Proceedings of the 2005 Winter Simulation Conference
M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.

EMERGENCY DEPARTMENT SIMULATIONS: MEDICINE FOR BUILDING EFFECTIVE MODELS

Carley J. Jurishica

Rockwell Automation
504 Beaver Street
Sewickley, PA 15143 U.S.A.

ABSTRACT

This paper will discuss proven practices for developing Emergency Department (ED) simulations based on recent project success. From human decisions to political agendas, an ED is filled with unpredictable elements, making it a difficult environment to model. However, the key decision-making information that will be uncovered from a study is worth the effort. This paper will thoroughly analyze each step of a typical ED simulation project, identifying key areas of focus and tips for success. Defining the objective, process map, scenarios, outputs and animation requirements are the first steps. A system for gathering the ED data will be discussed, as well as advice for the verification and validation phases. Finally, the presentation of the findings will be analyzed. No part an ED simulation project should be discounted. This paper will stress dependency of each phase on the successful outcome of the entire project.

INTRODUCTION

In today's fast-paced, technology-driven, world, everything happens quicker. From the internet to cell phones the ubiquity of instant communication and response is making society intolerant of waiting. Would a business traveler accept waiting in line since the implementation of easy check-in stations? The world is changing and people are demanding efficiency from all organizations. It seems absurd then, that among all the process improvements within the last couple decades, when it comes to health care, the stigma of long wait times remains. Hospital EDs are realizing that they must change with the times in order to stay competitive, profit and survive. In order to meet and exceed patient expectations many hospitals are planning expensive expansions, investing in new facilities, improved technology and consulting services to help improve their system. However, without the right decision making tools, a hospital will waste time and money, and fail at its attempts to improve patient satisfaction. One of the most useful tools to analyze the complexities of an ED environment is simulation. Simulation allows an analyst to create a virtual environment of a real or proposed system in order to examine its reactions to various conditions. Simulations are favored over analytical solutions when studying complex, dynamic systems such as an ED. (Ferrin, Miller, and Messer 2004) A simulation solution will assist analysts in understanding how different areas of the system interact. This information cannot be derived from a one dimensional analytical approach. For the projects discussed in this paper, Arena® Simulation Software was used.

ED SIMULATION PROJECT APPROACH

1 Project Objective

Defining a sound simulation project objective is the first step of the study. It provides an understanding of why the project is being conducted. Many ED simulation projects have common objectives:

- Identify and provide strategy for eliminating bottlenecks.
- Identify throughput gains from efficient and optimized patient flow.
- Provide the ability to understand the true throughput capacity and the impacts of change on throughput without the investment of additional capital or physical change.
- Analyze nurse, physician and bed utilizations.
- Determine the optimal resource schedule.
- Reduce the patient length of stay (LOS) in the ED.
- Identify strategies for capitalizing on future patient growth (Ferrin, Miller, and Messer 2004).

This paper will stress the importance of the objective during each phase of the study. All persons in contact with the project should be made aware of the study and its objective to ensure cooperation on each level. Additionally, the objective must be a static element. Changing the objective in the middle of the project will compromise the success and integrity of the study.

2 Process Map

After the project objectives have been set and agreed upon, the simulation team must define the process. Most EDs have a similar process. If a previous ED model has been built, the analyst should re-use that process map as a starting point for any new project (Ferrin, Miller, and Messer 2004). Developing the process map will involve interviews with a variety of persons intimate with the system as well as personal observation. At the highest level of detail, a typical patient visit to an ED will involve:

1. Patient Arrival (via ambulance, direct admission or a walk-in).
2. Triage.
3. Registration.
4. Sent to ED Bed.
5. Initial Assessments.
6. Testing and Treatment Procedures.
7. Disposition (Admission, Discharge, Transfer).

In order to clearly understand the system flow, a process mapping tool, such as Microsoft™ Visio®, should be used. This will allow for easy update of the process as changes occur during the map development phase. Additionally, an electronic form of the process will allow for convenient distribution and review by the project team. Furthermore, mapping out the process in Visio® will provide a framework for the actual programming in the Arena flow chart environment. Figure 1 displays an example of a Visio®, diagram used to detail the process flow of patients through an ED.

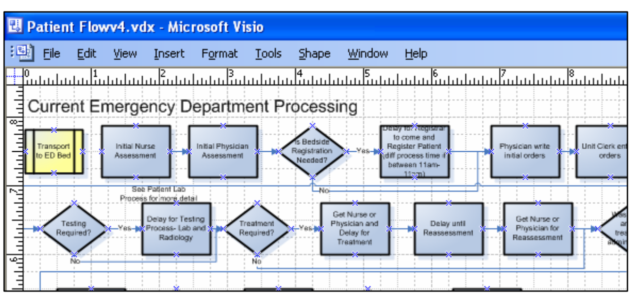

Figure 1: Example of Visio Process Flow

After the process flow has been mapped out, any additional business rules, including resource constraints, must be defined. A typical ED will include some combination of nurse, physician, tech, housekeeper and bed resources. Determining how much detail and how exactly the model should mimic real life requires further discussion.

There are numerous ways to program the process and resources. It is extremely important to understand and agree upon the level of detail that will be modeled during this phase of the project. In general, avoid adding detail if the objective can still be met without it. Often times, increasing the level of detail will not significantly impact the results. Additional detail will increase the model development, project testing, validating and data gathering times. In Figure 2, the detail level of a model is compared to the time to complete the project. In Figure 3, the impact of adding detail to a model and a sample of the resulting project value can be seen.

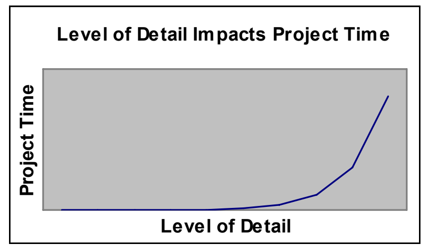

Figure 2: Level of Detail Impacts Project Time

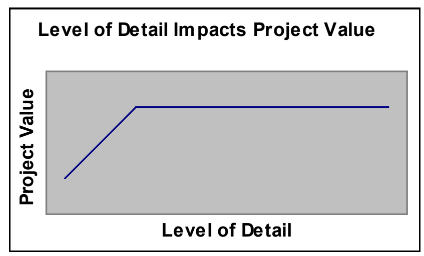

Figure 3: Level of Detail Impacts Project Value

Defining the level detail should be carefully assessed during the process mapping phase of the project. Understanding the project objective will be a guide to determining the correct level of detail. It is suggested to begin at the highest level and add detail if necessary. While additional detail in the model may be necessary to meet objectives, it should be clear that this decision may have a significant impact on the project timeline and no impact on the project value. Finally, once the current process flow and detail are agreed upon, a discussion on the "what if" scenarios and potential changes are next.

3 "What If" Scenarios

A useful simulation study cannot be conducted without knowing where the system is going. The simulation scenarios must be carefully constructed as they are key to providing information for the objective. The scenarios will be a guide for developing the appropriate level of flexibility in the model. There are 2 categories of scenarios that will be discussed; Variable Change Scenarios and Process Change Scenarios.

With a smart user interface and a flexible model, Variable Change Scenarios should involve little additional programming. For example, if the resource schedules are set up in an user interface as opposed to hard-coded in the simulation programming application, making changes to the schedules and reviewing how the system responds to the changes should be fairly easy. Additional Variable Change Scenarios include alterations to ED bed capacity, process times and percent inputs. Knowing the scenarios up front will dictate what should be included in the user interface and allow for running quick and easy scenarios.

Process Change Scenarios are more complex and involve additional process mapping and planning. For example, in a recent ED simulation study, the project team was considering a redesign of the patient flow through the ED. Patients were no longer triaged and registered up front. Instead, immediately upon arrival they are taken to a patient care room. In order to define and understand this new process flow, a Visio® diagram was created prior to any programming. Additionally, the programming for the new process flow was included in the original model. A simple trigger variable was used in the logic to ensure patients were only routed through the new flow during the scenario run. If the process redesign is not too drastic and some of the original logic can be re-used in the new scenario, include all scenario capabilities within a single model. This will eliminate the potential of having to maintain multiple models for a single project. Additionally, by including the scenario trigger to be set in the user-interface, the Process Change Scenario can easily be run.

4 Identifying Key Outputs for Analysis

There are an endless number of outputs that can be generated and analyzed in an ED model. Narrowing down the best quantitative statistics that will be used to assess all scenarios can be overwhelming. There is strategy that can be applied in order to determine the best outputs for analysis.

The flow chart in Figure 4 highlights the process involved in finding the key outputs for analysis.

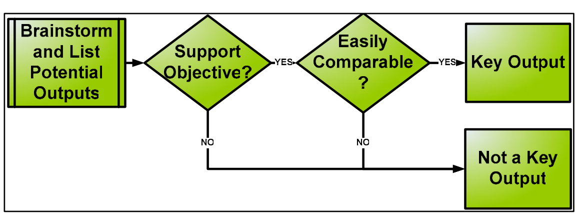

Figure 4: Strategy for Determining Key Outputs

The first step is to brainstorm and make a comprehensive list of potential data outputs. Next, for each data option, ask if it will support the project objective. If the answer is no, the output should not be considered key for the project. Outputs that support the objective must be analyzed further. While many data outputs will be analyzed during the project lifestyle for various testing and validation purposes, when it comes to the final presentation and report only a select number of key outputs should be considered. Limiting and prioritizing the outputs is crucial. Too many statistics will overwhelm and confuse the audience. The key outputs for analysis should be easily comparable among scenarios. They will provide powerful information for the decision-makers and project team.

In Table 1, several examples of simulation objectives and corresponding supportive outputs are listed. Additional details on each output may be necessary depending on the objectives. For example, a project with an objective to study and reduce specific queuing issues will require detailed outputs on the breakdown of patient wait times in the system (Takakuwa 2004). The project team must continuously ask if the current outputs will provide information to meet the objective and if any more significant data can be generated. The entire simulation project comes down the output results and the story they tell. Too much data, too little data and insignificant data will harm the entire project.

Table 1: Examples of Key ED Simulation Outputs

Simulation Objective	Outputs
Identify and provide strategy for eliminating bottlenecks	Average Queue Waiting Times (e.g. average time patients wait for ED bed)
Identify throughput gains from efficient and optimized patient flow	Patient Throughput (e.g. total number of patients through ED)
Analyze nurse, physician and ED bed utilizations	Resource Utilizations (e.g. percent of time bed is occupied, percent of time nurse is busy)
Determine the optimal resource schedule	Resource Utilizations, Average Queue Waiting Times, Cycle Times
Reduce the patient length of stay (LOS) in the ED	Cycle Times (e.g. average time in ED)

5 Animation

The animation for an ED simulation is critical as it will be the primary tool for the final presentation. In order to effectively "sell" the simulation as a representation of the current ED and to convince the hospital that the results are valid, a comprehensive animation is necessary. It is likely that the hospital administrators, nurses and physicians are not simulation specialists. They will prefer to see the outputs visually before examining any queue, resource or throughput statistics.

In Figure 7, a print screen of animation from an ED model visually demonstrates existing bottlenecks throughout time as patients queue up on the front end. The patients in the animation are waiting for triage, registration and an ED bed. Using the animation to communicate with the audience will be more effective than only declaring average queue statistics.

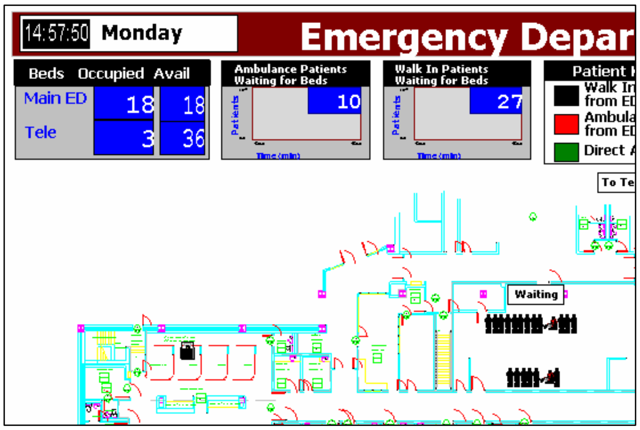

Figure 5: ED Simulation Animation Sample

The animation should be intuitive. Patients should be animated to move through the system and change states as the meet with nurses, physicians and undergo treatments. The project team and presentation audience should be able to visually see the bottlenecks and capacity issues throughout the run that the output statistics will support. In order to make the animation as realistic as possible in the Arena® simulation environment, an auto cad drawing of the ED may be imported and animation can lie on top. Again, the importance of keeping the project objective in mind while creating the animation is essential. If bottleneck identification is a key objective, significant queues should be displayed in the animation. Use graphs and other objects to enhance the system state throughout the simulation and impress the audience. In a recent project dynamic flags to indicate when a patient's LOS in the ED had reached a particular threshold were programmed to flash on the screen during the animation. Too little and poorly designed animation will negatively affect the project.

6 Data Requirements

Perhaps the most intimidating task of an ED simulation is the data collection process. Among EDs this process is likely to be significantly different. Some hospitals may have very efficient and useful data collection tools implemented in their current facilities, where others may have none. Understanding the pre-existing data available for the ED is crucial during data collection phase. There are several things to consider before beginning the data collection process for an ED project.

- What are the data requirements for the simulation model?
- Is there an existing data collection system for the ED, and what data do they already have?
- What data will need to be manually collected?
- Who should collect the data?
- How will the data collection process be perceived by the ED staff and how will good data be ensured?

First, what are the data requirements? Determining every specific piece of data necessary can seem overwhelming. However, with a good process map, functional specification and some simulation experience, it should not be too difficult. Step through the process flow and categorize each type of data that will be needed for the model. Consider the excerpt of a process in Figure 8. Based on this diagram, the following data requirements are apparent:

- Patient Walk-In arrival schedules.
- Time to greet and register a patient.
- Time to triage a patient.
- Patient acuity level.

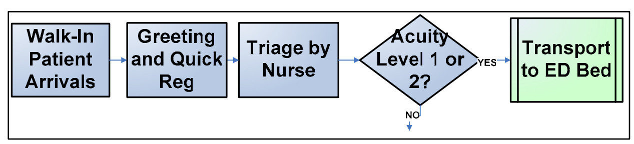

Figure 6: Example for Identifying Data

Stepping through the entire process map will provide the data requirements. The level of detail and other business rules defined will need to be in mind throughout the data requirement gathering phase. For example, if the nurse triage times are significantly different based on patient acuity, and this level of detail has been agreed upon for the model, more than one distribution for the time to triage category will need to be collected.

7 Functional Specification

After the project objective, process map, scenarios, outputs, assumptions, data and animation requirements have been solidified, a thorough functional specification should be completed. The functional specification should be agreed upon by all project team members before any model development begins. The functional specification is essential to the ED simulation project. It allows for a clear understanding of the project requirements.

8 Data Collection

After the data needs are identified, the means of gathering the information must be determined. Before any manual data collection takes place, an existing system that collects data for the ED should be assessed. Most EDs will be able to provide some historical data that can be used for the simulation project. If a data collection system already exists in the ED, seek out the person(s) most familiar with these tools. They will be the best help in determining what data needs to be manually collected and what data already exists. Review each data item on the list compiled in the first step of this phase with this person. Remember to asses the accuracy of the data and ensure that it is the right fit for the data needs. Any data that can be provided will reduce the data that will need to be manually collected by the project team.

Once the manual collection data has been identified, there are several considerations that need to be addressed prior to the collection process. First, how sensitive will the ED staff be to the collection process? It is important that the ED staffs are briefed on the project and its objectives. If any personnel feel that their jobs are at risk, they may behave different than normal and skew the data. One suggestion is to involve the staff in the data gathering process. This has proved to be a successful approach as the staff are familiar with the process and will not appear threatening to their peers. Additionally, they are already familiar with the ED environment and will have a better understanding of the data requirements. Regardless of whom the data collectors are, they must be cognizant and respectful of the staff and patients that are moving through the system.

In addition to determining the data collectors, creating data collection tools and providing data collection training are essential. While the data requirement may be the "Time to Triage a Patient", the data collection tool must provide an easy, accurate and consistent way of identifying this data. Table 3 is an example of a simple data collection tool to capture the patient triage time.

Table 2: Data Collection Tool Sample

Patient	Triage Start Time	Triage End Time	Total Triage Time (min)
1	11:05	11:11	6
2	11:10	11:19	9
3	13:43	13:50	7
4	14:28	14:37	9

The Total Triage Time can be converted and read by the Arena® Input Analyzer in order to find a best fit distribution. At least 30 data points for a valid distribution should be used.

The data collection tool to capture the patient triage time can be categorized as List Data. This data consists of discrete data points that can be represented using a mathematical distribution. There are 3 data categories:

1. List Data.
2. Single Value Data.
3. Schedule Data.

Single Value Data and Schedule Data will be discussed next.

Percentages, such as percent of walk-ins sent directly to an ED bed or percent of patients admitted from the ED, are typical examples of Single Value Data. If historical data cannot be provided, a manual collection will need to take place. Several data collectors should be dedicated to tracking where patients go. Use the process map as a guide to where in the system a patient may change paths. Data collectors will need to tally this information in order to determine the percentages of who goes where.

Finally, Schedule Data refers to patient arrival schedules as well resource schedules. Retrieving good patient arrival data is critical. This information will drive the model. This data will typically not need to be manually collected. The hospital should have historical data detailing patient arrivals. If the hospital under study is unable to provide this data use a benchmark hospital with similar patient flows. This will be more efficient and accurate than having data collectors manually track this information. If this information is still not available, a manual study will be necessary. As for resource schedules, this information should be easily garnered through hospital interviews.

Capturing the data will be a challenge. From patients to staff, people will hesitate and resist the process. Clear communication regarding the project is imperative. Additionally, where there are holes in the data, best guesses will have to be sufficient. Good data capturing tools and well trained data collectors will help ensure a successful simulation project.

9 Model Interface and Programming Development

The ED simulation models were built using Arena® and a Microsoft™ Excel User Interface. As mentioned earlier, developing a flexible model and interface is key to any simulation study. Increased flexibility will allow for more model scenarios, adding value to the final product.

The interface should be user-friendly. Creating an Excel Interface provides the user with a tool they are likely already familiar with. Additionally, they will not need to know any underlying programming to run the model. Incorporating all inputs, outputs and run-time selections in one application that talks to Arena will result in a single tool necessary to quickly run and analyze scenarios. The Arena model will, however, be necessary to view the animation.

When developing the input portion of the interface, at the least, the following categories of data should be included:

- Percentages (e.g. percent of patients that require testing, percent of patients that require treatment, percent of patients that are admitted).
- Process Delays (e.g. delay for nurse triage, delay for registration, delay for physician assessment).
- Patient Routing Delays (e.g. time for patient transport from waiting room to ED bed, time for patient to be routed from ED to admit room).
- Resource Schedules (e.g. number of nurses available, number of ED beds available).

The user will be able to change inputs and create endless scenarios for analysis.

Output statistics should also be incorporated in the Excel Interface. Typical outputs for ED simulations:

- Patient queuing time at each process.
- Number of patients in queue at each process.
- Number of patients through the ED.
- Utilization of ED resources (nurses, physicians, beds).
- Patient cycle times in ED.

Isolating specific statistics to the Excel Interface will eliminate having to data mine through multiple reports to find useful information. Selecting and confirming outputs at the onset of the project is important in maintaining focus and assuring the objectives are met. The outputs declare to the entire project team what the simulation will show and how different scenarios will be measured.

Creating a smart interface can be time consuming, but once the inputs and outputs are established, the ease of effort involved in setting up and running scenarios will make it worth the time.

10 Verification and Validation

Once the model has been developed it can be verified. The verification of the model involves ensuring that the model behaves as expected. Once the real data has been input, the validation process can take place. The validation process involves confirming that the model behaves like the actual ED under study.

The animation of the ED model is extremely useful in the verification and validation processes. The model can be easily verified by watching entities move through the ED. Adding specific programming to enhance the animation is key to making the model believable. For example, changing patient pictures as they are treated, undergo testing, or receive care is crucial to verifying that all procedures are incurred throughout the patient stay.

The ED simulation model can be best validated by comparing output values to the actual values seen in the ED. This may involve comparing the simulation reported time to the times collected by data gatherers as well as comparing the times to an internal data collection system. Selecting outputs at the beginning of the project that can help to validate the model is important.

No phase of a simulation project should be overlooked, especially the validation process. Without a valid model, new scenarios will not provide any additional information for analysis and final decision making.

11 Final Presentation

The final presentation should be short, simple and understandable. The audience will not consist of engineers and simulation specialists. They will ask few, if any, questions regarding the programming, statistical calculations and computations. The animation should be the primary tool for describing the system. A good animation will show bottlenecks and specific queuing problems. Watching the animation of a valid model for an extended period of time will allow the audience to buy into the simulation and believe the results of any scenarios run. Additional graphs and visual aids to clarify the project should be used. Presenting large lists of raw data must be avoided. While many outputs have been developed, the presentation should involve comparison among a few key outputs. Next, the results of the scenarios agreed upon should be discussed and compared to the baseline model. A final report on the project should include additional statistical outputs for a more in-depth comparison among scenarios.

CONCLUSION

The phases of an emergency department simulation project are intertwined. Each part must be carefully planned and executed for beneficial results and a useful end product. Keep in mind the following key elements to ensure the project is a success:

- Define clear objectives.
- Create a complete functional specification including objectives, process maps, scenarios, inputs, outputs and animation requirements at the beginning of the project.
- Determine the appropriate level of detail.
- Identify key outputs for analysis.

REFERENCES

Miller, M., D. Ferrin, and M. Messer. 2004. Fixing the Emergency Department: A Transformational Journey with EDSIM. In *Proceedings of the 2004 Winter Simulation Conference,* ed R.G. Ingalls, M.D. Rossetti, J.S. Smith, 1988-1993. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Takakuwa, Soemon 2004. Functional Analysis for Operating Emergency Department of a General Hospital. In *Proceedings of the 2004 Winter Simulation Conference,* ed R.G. Ingalls, M.D. Rossetti, J.S. Smith, pp. 2003-2011, Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

AUTHOR BIOGRAPHY

CARLEY J JURISHICA is a simulation consultant with Rockwell Automation. She has a B.S. in Industrial Engineering from Northwestern University. Her email address is <cjjurishica@ra.rockwell.com>.