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Improving Medication Delivery using Systems Engineering Approach

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Abstract
Systems engineering approach has been used in many applications to achieve major improvements in quality and safety in a wide range of manufacturing and service industries. Current research indicates that one of the major reasons causing risks for patient safety and creating wastes to the hospital is the poor design of medication delivery systems. This paper presents a systems mapping and analysis method with two analysis instruments for medication delivery improvement. The effectiveness of our method of systems mapping and analysis is illustrated by a case study that we conducted in the ER Department at Bozeman Deaconess Hospital, MT.

Keywords
health care, systems engineering, medication management

1. Introduction
There is a growing national concern that poor design for medication delivery systems combining with constantly growing number of patients and overcrowding are often the major reasons causing risks for patient safety and creating wastes to the hospital. Medication errors occurring either in or out of the hospital, are estimated to account for over 7,000 deaths annually [1]. One recent study conducted at two prestigious teaching hospitals, found that about two out of every 100 admissions experienced a preventable adverse drug event, resulting in an average cost of $4,700 per admission or about $2.8 million annually for a 700-bed teaching hospital [2]. If these findings are generalized, the increased hospital costs along with preventable adverse drug events affecting inpatients are about $2 billion for the nation as a whole [3].

Systems engineering approach has been used in many applications to achieve major improvements in the quality and safety in a wide range of manufacturing and service industries. Given the complexity of medication delivery system that involves the coordination and management of hospital employees, multiple streams of information and material flows across multiple care settings, it is almost shocking that health care professionals have not made better use of the design, analysis, and control tools of systems engineering [4-5]. This paper presents a systems mapping and analysis method for medication delivery improvement. The goal is to improve the hospital's medication delivery system so that it will be able to "deliver the right dose of right medication to the right patient at the right time through the right route" (5Rs) [5]. The effectiveness of our method is illustrated by a case study that we conducted in the ER Department at BDH.

2. Systems Mapping and Analysis
Medication delivery system cannot be successfully improved and implemented without a clear understanding of various process flows (i.e., medication flow, task flow, departmental flow, information flow, etc.) running around the entire hospital system at the beginning. Figure 1 shows our systems mapping and analysis method, which is user-friendly and is capable of analyzing and improving different process flows that take place everyday within and between various departments in the hospital. A visual representation of medication delivery system, a current state map, effectively points out all the wastes and inefficiencies that exist in the current system. After discovering all the core sources of problems using current state map and system analysis, the hospital managers can improve the system by solving the right problem in the right way at the right time. The improved medication delivery system is then shown by another visual representation, a future state map.

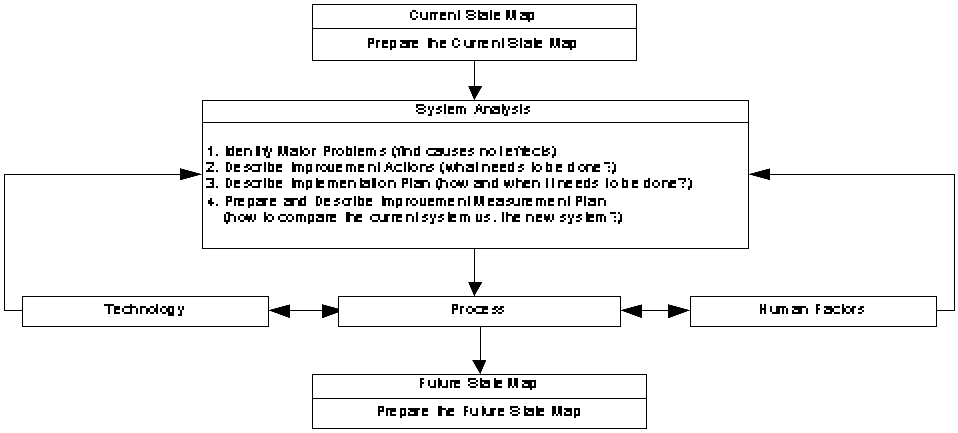

Figure 1: The Systems Mapping and Analysis Method

The system analysis is accomplished by a cognitive micro-level system analysis approach [6-7] in order to improve the system from a current state map to a future state map: 1) identify major problems (find causes, not effects); 2) describe improvement actions (what needs to be done?); 3) describe implementation plan (how and when it needs to be done?); and 4) prepare and describe improvement measurement plan (how to compare the current system vs. the new system?). During these four steps of system analysis, the hospital managers should always focus on the following three principles: 1) Technology: There is considerable evidence linking the use of technology to improved quality and safety of medication delivery [3-5], [8-10]. The managers should strive to achieve higher productivity, efficiency and improved patient satisfaction through a more proficient use of automation and information collection, processing, communication and management; 2) Process: The managers should try to simplify and standardize the workflows within their systems [11-13]. In general, simplifying key medication delivery processes can minimize problem solving and greatly reduce the likelihood of errors. The purpose of standardization should be to reduce reliance on memory and vigilance as well as to make effective use of constraints and forcing factors [3-5]. It allows the newcomers who are unfamiliar with a given process or device to use it safely; 3) Human Factors: Human beings do have certain intellectual strengths, such as their large memory capacity, a large repertory of responses, flexibility in applying these responses to information inputs, and an ability to react creatively and effectively to the unexpected events. However, human beings also have limitations including difficulty in attending carefully to multiple things at once, difficulty in recalling detailed information quickly, and generally poor computational ability [14-18]. The hospital managers should focus on integrating the human elements into the system analysis, modeling and design.

Overall our method of systems mapping and analysis including two instruments (task analysis and connection analysis) is to help managers analyze, evaluate and understand the underling structure of their medication delivery system in the hospital, and finally complete the current and future state maps of the system.

2.1 Task Analysis and Connection Analysis

From our studies at BDH, we have learned that data acquisition for medication delivery should and can be standardized. In addition, data collection and data recording for medication delivery system can be a tremendous effort and challenging task. It is not possible to create a well-structured current state map during the "shadowing" sessions due to the dynamic interactions with the participants in the study. There is a need for standard data collection and recording instruments. In response to these, two standard instruments for task analysis and connection analysis (Figure 2) are developed in our method to help complete the current state map. Using these standard instruments, both qualitative and quantitative data are collected and recorded from two primary sources based on the participant-observer method [19]: 1) Direct Observation: We noticed that quite often the problem-solving and system improvement efforts in the health care sector failed during the implementation because the managers did not sufficiently understand the current conditions. In-depth and detailed understanding of the current process as it is actually performed, rather than how it should be done or how someone says it is done, is absolutely critical. Workers and supervisors can often describe how the process generally works, or how it is supposed to work, but deviations from this general or hypothetical conception usually hold the key to the problem. So *direct observation* is needed. 2) Direct Conversation: The information for describing the extent of the problem should be accurate and precise, and should not rely on educated guesses. So *direct conversation* is needed.

Using the participant-observer method with our standard instruments, all participants (i.e., nurses, managers, technicians, unit clerks, etc.) have to evaluate/comment on each task and connection that exist in the studied system. The task analysis instrument includes the following three evaluations: 1) Technical Evaluation: including task workflow sequence (i.e., independent, dependent, and interdependent task relationship); task activity workflow to describe how the work is done; batch size and cycle time using triangular (T) or uniform (U) distribution; and available time representing the pre-established procedural time; 2) Resource Evaluation: including a list of resources used and their corresponding evaluations by the scale of adequate (no changes needed), adequate (adjustments needed), and not adequate (changes/replacement needed); and 3) Employee Evaluation: including a list of employees and the corresponding evaluations to see their qualification level to work on the task using the scale of qualified, over qualified, qualified (training needed), and not qualified. Similarly, the conection analysis instrument includes the following three evaluations: 1) Technical Evaluation: including a list of departments involved in the connection; connection types (i.e., one-to-one, one-to-many, and many-to-one); connection activity workflow to describe how the work is executed and flowed from one department to another; batch size and cycle time using triangular (T) or uniform (U) distribution; and available time representing the pre-established procedural time; 2) Resource Evaluation: including a list of resources and their corresponding evaluations by the scale of adequate (no changes needed), adequate (adjustments needed), and not adequate (changes/replacement needed) and 3) Employee Evaluation: including a list of employees and the corresponding evaluations to see their qualification level to work on the task using the scale of qualified, over qualified, qualified (training needed), and not qualified.

In Figure 2, task B2 was evaluated with two experienced ER nurses. The two nurses were selected by the ER manager due to their knowledge and experience on medication delivery process in the ER Department.

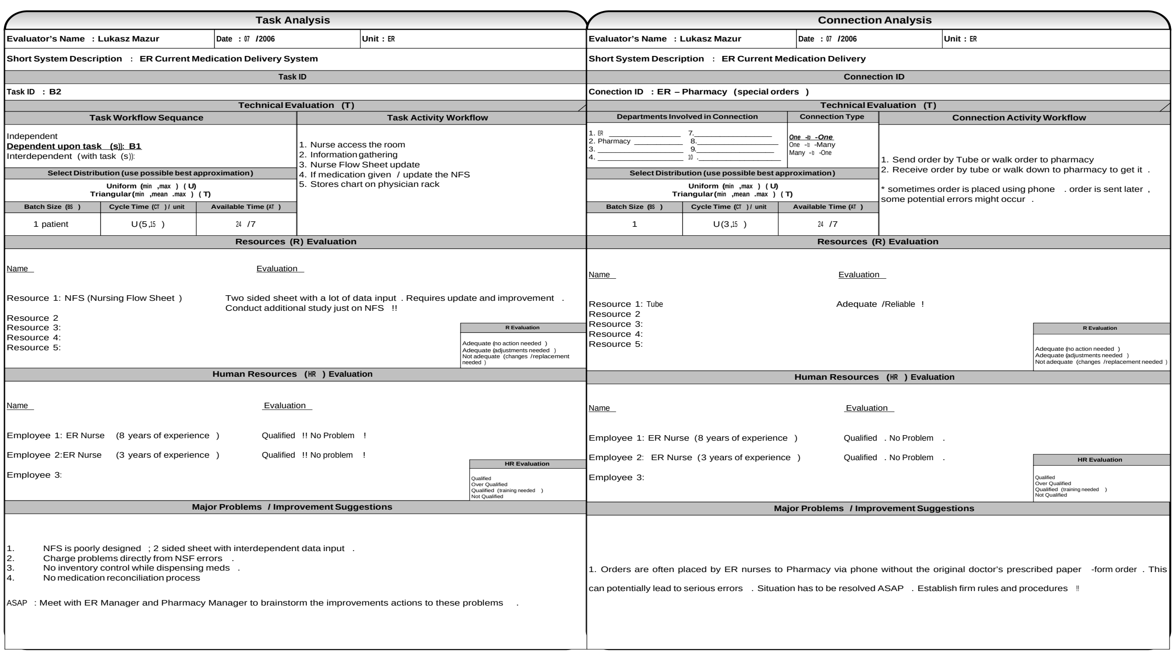

Figure 2: Task and Connection Analysis Instruments

Task B2 was found to be dependent on task B1, which means task B2 can not be started before task B1 is completed. After numerous observations on both ER nurses, we concluded a 5-step sequence in the activity workflow that the ER nurses took to complete task B2. The batch size was always equal to one patient. The cycle time was observed and measured 10 times and was uniformly ranging from 5 to 15 minutes, which was consistent with the ER nurses' comments during our *direct conversation* session with them. We marked the available time of task B2 as "24/7" that means this task can occur at any time in any day. Please note that some other tasks may be scheduled to do during a specific time and day. Both nurses were evaluated as qualified employees to take care of task B2. Both nurses stated that they have no problems working on this task. Finally, through our *direct observation* and *conversation* sessions, we identified some major problems related to the task. We found that the poor design of

Nursing Flow Sheet (NFS) was often the major reason behind the errors occurred in the ER Department. For example, very often the ER nurses forgot to fill in all the required information on NFS due to the two-sided sheet design with interdependent information input needed for both sides. This has been the primary factor creating a lot of patient charging errors (i.e., overcharging or undercharging). In addition, there was no inventory control and medication reconciliation process for medication dispensing of task B2. The suggestion was both ER and Pharmacy managers should meet immediately to brainstorm the improvement actions for these problems. The overall format of connection analysis is similar to task analysis. The only difference is the absence of "Task Workflow Sequence" that is replaced by "Departments Involved in Connection" and "Connection Type".

2.2 Current State Mapping

Figure 3 shows a current state map we created for the ER Department at BDH. Please note that the current state map is completed by virtually copying the data and information recorded using the two instruments of task and connection analysis. The layout organization of the current state map depends on the evaluator's preferences. However, we recommend keeping the current state map as "constructively simple" as possible. We can always add the complexity to the map later, if necessary. In general, the current state map provides a visual representation of the system and major problem causes (e.g., sources of errors and inefficiencies highlighted by the "storm burst" symbols in the map). According to Institute of Medicine [5], very few health care professionals or administrators are equipped to think analytically about health care delivery as a system. We believe such systems mapping can greatly help managers visualize and comprehend their medication delivery systems, and consequently lead to effective improvement actions.

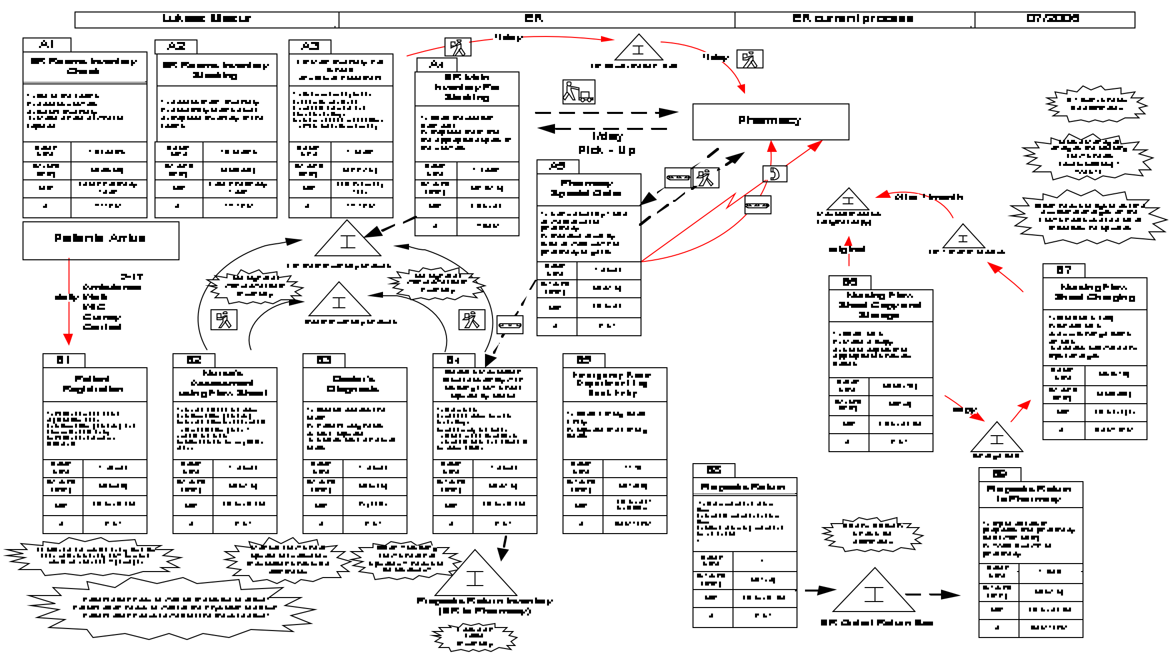

Figure 3: Current State Map for the ER Department at BDH

2.3 System Analysis

Researchers have suggested that health care is a complex industry where one component in the system can interact with the other components, sometimes in unexpected or invisible ways [17-18]. Such settings very often result in perception bias that leads evaluators into simplifying the causes of an accident, highlighting a single element as the cause, and overlooking multiple contributing factors to arrive at a simple solution or to blame an individual, but difficult to determine what really went wrong within the system. To avoid such oversights, we develop a system analysis instrument that includes the following four steps: 1) Identify major problems (find causes, not effects); 2) Describe improvement actions (what needs to be done?); 3) Describe implementation plan (how and when it needs to be done?); and 4) Prepare and describe improvement measurement plan (how to compare the current system vs. the new system?)

From our studies at BDH, we have learned that problem's root causes are not easy to find. The current state map can greatly help with this issue by providing a visual representation of the entire system on one-sided 8 by 11 inches piece of paper. According to our current state map for the ER Department shown in Figure 3, we have identified the following major problems: a) dispensing of medications from the ER Department's main/room inventories is done without any "inventory control signal" to Pharmacy that often causes some particular medications at the ER Department to run out and forces the ER nurses to proceed with special orders to Pharmacy; b) with the previous "inventory control" problem, consequently, the par levels for some particular medications at the ER Department are not adjusted to the current needs in the hospital; and c) the design of Nursing Flow Sheet (NFS), where the prescribed medications are marked, is a two-sided patient medication form with interdependent information input to both sides that causes many errors in medication prescribing, transcribing, dispensing, administering and charging. After detailed analysis we have identified the following improvement actions for the ER medication delivery system: a) automate the system by implementing the medication dispense cabinets at the ER Department that is established to tackle the first two identified problems concerning the inventory control and par levels; b) redesign the NFS form in order to eliminate the errors in medication prescribing, transcribing, dispensing, administering and charging; and c) redesign the medication delivery processes to eliminate the inconsistency and inefficiencies and therefore increase patient safety. The implementation plan to accomplish the targeted conditions has been strategically developed by team consisting of information systems manager, nursing supervisor, ER manager, pharmacy manager, and engineering consultant. Finally, the following three measurements have been selected as quality improvement indicators a) medication delivery cycle time; b) nurse's satisfaction; and c) % of medication delivery errors.

2.4 Future State Mapping

According to the system analysis, Figure 4 shows a future state map we completed for the ER Department. In general, the future state map provides a visual representation of a better system that we want to achieve. It also highlights the important areas that need to be addressed using the "storm burst" symbols in the map. We believe such visual representation of the future state system can greatly help managers comprehend their goals and consequently lead to effective and efficient implementation for system improvement.

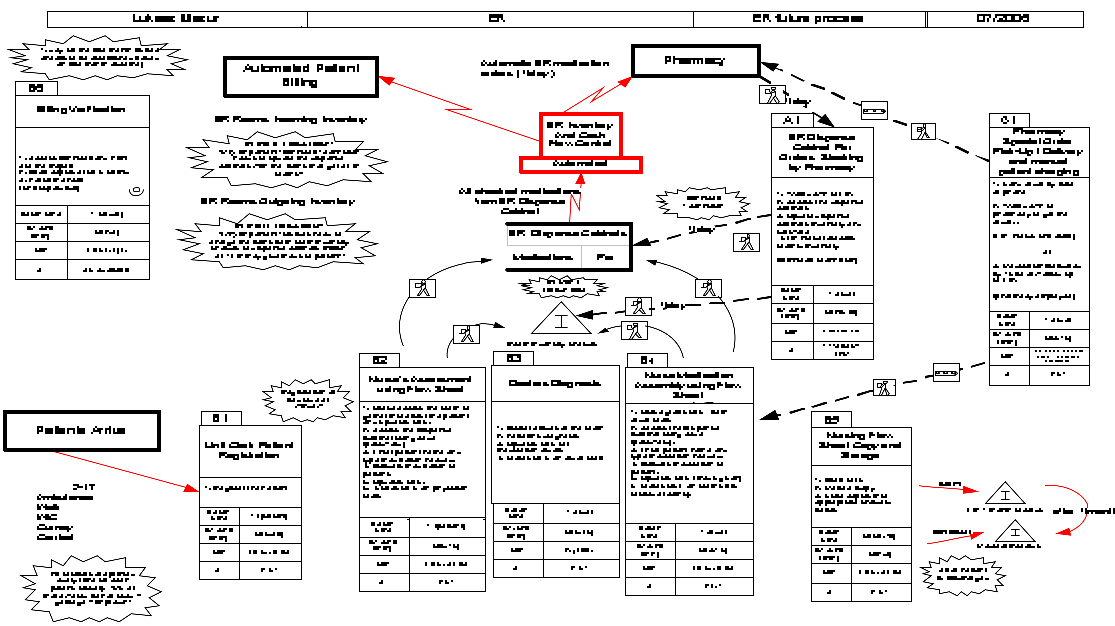

Figure 4: Future State Map for the ER Department at BDH

3. Conclusions

Our systems mapping and analysis method proved to be a useful tool for medication delivery improvement. It is capable of mapping and analyzing how the system actually works. Not only does it allow the managers to visualize and better understand their medication delivery system, it also endows them with the realization of system inefficiencies and potential error sources. It also helps removing any inaccuracies and over-generalizations during the analysis meetings where the system improvements were discussed. Additionally, the two standard instruments for task and connection analysis proved to be an effective and efficient approach to healthcare settings. From our studies at BDH, we have learned that it is not possible to create a well-structured current state map during the "shadowing" sessions due to the dynamic interactions with the participants in the study. Therefore, our one-page per task or per connection instrument allows users to easily record data during each observation or interview session, so that accurate current state maps can be constructed in a later stage without any distractions and potential los of any key data.

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