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LESSONS LEARNED BY APPLYING AXIOMATIC DESIGN TO AN EMERGENCY DEPARTMENT

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ABSTRACT

Without a doubt, a hospital's Emergency Department (ED) is a complex system. The operations of an ED are complicated by a mix of Technology (testing equipment, electronic medical record, computer services, treatment devices, etc.), human issues (staff needs and interactions, patient needs and interaction, and interactions between staff and patients), politics (issues of health insurance, laws governing health treatment, privacy issues, hospital management, etc.), and many more factors. This complexity not only makes ED operations difficult, but also communicating an issue both inside and outside of the ED can become difficult without a common understanding of the forces at work.

This paper uses the Emergency Department Design Decomposition (ED^3), an Axiomatic Design of an Emergency Department, to identify, understand, and communicate problems in an ED. We begin by summarizing the ED^3. Then the ED^3 is used to identify the inherent functional couplings in the design of an ED system. Next we analyze the couplings and judge how the complications the couplings suggest are equivalent to our findings in a case study performed at a suburban community hospital in Massachusetts.

Although the problems that are identified are known to a certain degree by practitioners, by mapping the issue to specific functional requirements and design parameters the problems can be better understood and communicated. This will lead to accurate assessment and understanding of the real systematic problems, rather than studying problems that may merely be side effects of the true issue. By using the ED^3 to identify current problems, potential is shown for further use of the ED^3 for discovering more subtle less well-known couplings. This lays a base for practitioners and researchers to sustainably improve EDs in the future.

Keywords: Health Care, Functional Couplings, Emergency Department, Axiomatic Design Decomposition, Complexity

1 INTRODUCTION

Today's emergency departments (EDs) in the United States carry significant responsibilities in the world's healthcare system. In addition to providing medical care to the patients whose illnesses or injuries demand immediate attention, it has become a major resource to provide medical care to the uninsured. Increasing numbers of patients are showing up at EDs since they can not, or do not want to, wait until the next available appointment with their physician. EDs are also required to play a key role in disaster preparation and responses.

Unfortunately, this growing demand for ED care is not supported by appropriate increases in ED capacity. It has been well documented that there is a growing imbalance between the demand-supply for emergency care system. While ED visits have been growing rapidly, by more than 10% during the last decade, the number of EDs has decreased by almost 10% during the same period [IOM, 2006]. One of the consequences of this demand-supply imbalance is, naturally, overcrowding [Asplin, *et al.*, 2003]. When an ED is overwhelmed, ambulances are diverted away, patients wait for long hours, and ED staff is under constant stress while struggling to move patients in and out of the ED [Olshaker and Rathlev, 2006]. These pressures lead to a decrease in patient satisfaction and quality of care.

Because of challenges such as ED overcrowding, many medical professionals are turning to systems scientists and complex system designers in order to find robust solutions. This paper seeks to employ Axiomtic Design (AD) [Suh, 2001] in order to analyze an ED and find design couplings that contribute to ED operational difficulties and crowding.

There can be no question that the operation of an Emergency Department (ED) has many complexities. There are many different technologies being used, employees with different skills performing processes, government regulations, interaction with suppliers, patients, the rest of the hospital, Emergency Medical Services, health insurance, etc. All of these different entities are involved with the operation of the ED, making the ED a complex system.

With the understanding that the ED is a complex system that is working towards specific goals, it is necessary to understand those goals clearly on all levels in order to properly analyze and re-design the system. This is a strong case for applying AD.

Since an ED is so complex, it has a great deal of Functional Requirements (FR) on many levels. In normal practice, the more FRs there are, the more difficult it can be to satisfy the highest level requirements. AD simplifies how the system is viewed which allows the proper decisions to be made at all levels, resulting in an efficient design. In the following sections a functional decomposition of the ED is created, then, using AD tools, conclusions about the ED and potential areas for improvement are identified.

2 THE EMERGENCY DEPARTMENT DESIGN DECOMPOSITION (ED^3)

The creation of a detailed design decomposition requires a strong working knowledge of the system. One must be familiar with the system at all levels in order to accurately identify the functional requirements at these levels. In order to achieve this working knowledge, researches from the Park Center for Complex Systems (PCCS) partnered with a suburban community hospital in the greater Boston area.

Through this connection, researchers spent time in the hospital ED observing the activities. Conversations were held with staff in order to ask them about their duties, their views of the ED and the processes that are regularly performed. There were also weekly scheduled meetings with ED management in order to discuss observations and ED official policy. Meetings were also held with nurses, physicians, and higher level hospital management. The result of all of these meetings and observation was an ability to create The Emergency Department Design Decomposition (ED^3), an AD decomposition of the ED System. [Kolb, 2007, Peck, 2008]

While building the ED^3, and generally when using AD, it is important to ensure that functions are stated in a 'solution neutral' fashion. Being solution neutral means that the objectives are clearly separated from the means of achieving them, in other words, the observed DPs do not define the FR. When analyzing a system by observing its current operations, it is easy to be biased by current design decisions. When making design decompositions a designer must be aware of the biased tendency and be careful to choose FRs based on what the system MUST achieve rather than what it IS achieving. If one is considering current operations when defining FRs, it is common to make compromises in the design to fit the bias based on observed solutions rather than searching for alternative solutions. In the ED^3, we force ourselves to overcome the biases caused by immersing ourselves in the system, by making sure our observations were focused on understanding why tasks are done, rather than what tasks are done.

As discussed earlier, using AD we start out with the high-level FRs of the system. These FRs tend to be fairly abstract. Then each FR is broken down into sub-FRs which have clearer meanings. Like the high level FRs, high level DPs are also abstract and broadly stated. Then as we get to lower levels the DPs become more tangible, and may be more readily recognizable as the observable activities and protocols being performed in the ED. If this decomposition were taken to the greatest detail possible, every single required action or process that is performed in the ED would be taken into account, from a doctor writing a prescription to cleaning staff mopping the floors. In order to maintain a high level view of the system and make changes that do not necessarily require clinical expertise, we decided to limit how deep the decomposition would go.

When dealing with complex engineering systems, a major problem is that the stakeholders involved with the system have different understandings of the system's actual objectives. By listing the FRs and DPs in a hierarchical fashion, low-level activities and decisions are related to high-level goals and objectives, giving a clear perspective. Figure 1 illustrates the decomposition process with the first two levels of decomposition from the ED^3.

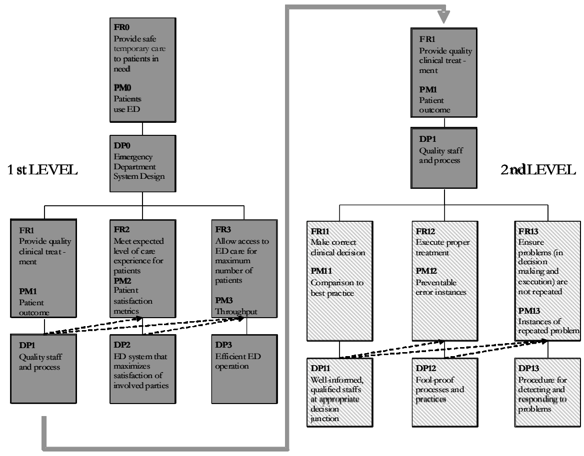

Figure 1: Decomposition structure of ED^3

Having a clear, visible reference to the system's objectives and functions facilitates communication among the stakeholders. Since the ED^3 clearly states objectives separate from the means and relates low-level activities and decisions to high-level goals it contributes to better communication and helps create mutual understanding and support from various stakeholders.

The ED^3 is a first attempt at decomposing the ED system and lists about 200 functional requirements. Figure 2 is a high level view of the ED^3. As can be seen from the figure the ED^3 has five top level requirements: quality, satisfaction, safety, access, and growth. Under each of these top level FRs are many more detailed levels of FR decomposition. Like many other design decompositions, the ED^3 is intended to be a living document that will evolve with future studies and new understandings.

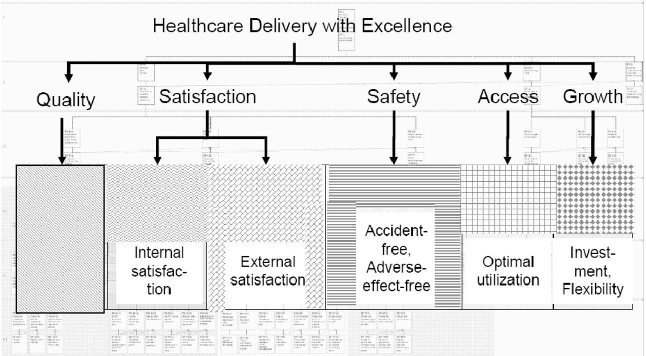

Figure 2: Emergency Department Design Decomposition (ED³)

3 USING THE ED³ TO IDENTIFY FUNCTIONAL COUPLINGS

The ED³ can be used to capture the interrelationships among the different elements of a system. As is called for by AD, for every FR, there is a matching DP to satisfy it. However, a DP may have unintended affects on other functions of the ED. For example, FR2.1.1 calls for competitive salaries and compensation for workers as part of maintaining internal satisfaction. DP2.1.1 is to pay based on education and workload. A manager would like to accurately compensate staff in order to keep them satisfied, but high compensation can strain the budget, hindering other functions in the ED. These unintended effects, due to a coupled design as described earlier, often make it difficult to satisfy all of the objectives of the system and are clear targets for re-design focus.

In order to bring out the couplings in the ED³, the decomposition was entered into a program used for AD called Acclaro® which was developed by Axiomatic Design Solutions Inc. This program makes it easy to organize the functional decomposition into a matrix form (Figure 3).

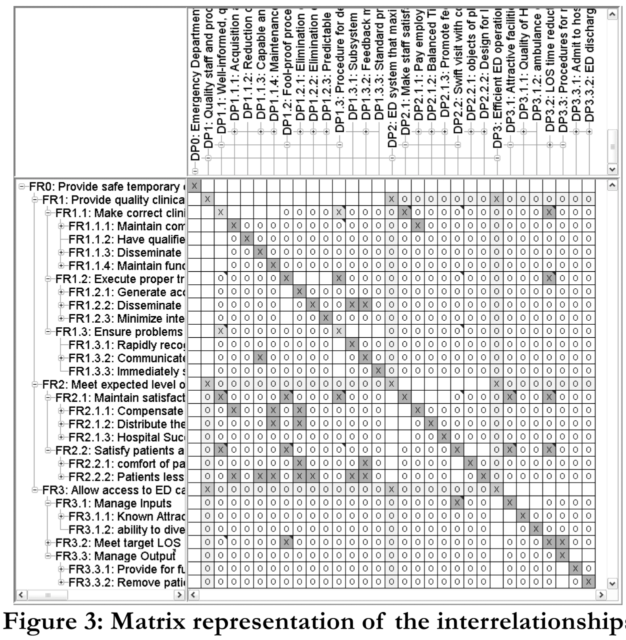

Figure 3: Matrix representation of the interrelationships between design parameters and functional requirements of the ED³.

As seen in the above figure, the program creates a matrix with FRs on the vertical axis and DPs on the horizontal axis. Where an FR meets a DP there is a box that can have the value of '0', which means there is no relationship between the FR and DP, or 'X', which means there is a relationship. While in the matrix form, the user can analyze each FR/DP intersection, identify when a DP affects an FR, and denote that relationship with an X. Since each DP was created to satisfy one FR there is a diagonal line of Xs, if these were the only Xs then the design would be uncoupled. If the DP of one FR is tied to another FR, and the second FR's DP is tied to the original FR, then the pair is considered completely coupled and the program highlights the Xs.

The matrix is an effective view for identifying couplings and analyzing how much they will affect the system. However, when the matrix representation of the ED³ is completely expanded, as in Figure 3 it can sometimes be overwhelming to pick out specific problems and couplings. Fortunately the matrix can be expanded or compressed to allow as much, or as little, detail as is desired. Figure 4 is the compressed version of the matrix only showing the highest level FRs and DPs.

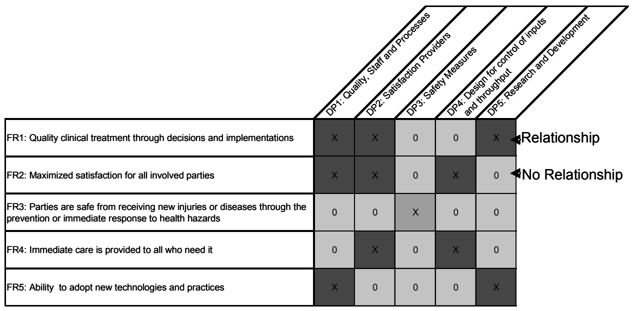

Figure 4: Compressed matrix representation of ED³

As can be seen in the above figure, there are many high level couplings in the ED³. Anyone who is familiar with the complexity of the ED system will not be surprised by this. Identifying all of the complex interactions and couplings is a worthwhile exercise. However, in the interest of identifying a specific problem and then working on it, steps were taken to simplify the ED³ even more. Looking at Figure 4 it can be seen that FR3, Safety, is not coupled with any other FR, this is because safety measures and precautions can generally be taken without strongly affecting any of the other FRs; this means that it can be removed from the matrix. The ability to make this kind of a statement stems from a clear definition of each FR, any ambiguity allows designers too much room for interpretation and would cause couplings that may not exist in a clearer design. FR5 is coupled with FR1 because growth in terms of new knowledge and practices does affect quality; however it only does so in that it affects future quality as opposed to maximizing what currently exists in the ED, so since the focus of this study is to re-design current practices, FR5 can be removed from the matrix. This results in the simplified compressed matrix seen in Figure 5 below.

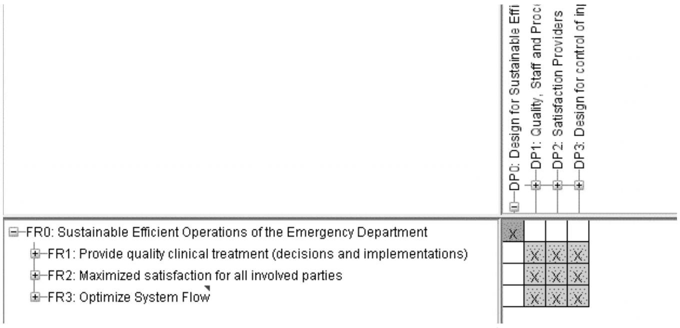

Figure 5: Simplified, Compressed ED³ Matrix

With the matrix simplified it can once again be expanded, however now it will be less difficult to identify problems and discuss them in greater detail. The following sections will be examples of design couplings that occur in an ED as identified using the ED³. The couplings chosen are on a high level and therefore may seem obvious; however they illustrate the potential for using the ED³ to identify problems which can be adopted on more detailed levels. The examples also show usefulness of the ED³ as a communication device, since it clearly identifies problems that are otherwise generally understood but not normally, systematically shown.

4 IDENTIFYING THE FUNCTIONAL COUPLINGS WITH REAL OBSERVATION

Having explained how the ED3 was manipulated in order to identify the functional couplings in an ED design, these couplings can now be expanded and discussed in context with real world observations made by the team when visiting a local suburban ED and researching ED management.

4.1 FR1.1 VS. FR2.1 – STAFF QUALITY VS. STAFF SATISFACTION

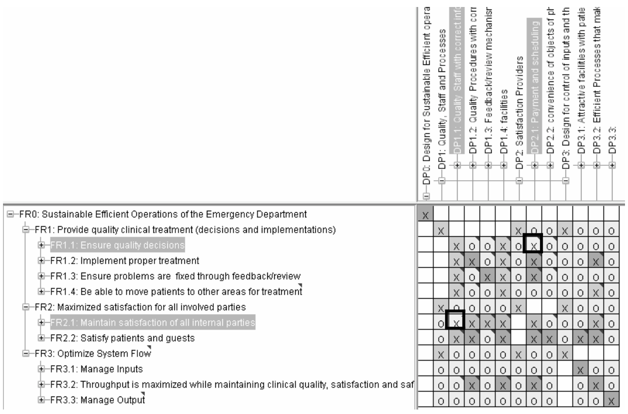

Figure 6: Simplified Matrix of ED³ Expanded one Level Showing FR1.1 vs FR2.1 Coupling

Figure 6 shows one specific coupling between quality and satisfaction. This is in fact the coupling that was mentioned hypothetically earlier, having to do with the cost of satisfying employees. The FRs and DPs that are being analyzed are highlighted and the coupling between them is denoted by X boxes with a thick outlines.

FR1.1 calls for making quality decision, however that requires paying for quality staff, which affects the ability of ED management to afford all of their staff, in that way DP1.1 which is to hire quality staff directly affects the ability to satisfy staff as a whole due to limited funds. This means that an ED manager must make decisions that balance hiring the very best, with satisfying all current employs.

On the other hand, DP2.1 calls for payment and scheduling practices in order to maintain satisfaction. In order to maximally satisfy staff they will be scheduled such that they are never overworked, but are never bored. However in order to maintain highest quality in treatment, ideal patient/caregiver ratios must be reached that may not allow for ideal scheduling that satisfies staff. In other words scheduling to satisfy staff may affect quality.

Although this interaction is indeed a very serious problem, it is actually de-coupled given a certain amount of money. Greater funds would allow hospitals to hire enough quality staff such that necessary ratios are always reached while not overworking any specific staff member. Another de-coupling factor is the ability to hold funding constant, but improve the efficiency of the ED and lower the optimal patient to caregiver ratio. [Kolb, 2008]

4.2 FR1.3 VS. FR2.1 – IMPROVING QUALITY VS. STAFF SATISFACTION

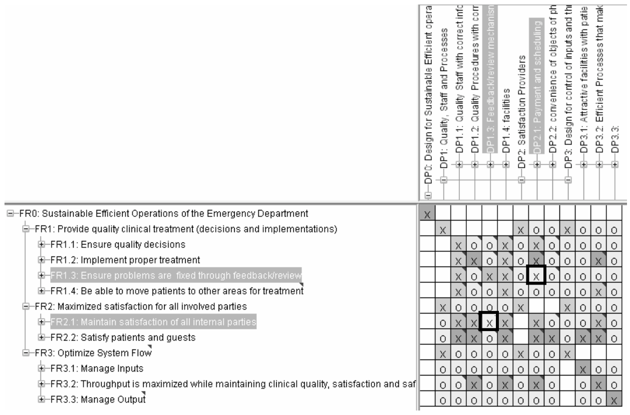

Figure 7: Simplified Matrix of ED3 Expanded one Level Showing FR1.3 vs FR2.1 Coupling

Figure 7 uses the ED³ matrix in order to show another coupling between quality and satisfaction. In this case the coupling is between efforts to improve quality through feedback and the satisfaction of employees. It is important to receive feedback on how employees are performing; this allows management to make changes in order to improve quality operations. However performance feedback has the very strong potential of affecting staff satisfaction. Staff members want to feel secure in their jobs, if they feel that they are constantly being evaluated then, although quality may improve, they may not feel as satisfied.

Besides how feedback applies to evaluation of performance there is also staff generated feedback. Staff can offer feedback by reporting mistakes allowing for clinical staff to find the cause of the mistake and ensure it does not happen again. This has potential effects on satisfaction in that staff will not want to report a mistake if they feel it will endanger their job. In order to overcome this coupling many hospitals have offered not to punish for any single mistake as long as it is reported quickly and honestly [Leape, 1998]. Staff feedback can be taken to a higher level through active feedback. In this case staff members actively seek problems and report them in order to encourage constant improvement. Such feedback is the backbone of many continuous quality improvement strategies that have been reported in the healthcare setting [Spear, 2005]. By being able to provide feedback employees gain a sense of ownership, which increases satisfaction while also increasing quality.

4.3 FR1.2 VS. FR3.2 – TREATMENT QUALITY VS. THROUGHPUT

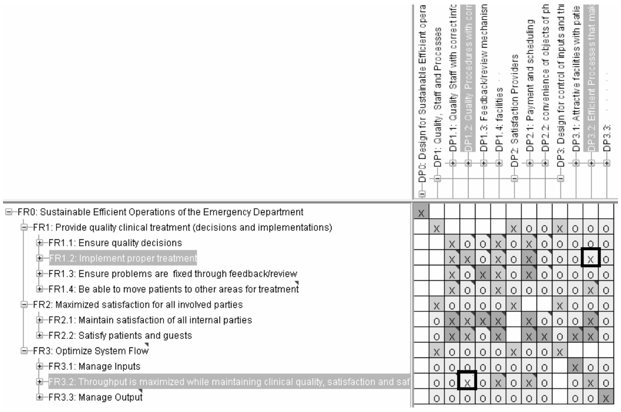

Figure 8: Simplified Matrix of ED3 Expanded one Level Showing FR1.2 vs FR3.2 Coupling

The coupling between FR1.2 and FR3.2, shown in Figure 8, is one that occurs in many kinds of systems that have to deal with product flow. It is desirable to move as many patients through the ED as fast as possible, from a productivity point of view. In the case of EDs, there is extra impetus for speed because ailments can get worse with time and thus having a patient wait for too long can be hazardous. It is also important to move patients through the system quickly in order to avoid crowding. However speedy treatment has direct consequences on quality of treatment. Pushing staff to work too fast can lead to stress and exhaustion which can be linked to harmful consequences in a treatment quality [Firth-Cozens, 1997]. A balance between high throughput and high quality must be found in order to satisfy both FRs. This can be made easier through improved efficiency that would allow for higher quality and higher throughput; however the coupling would still exist to some degree.

4.4 FR1.4 VS. FR3.2 – DIVERSE QUALITY VS. THROUGHPUT

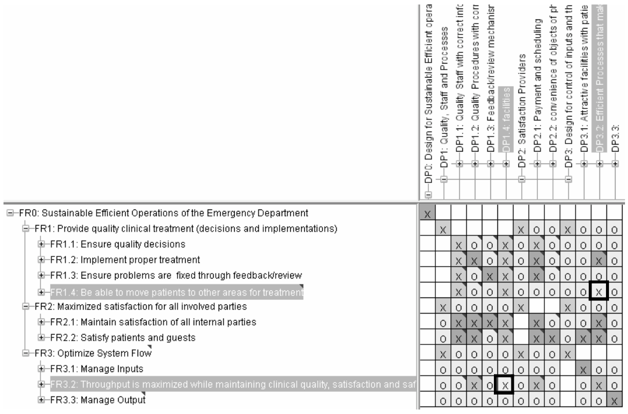

Figure 9: Simplified Matrix of ED3 Expanded one Level Showing FR1.4 vs FR3.2 Coupling

As mentioned in section 2.3, it is easy to take certain design decisions for granted when analyzing the design of a system rather than designing it from scratch. A key aspect of the design of an ED that feels strange to question is, why locate an ED in a Hospital? From a management standpoint there are many possible reasons such as infrastructure benefits of being part of a larger building (ie. Parking, Operations Overhead, Access to Hospital Food Courts etc.). In terms of the ED^3, the reason for attaching an ED to a hospital manifests itself in FR1.4. In order to provide quality treatment, the ED must also be capable of providing a diverse range of treatment; this coupling is shown in Figure 9. In some cases it is not reasonable to have an ED with all of the necessary facilities to fully treat every patient that arrives, this is why the ED must have the ability to send a patient to the larger hospital facility, after being stabilized, in order receive complete treatment.

The necessity of being part of a hospital and sending patients for admittance to the hospital has significant consequences in terms of patient throughput. Often due to bed or staff shortages or other causes, an ED patient can not be immediately sent for admittance to the hospital. This causes flow bottlenecks in the ED which then results in ED crowding [US GAO, 2003].

5 CONCLUSION/FUTURE WORK

The field of healthcare is evolving. The days when a doctor had time to pay individual house calls to a patient and carried all that they needed in a small black bag are gone. Now doctors can not afford the time to make personal trips, in fact they are often restricted in how much time they are permitted to spend with a single patient on site. This is all due to the ever increasing demand for faster, higher quality, yet cheaper service. This increasing demand without a proportional increase in supply is causing a great deal of crowding in EDs.

Using AD it was possible to analyze the ED system and highlight design couplings to which many of the EDs problems can be attributed. Some of these couplings may have already been known intuitively by those who work in the field however with the detailed functional decomposition it is easy to fully understand the interactions that form the coupling, which facilitates communication about the issue as well as the invention of ways to eliminate or alleviate the problem.

Having shown that the ED^3 can successfully identify problems, future work would include deeper analysis of the decomposition to identify more problems that are less commonly understood and offer insights into solving them. The idea of facilitating communication of problems within an ED can be furthered by efforts to spread the ED^3 to practitioners and encourage its use.

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