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Application of Systems Engineering Tools and Methods to Improve Healthcare Delivery Inside the Emergency Department of a Mid-Size Hospital

Mohamed Elshal, Hazim El-Mounayri, Omar El-Mounayri

***Abstract*—**Emergency department (ED) is considered as a complex system of interacting entities: patients, human resources, software and hardware systems, interfaces, and other systems. This paper represents a research for implementing a detailed Systems Engineering (SE) approach in a mid-size hospital in central Indiana. This methodology will be applied by "The Initiative for Product Lifecycle Innovation (IPLI)" institution at Indiana University to study and solve the crowding problem with the aim of increasing throughput of patients and enhance their treatment experience; therefore, the nature of crowding problem needs to be investigated with all other problems that leads to it. The presented SE methods are workflow analysis and systems modeling where SE tools such as Microsoft Visio are used to construct a group of system-level diagrams that demonstrate: patient's workflow, documentation and communication flow, data systems, human resources workflow and requirements, leadership involved, and integration between ER different systems. Finally, the ultimate goal will be managing the process through implementation of an executable model using commercialized software tools, which will identify bottlenecks, improve documentation flow, and help make the process faster.

***Keywords*—**Systems modeling, ED operation, workflow modeling, systems analysis.

I. Introduction and Problem Formulation

SYSTEMS engineering can be described as the process of choosing the system of interest, identifying all system requirements and interfaces, choosing the appropriate technical performance measures, and selecting the best modeling tool. SE holds significant promises to improve healthcare delivery; however, there are some significant challenges, and some of these challenges are: extensive data requirements for a healthcare system, and the difficulty to make healthcare providers to think analytically in a "systems thinking" way. In addition, healthcare system is difficult to change unlike other manufacturing systems [1].

We can apply SE concepts in multiple ways depending on the challenge we address and the type of the system we have. For a healthcare system, we have multiple stakeholders: patients, small clinics, large healthcare organizations, and community. Each of these stakeholders has his own challenge, and each challenge can be addressed using several SE methods and tools [2].

In order to create a SE model for the ED, we need to capture: the problem formulation, system boundaries and interfaces, Technical Performance Measures (TPMs), the different system elements with their interactions and interfaces, selected modeling methodologies, system stakeholders, system requirements and constraints. Moreover, several alternatives should be determined and analyzed, and a powerful model tool should be used for implementation. The most important step is the first one, which is the problem formulation since the model shall be constructed based on the stakeholder needs and problems, not based on the available modeling tool or the modeler experience; therefore, we shall formulate the problem correctly, and identify the real cause of the problem [3].

The ED under study has approximately of 1.9 million patients (2% of all ED visits) left without being seen, and 500,000 ambulance diverted away from the closest hospital every year, and much more problems for different EDs. Therefore, before constructing a SE model for a specific ED, we need to identify and formulate the problem first based on the system stakeholders needs.

First, literature review is done to study several models developed for the ED processes. These models have variety of problems, different approaches and several suggested modification scenarios that could help solve those problems. We can conclude that the main problem to focus on is the crowding problem; however, there are several problems which might lead at the end to the crowding problem such as: patients discharge problems, documentation and communication problems, integration problems between the ED and different departments, leadership problems, resources allocation problems, night shift problems, or even problems that come from housekeeping process [4]-[7].

The addressed hospital for this application is a mid-size hospital in central Indiana State. From conducting an initial meeting and initial interviews with the main system stakeholders (e.g. physicians and administrative nurses), we can conclude that, based on these stakeholders needs, the ED has many problems such as: the problem of back flow patients staying for a long time in the impatient unit for seven and eight hours, and sometimes staying for more than one full day. This problem can be considered as an integration problem between the ED system and the inpatient unit (IU) system, which leads to overcrowding inside the ED. Another problem

Mohamed Elshal is with the Indiana University-Purdue University of Indianapolis, 554 Drake Street, Indianapolis, IN, 46202 (phone: (1) 843-781-3988, e-mail: melshal@iupui.edu).

Hazim El-Mounayri is with the Indiana University-Purdue University of Indianapolis, 723 W Michigan St. SL 260 (phone: (1) 317-490-6079, e-mail: helmouna@iupui.edu).

that causes overcrowding is the problem of insufficient resources especially beds and nurses (resources allocation problem) [4], [7]. Moreover, they have some problems related to data management which are: the difficulty of accessing feedback data, the problem of getting data in and out at each stage of the process, database errors, and finally, the problem of presence of large number of systems inside the ER that is estimated to be 175 systems, which they plan to integrate into 16 or 15 systems only. All these problems and much more problems have some external factors and interfaces which affect it such as: hiring and firing employees and training new ones, overlapping of resources which will lead to inefficient utilization of the resources, the problem of work duplication and redundancy, the problem of residence and students inside the hospital, and night shift problems. The best and efficient way to manage all these problems, and to model such a complex system is to create a SE model and to use SE approaches. This will be explained in detail in the next sections.

II. Methodology and Approach

As we mentioned, SE can be applied in multiple ways depending on the specific challenge we have and the system stakeholder needs. We are proposing eight steps to model the ED system. The eight steps are:

1. Defining the system boundaries and interfaces.
2. Identifying TPMs of the system.
3. Building up the system and its elements.
4. Selecting the best modeling tools and methods.
5. Identifying the system requirements with verification and validation method.
6. Coming up with multiple modification scenarios and analyzing alternatives.
7. Testing the modification scenarios.
8. Identifying implementation options.

The first five steps will be explained in detail since their approaches have been currently developed. The last three steps will be demonstrated in the recommendations section; because at this stage, we are planning to create a SE model for the system first before start developing and testing any alternatives; and before implementing the system in a software tool.

A. Defining ED System Boundaries and Interfaces

The first step is the construction of the context diagram to show the boundaries and interfaces of the ED system. This system context shows systems and subsystems related to our system of interest, which might be systems inside the hospital, systems inside the ER which are not made and designed in the ER, and systems outside the hospital.

As most of the systems, we have three types of environments interfacing with the ER system: man-made environment can be expressed as hospital systems such as: fire alarm system in the hospital and ambulances available, electrical system in the hospital and HVAC system. Natural environment can be expressed as: seasonal weather conditions and time of day where we have different types of diseases and different number of patients for each season or day time. For example, we have more car accidents' injuries at the night shift time. Finally, in induced environment, examples are X-ray radiations, MRI field, and cell phone interferences. Furthermore, we have other systems which have great impact on our system of interest such as: pharmaceuticals, government regulations, other hospital departments, hospital administration, and patient's data and records. For example, emergency room might not have access to patient's data and critical information; therefore, physicians at the ER shall start from ground zero building a new patient profile. At this stage, all the system boundaries and interfaces shall be identified in order to start the next stage of building up the system and identifying the TPMs.

Fig. 1 shows the context diagram of the ED with all external interfaces.

B. Identifying System TPMs

In order to construct a SE model for the ED, several TPMs shall be considered, and a large number of detailed results shall be supplied based on the stakeholder needs and based on the challenge we have. Typical TPMs for the ED process include, but not limited to:

- The average time spent by each patient in the ED.
- Percentage of patients left without being seen.
- Time to initial assessment.
- Time to treatment.
- Care service experience.
- ED resources utilization.
- ED personnel workload.

C. Building up the System and Its Elements

Fig. 2 shows a schematic block diagram, which can be considered as the best way to describe the sequence of building up the system. As we are interested to model the workflow of patients, we have internal interfaces affect and interact with our system of interest such as: documentation and communication flow, ER resources, and requirements of the system. Moreover, we have external interfaces such as: patients' admission and discharge and hospital administration. This schematic diagram shows that we are modeling three aspects of the system: the physical system, logic of the system, and its behavior.

D. Selecting the Modeling Tool and Method

Analysis and modeling of the patients' workflow and process mapping are our SE tools and methods to understand and model the current process of the ED "As-Is" process. Workflow modeling and analysis technique is applied widely in many industries; however, its use is limited in healthcare, since the healthcare delivery process is less predictable and has less potential to undergo changing. Workflow analysis will be done in two steps: process mapping and process shadowing.

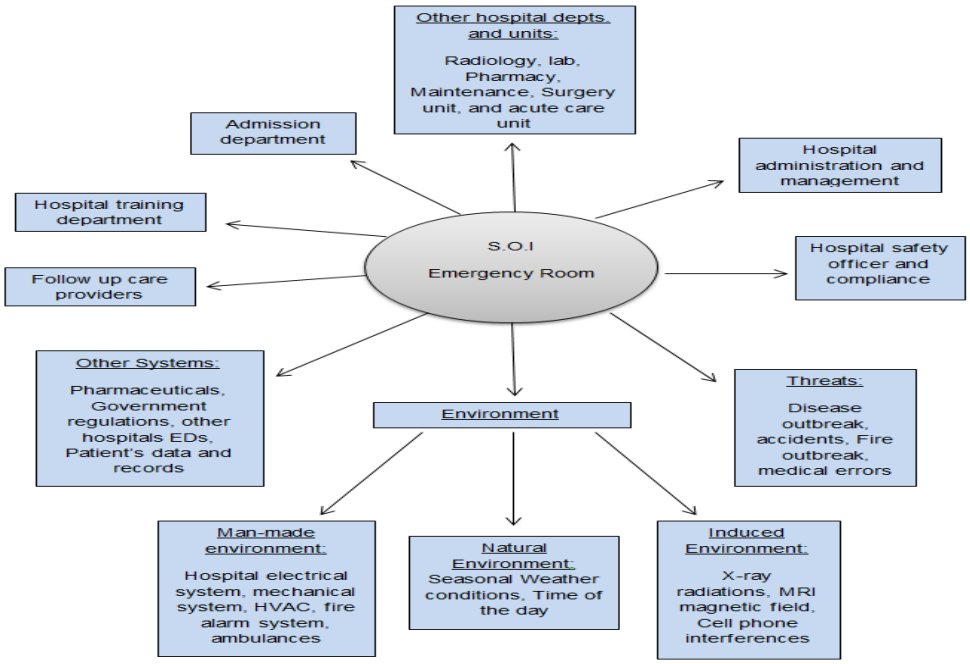

Fig. 1 ED Context Diagram showing our S.O.I with its boundaries and external interfaces

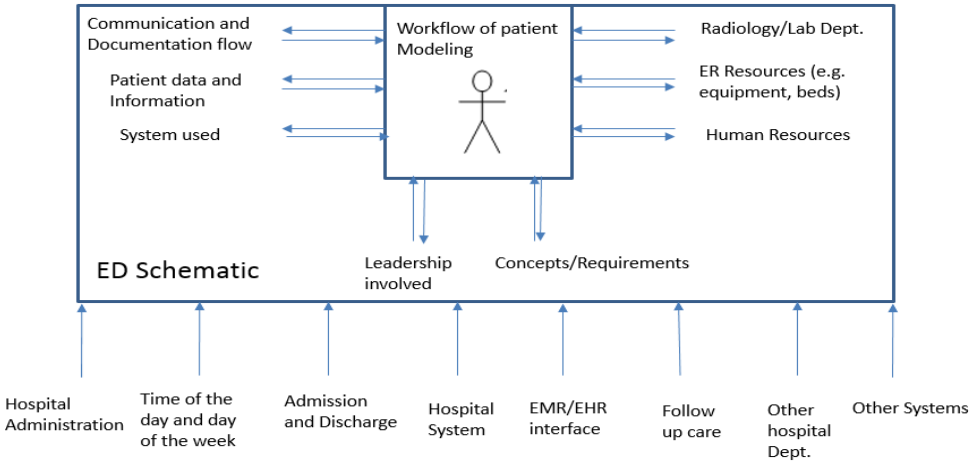

Fig. 2 ED Schematic Block Diagram

Process Mapping. The first step to be done is mapping of the process or "flowcharting". Although, process mapping is usually done in a later stage after the detailed understanding of the process sequence and logic; however, our approach is to create a map or a flowchart of the process as a starting point or as a guide before going to the process shadowing stage. Fig. 3 shows a basic process flow chart showing the workflow of patient inside the ER. This flow chart contains the main starting/ending points, functions, and decision points and it shows the main four sections of the patient workflow: **admission, assessment, treatment,** and **discharge** [8].

After constructing this flow chart and before going to the *"process shadowing"* stage, we need to collect some information and data at each of the four stages in order to model the workflow accurately. This information includes: historical and real-time data of patients' arrivals and departure, code of scanning used, information system used with its interfaces and integration, documentation and communication at each stage, lead time, process times (optimistic, pessimistic and most likely), logic of the process, workflow of ER resources, logic of the process from leadership prospective, redundant activities, and requirements of each activity. We plan to get all this kind of information and much more during the shadowing stage, and through conducting interviews with the medical staff and administrative people there. From all these information, we should be able to model our physical system, its logical structure, and its behavior.

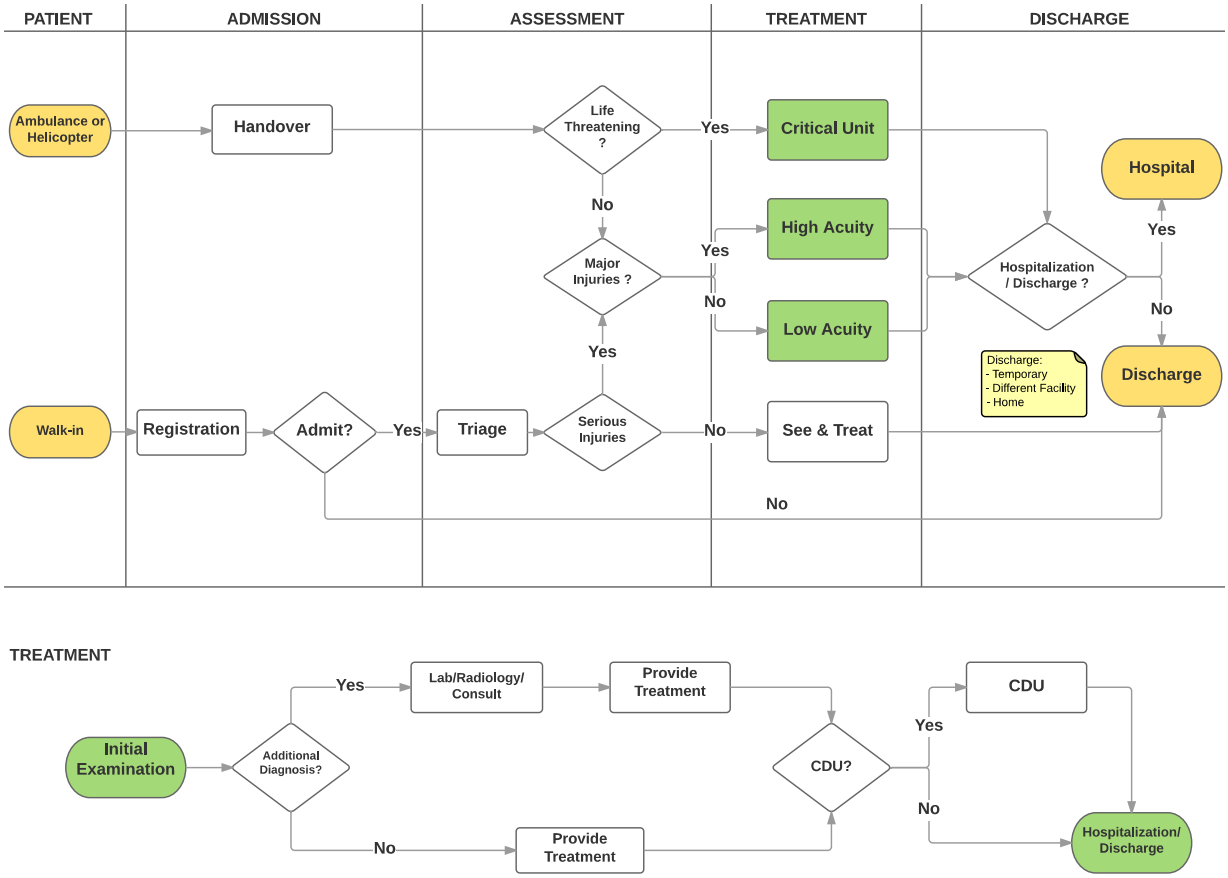

Fig. 3 Generic Process Flow Map showing patients' workflow inside the ER

Process Shadowing and Analysis. The next step will be "*Process shadowing"* to model the workflow of patients inside the ER. The recommended process shadowing approach is to start from the **endpoint** (patients' discharge) and moving backwards, since it is expected that the bottleneck always comes from the end for the ED process. Shadowing of the process will be done by walking-through the ED at different times of the day, and different days of the weak because: e.g., the bottleneck might be from the night shift because there is no signature or there is a communication gap with the morning shift. At this stage, the ED processes shall be fully investigated in order to prepare for the next stage of system requirements identification [9].

E. Identifying System Requirements with Verification and Validation Methods

The first step in identifying the system requirement is the **stakeholder identification**. This step shall be done through conducting interviews with all system stakeholders involved in carrying out each activity inside the ER, but mostly important with: administrative people and administrative nurses, since they should have a better understanding of the workflow. After that, system requirements should be identified at this stage of the process include: process requirements, resources requirements, data requirements, integration requirements, communication requirements and documentation requirements. After that, all of the identified requirements shall be verified by using system verification testing (testing those requirements through conducting a test case).

After mapping and shadowing the process, a big meeting shall be done with the ER management and the ER administrative people for validation. Moreover, we can use other validation methods:

- Modeling the process at different times of the day, and different days of the week.
- Modeling the process in at least two months' period.
- Bring together a multi-disciplinary team to do the shadowing of the process, and assign different tasks for different members of the team.
- Investigate the nature of problems inside the ER such as overcrowding (is it really overcrowded or the delay comes from another place?). The remaining three steps in our SE approach will be explained in the recommendations and future work section.

III. Recommendations and Future Work

After completing the workflow analysis and modeling, we need to come up with several modification scenarios and solutions and present them to the ED. As we modeled the "As-Is" process in the ED, the end result of implementing the workflow should be a "vision" of how the ED will operate

(vision of "To-Be" workflow) after modifications. This could be done through the following steps:

1. Implement the workflow in a process modeling platform to verify the process, show its bottlenecks and show different results and analysis for the ED TPMs. This platform shall have the predictive capability in order to help the physicians in the decision making process in a timely, automated, and integrated fashion.
2. In order to make the ED implement the suggested improvements and changes, **pilot testing** is recommended, where people from the ED should be assigned to test the modification scenarios as a first step for implementation.
3. In order to implement the improvements after pilot testing, The ED can start the implementation process from the workflow which has the less impact (e.g. start implementation from the simply injured patients' workflow).
4. In case we have integration problem, we can focus on the visibility problem as one of the possible problems we have. This will lead to the implementation of a "**real-time dashboard**" with the aid of a commercial software and data analytics.
5. The final scope and objective is to implement the ED system in a commercial PLM system software tool. This tool will help in reconfiguring the workflow and overall environment; which can help to reduce the burden of work while improving the performance of the system.

IV. Conclusions

As this paper represents a research of applying SE methods and tools to model a complex system such as the ED system, we can conclude that we have passed the planning phase in order to build a successful SE model for the ED due to the following points:

- The ED main problem is defined and formulated based on the stakeholder needs, with all other problems affecting it.
- A SE approach is defined to model a complex system such as the ED system.
- ED system boundaries and external interfaces are defined.
- The system and its elements are build up, and ready to go to the modeling stage.
- An appropriate modeling technique is identified and ready to be applied.
- After we are done with modeling of our system, the model can be implemented in a predictive simulation platform, which will help suggest and analyze several modification scenarios and present them to the ED in order to help mangers and physicians with the decision making process, and in order to make the process faster.
- Finally, our system is ready to enter the next stages of the design which are: discovery, development, and implementation.

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