 2 hours, 3 hours, 4 hours, 5 hours, 6 hours, and 7 hours for each dilation state. The results confirmed the inverse relationship between the number of cesarean deliveries and the number of complications. We were able to see the largest benefit for waiting an additional hour is for extending the 2 hour and 3 hour rules. That is, allowing women to labor longer than two or three hours before declaring a failure to progress diagnosis gives the most benefit in terms of the reduction in the number of cesarean deliveries. Alternatively, the number of complications increases by the largest margin for the 2 hour and 3 hour rules. Both graphs show that as the stopping rules increase, the marginal benefit (and loss) is minimal. To gain further insight into an optimal stopping rules, we set an upper bound of complications to 437 (the average of the number of complications for Scenarios 1, 2, and 3) and identified a policy that minimizes the cesarean section rate. We see that the best scenario, Scenario 1, minimizes the cesarean section rate by allowing the rule to vary depending on dilation state. The comparison of rates and number of complications are displayed in Figures 6a and 6b as well.



a)



b)

Figure 6: Figure 6a (left) graphs the percentage of cesarean deliveries for various stopping rules. The current rate is indicated by a solid line and the best scenario rate is indicated by a dashed line. Figure 6b (right) graphs the number of complications associated with delivery and the length of time in labor for various stopping rules. The number of complications for current and best scenario is indicated by a solid line and dashed line, respectively.

4 DISCUSSION

Model 1 provides interesting insight into the total length of active labor for nulliparous women. Since various complications correspond to the duration of active labor, it is important to understand exactly how long active labor can last. The model suggests that the longest active labor was approximately 21 hours which tells us that an active labor lasting longer than 21 hours may be seen as abnormal. We were also able to show the minimum, average, and maximum duration of labor for each dilation state. As evidenced by the data provided from Zhang, Troendle et al. (2010), Zhang, Landy et al. (2010), and Harper et al. (2012), the longest labor duration is for the progression from 3 to 4 cm. The labor duration times decrease as cervical dilation increases until reaching 10 cm which is similar to other studies.

The results of Model 2 show the importance of dilation-state-specific decision rules for determining when a patient has failed to progress. The nature of the Friedman Curve provided a blanket stopping rule which determined that a failure to progress diagnosis should be given after a patient has not progressed from one centimeter to the next after two hours. We also see from Figures 6 and 7 that the lower cesarean section rates correspond to a higher number of complications and vice-versa. Since it is not possible to lower the cesarean delivery rate without increasing the number of complications, an optimal policy for ending a trial of labor is one which does not exceed an established amount of complications while also minimizing the cesarean section rate. The cesarean section rate and number of complications can be best minimized by employing a varying time stopping rule dependent on the dilation state.

We developed a natural history Simio® simulation model (Model 1) assuming a Beta-Pert distribution for duration of labor using information from Zhang, Troendle et al. (2010), Zhang, Landy et al. (2010), Rouse et al. (2009), and Harper et al. (2012). Exploring different distributions for dilation time may provide more insight into the upper bound of the duration of labor and thus aid in understanding more about the connection to total time in labor and the rate of complications. A few other distribution candidates would be the Beta, Exponential, or Lognormal. Since we are limited to only the min, max, and median times, we felt Beta-Pert was the most appropriate distribution.

Another interesting aspect of this problem, not yet considered, is the effect that epidural analgesia may have on labor progression. Vahratian et al. (2004) and Thorp et al. (1991) conducted studies comparing the use and placement of epidural analgesia in labor and its effect on labor progression for singleton nulliparous deliveries with a spontaneous labor. The results from Vahratian et al. (2004) showed that the use of an epidural analgesia did not have much effect on labor progression and results from Thorp, et al. (1991), determined that administering an epidural analgesia resulted in a longer first and second stage of labor. Although the results of these two studies differ in their results, there may still be reason to consider the effect that something like epidural analgesia may have on labor progression.

An extension of this model would be to allow for interventions of labor such as induction and assisted delivery. Here we do not explicitly explore these options. Including these interventions would provide more insight into what actually happens in practice. However, it is implicitly assumed that if labor is not interrupted by cesarean section then other methods of labor intervention may be taking place in the course of the trial of labor. A further extension of this model would be to explore other causes of emergency cesarean delivery. We only use "failure to progress" as a basis for an emergency cesarean delivery but there are other complications that occur during pregnancy that prompt for an emergency cesarean section such as cord prolapse, fetal distress, uterine rupture, and hypertensive disorders.

5 CONCLUSION

The labor and delivery process has changed a great deal over time. Although it can be argued that the Friedman Curve is no longer effective, its use may still be prevalent and no new clear guidance has been provided. Since there are different delivery guidelines practiced by various obstetricians, midwives, and other labor and delivery specialists, we develop a simulation model of labor progression and evaluate stopping conditions for a trial of labor to mimic the rate of cesarean deliveries given a failure to progress diagnosis and identify guidelines to assist in reducing the rate of cesarean sections and rate of complication. This project provides insight into how to model the labor process and lays the foundation for further research in this area. The decision to administer a cesarean section is a combination of the health of the mother and child, the length of time of time a woman labors, and her discomfort level. We have determined that an appropriate labor progression plan is one in which nulliparous singleton births of women with no prior complications should be allowed to labor longer than two hours which was established by the Friedman Curve; instead the time should be a function of dilation stage. This is in line with the current guidelines released by ACOG and SMFM.

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