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THE EMERGENCY DEPARTMENT DESIGN DECOMPOSITION (ED^3)

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1 INTRODUCTION

1.1 Objective

With patient data from a hospital in Massachusetts/USA, we deployed Axiomatic Design (AD) [1]. To our best knowledge, the research at hand is the first use of AD in a medical system. AD is applied with the goal of enhancing a system design by identifying system couplings using a design matrix and changing the design to remove these couplings. In this paper we apply AD to an Emergency Department (ED) system to identify system inherent couplings. We assume these couplings to be the most promising future research topics for ED design improvement.

1.2 Background

An ED is often the only resource of emergency medical care for traumatic injuries and acute illness. Unfortunately, crowding appears in many EDs around the world on a daily basis [2]. Overcrowding has dramatic consequences: although an ambulance with a patient is close to a hospital, it may have to be diverted to another hospital further away, as the initial ED was full. This incident is called 'diversion status' of the overcrowded hospital. Frequently, hospitals in an area go on diversion status simultaneously. This leads to higher mortality rates for diverted patients in that particular area [3].
ED overcrowding is believed to be a systemic problem [4]. Overcrowding is commonly perceived as a situation in which there are more patients than staffed treatment beds and waiting times exceed reasonable periods. Crowding typically involves three types of patients: those waiting for ED admission, those being monitored in non-treatment areas, and those awaiting transfer to the inpatient unit (IU), which is the inpatient wards/clinics.

2 DEVELOPMENT OF THE EMERGENCY DEPARTMENT DESIGN DECOMPOSITION

2.1 The Emergency Department as a Complex System

There are many ways to define a system. This definition depends on the field of application and the background of the person making the definition. Based on system definitions from many different sources, a system has been summarized as "an assemblage of interrelated components working together towards the accomplishment of certain goals" [5].
There can be no doubt that an ED is a system that involves many complexities: numerous technologies, staff with various skills, differing government regulations, interaction with partners and suppliers, patients with high variety of illnesses and injuries, health insurance etc.

2.2 Application of Axiomatic Design

Developing the detailed Axiomatic Design Decomposition requires the researchers to have comprehensive understanding of the ED. To attain this, we partnered with a community hospital in the greater Boston area. Spending time in the ED allowed for the observation of all staff activities. Interviews were held with staff to learn about their duties, processes, and general views of the ED. In addition, weekly scheduled meetings with ED management provided insights into the processes by

discussing observations and comparing them to official ED policies. Meetings with nurses, physicians, and top management of the hospital filled the last gaps of knowledge acquisition.
Our first attempt at decomposing the ED system resulted in five top level Functional Requirements (FRs) which are quality, satisfaction, safety, access and growth. Throughout the AD process the distilled version of three top level FRs was shaped. First, this was achieved by removing 'safety', as its measures and precautions can generally be regarded as not affecting another FR. Second, the FR 'growth', which was coupled with FR1 'quality', became obsolete, as we aimed at developing the ideal ED. The mid and long term strategy, which relates to the FR 'growth', would have to be developed aside.

2.3 Emergency Department Design Decomposition (ED^3)

In the following we present our final decomposition, which we call The Emergency Department Design Decomposition (ED^3) [6] [7]. The ED^3 captures functions, their implementations, and their interrelationships. In a perfectly uncoupled system every single FR would be satisfied by exactly one Design Parameter (DP), but in our depiction of the current ED design, some DPs affect other FRs as well. We used the commercial software Acclaro® to systematically identify the couplings. The ED^3 is shown in Figure 1.

Functional Requirements (FRs)	0 Design for Sustainable Efficient operation	1 Quality, Staff and Processes	1.1 Quality medical decision making Staff with correct	1.2 Quality Procedures with correct information	1.3 Feedback/review mechanism (e.g. on-the-spot)	2 ED design and opperoration includes Satisfaction Providers	2.1 Make staff satisfaction providers available	2.2 Swift visit with convenient access to objects of physical	3 Design for control of inputs and throughput	3.1 Attractive facilities with patient acceptance controls	3.2 LOS time reductions	3.3 Procedures for moving patients
0 Sustainable Efficient Operations of the ED	X											
1 Provide quality clinical treatment		X				X	0	0	X	0	0	0
1.1 Staff generate quality decisions			X		X	0	X	0	0	0	X	0
1.2 Staff Implement proper treatment				X	X	0	0	0	0	0	X	0
1.3 Ensure problems are fixed			X	0	X	0	0	0	0	0	0	0
2 Satisfy all involved parties		X	0	0	0	X			X	0	0	0
2.1 Maintain satisfaction of all internal parties		0	X	X	X		X	0	0	X	X	0
2.2 Satisfy patients and guests		0	X	X	0		0	X	0	X	X	0
3 Optimize System Flow		X	0	0	0	X	0	0	X			
3.1 Manage Inputs		0	0	0	0	0	0	X		X	0	0
3.2 Meet target LOS		0	0	X	0	0	0	0		0	X	X
3.3 Manage Output		0	0	0	0	0	0	0		0	0	X

Figure 1. Two Level ED^3 Matrix. All level one FRs and DPs are coupled.

Figure 1 shows that there are multiple instances of functional coupling in the current ED system. These couplings are indicated by red boxes in the matrix. As such, satisfying all system objectives (FRs) independently is not possible. Per AD principles, this warrants a search for careful and clever alternative solutions to make it a decoupled design. In other words, these coupling instances are critical issues for the system but simultaneously offer a chance for improvement.

3 LESSONS LEARNED FROM THE ED^3

In discussion sessions with the ED staff it turned out that the ED^3 serves as a great basis for communication. Problems that may usually be recognized from different viewpoints are directly identified as a specific coupling and offer detailed FRs and DPs that cause it. Thus, the staff's discussions are structured and focussed around constructive problem solving. Below are two examples of couplings that were identified in the ED^3 and are generally known by hospital management.

3.1 Coupling of Quality Improvement vs. Staff Satisfaction

Continuous quality improvement is necessary for any system, as was evidenced by Japan's quality revolution such as the achievements by Toyota production system. Fault tracking is crucial in a

medical system. However, its implementation is far from easy. Staff members fear consequences after making mistakes and therefore do not report them. Obviously there is a huge quality deficiency caused by mistakes during the decision process, driven by the required speed during the whole process. Therefore it is crucial to have a self learning system in place in the ED which should lead to a higher consciousness for avoiding mistakes. However in practice such a system proved difficult to implement. If a decision was wrong, the MD, PA or nurse would fear consequences to their career, such as a lawsuit or even a patient's death.
In order to overcome the coupling of 'quality improvement vs. staff satisfaction', many hospitals offered to not punish single mistakes as long as it is reported quickly and honestly. In this case staff members actively seek problems and report them in order to encourage constant improvement. Such a feedback process is the backbone of many continuous improvement strategies that have been reported in healthcare settings [8].

3.2 Coupling of Treatment Quality vs. Throughput

This coupling is the main reason for an ED to be connected to an IU. An IU provides the full diagnostic and treatment range, which could not be delivered in a stand-alone ED. However, the connection to the IU causes backlog which worsen the ED length of stay times [9].
One major contradiction of any process improvement is the dichotomy of increasing quality and reducing process times. As much as swift treatment leads to short length of stay times, hurried treatment has direct negative impact on the quality of treatment. Emergency medical staff, which works too hasty, may suffer exhaustion. This again leads to dangerous consequences for a patient's treatment. The only solution of the dichotomy is a balance between high throughput and high quality, which must be found in order to satisfy both FRs – FR 'treatment quality' and FR 'throughput'.

3.3 Limitations

We did not undergo a rigorous validation of the ED^3. However, we do believe it to reflect the FRs that when properly satisfied will create an ideal ED. The various expert discussions at our partner ED as well as the couplings which reflected the major real world issues showed a strong indication for a valid model.

4 APPLYING THE LESSONS LEARNED OF THE ED^3

The development of the ED^3 showed us many key success factors. Our short analysis time in the hospital with the AD approach led to insights similar to a very experienced practitioner level. Chapter 3 pointed out only a few of the many insights into ED design, which stand out in the ED^3. We show the capability of AD to recognize problems and re-structure the complex socio-economic system of an ED.

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The Emergency Department Design Decomposition (ED^3)

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Agenda

- Introduction
- Developing the Emergency Department Design Decomposition (ED^3)
- Applying the ED^3 to investigate the tradeoff between 'quality improvement' versus 'staff satisfaction'
- Analyzing the tradeoff between 'treatment quality' versus 'throughput'
- Conclusion

Motivation

Why is the healthcare system and especially the Emergency Department (ED) under pressure?

Past

- People get sick around the clock, when the ED is the only source of emergency medical care
- For uninsured people EDs are the only accessible medical care
- Growing population at the end of the 90s
- Financial and resource restrictions

Present

- Nowadays the insured population understands healthcare as a "human right" for themselves incl. short waiting times as an implicitness
- Personnel has been cut in the last decades due to overcapacity in that time
- Cost cuts in healthcare sector leads to consolidation for hospitals
- Population is growing again
- Baby boomers are aging and need more medical resources

Two decades ago *the ED crowding was solved by efficiency improvement and shrinking populations*
Today *factors of overcrowding to be solved by ?*

Study's Objective

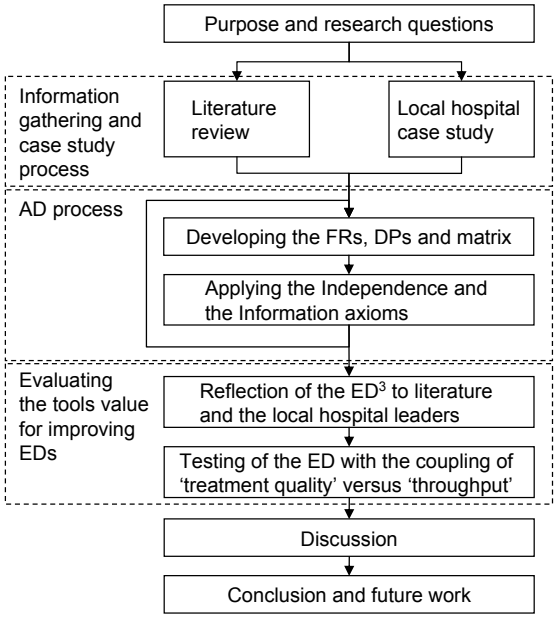
Study's purpose

- Detailed understanding of the complexities of an Emergency Department
- Apply Axiomatic Design to a socio-economic system
- Development of an ideal Emergency Department concept to support the improvement of EDs through:
  - a basis for communication,
  - identifying the issues, and
  - to anchor the efforts to improve the system.

Research question

- How does the ideal Emergency Department look like, following the method of Axiomatic Design?

Research Design



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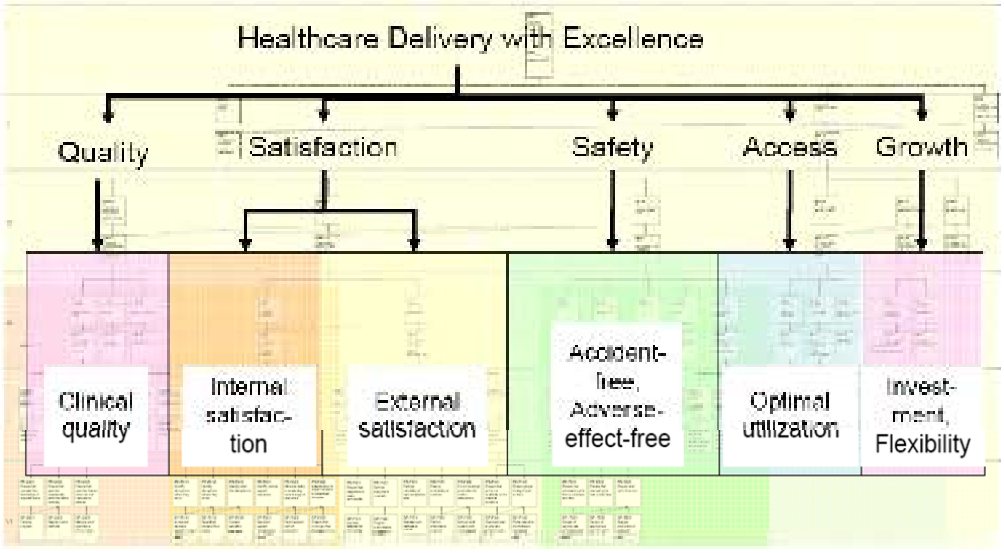
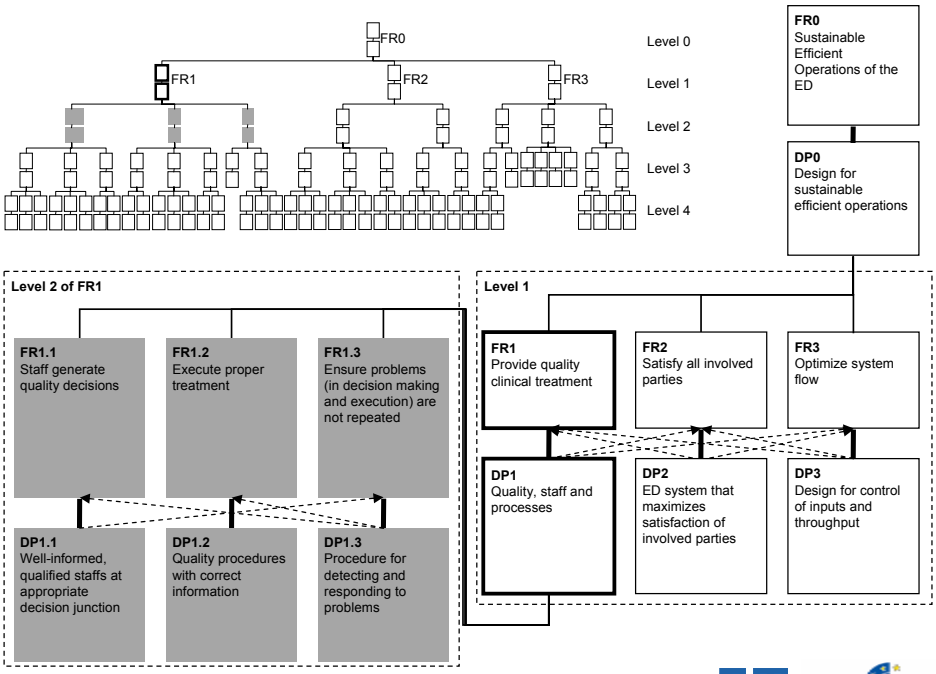
Early Top Level Functional Requirements



Decomposition Structure of ED^3



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ED^3 Matrix (two levels)

Functional Requirements (FRs) \ Design Parameters (DPs)	0 Design for Sustainable Efficient operation	1 Quality, Staff and Processes	1.1 Quality medical decision making Staff with correct	1.2 Quality Procedures with correct information	1.3 Feedback/review mechanism (e.g. on-the-spot)	2 ED design and opperoration includes Satisfaction Providers	2.1 Make staff satisfaction providers available	2.2 Swift visit with convenient access to objects of physical	3 Design for control of inputs and throughput	3.1 Attractive facilities with patient acceptance controls	3.2 LOS time reductions	3.3 Procedures for moving patients
0 Sustainable Efficient Operations of the ED	X											
1 Provide quality clinical treatment		X				X	0	0	X	0	0	0
1.1 Staff generate quality decisions			X		X	0	X	0	0	0	X	0
1.2 Staff Implement proper treatment				X	X	0	0	0	0	0	X	0
1.3 Ensure problems are fixed			X	0	X	0	0	0	0	0	0	0
2 Satisfy all involved parties		X	0	0	0	X			X	0	0	0
2.1 Maintain satisfaction of all internal parties		0	X	X	X		X	0	0	X	X	0
2.2 Satisfy patients and guests		0	X	X	0		0	X	0	X	X	0
3 Optimize System Flow		X	0	0	0	X	0	0	X			
3.1 Manage Inputs		0	0	0	0	0	0	X		X	0	0
3.2 Meet target LOS		0	0	X	0	0	0	0		0	X	X
3.3 Manage Output		0	0	0	0	0	0	0		0	0	X

Agenda

- ✓ Introduction
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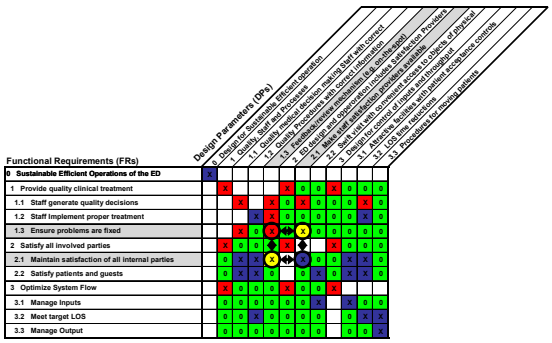
Coupling of FR1.3 Quality Improvement vs. FR2.1 Staff Satisfaction

Functional Requirements (FRs) \ Design Parameters (DPs)	0 Design for Sustainable Efficient operation	1 Quality, Staff and Processes	1.1 Quality medical decision making Staff with correct	1.2 Quality Procedures with correct information	1.3 Feedback/review mechanism (e.g. on-the-spot)	2 ED design and opperoration includes Satisfaction Providers	2.1 Make staff satisfaction providers available	2.2 Swift visit with convenient access to objects of physical	3 Design for control of inputs and throughput	3.1 Attractive facilities with patient acceptance controls	3.2 LOS time reductions	3.3 Procedures for moving patients
0 Sustainable Efficient Operations of the ED	X											
1 Provide quality clinical treatment		X				X	0	0	X	0	0	0
1.1 Staff generate quality decisions			X		X	0	X	0	0	0	X	0
1.2 Staff Implement proper treatment				X	X	0	0	0	0	0	X	0
1.3 Ensure problems are fixed			X	0	X	↔	X	0	0	0	0	0
2 Satisfy all involved parties		X	0	0	↕	X	↕		X	0	0	0
2.1 Maintain satisfaction of all internal parties		0	X	X	X	↔	X	0	0	X	X	0
2.2 Satisfy patients and guests		0	X	X	0		0	X	0	X	X	0
3 Optimize System Flow		X	0	0	0	X	0	0	X			
3.1 Manage Inputs		0	0	0	0	0	0	X		X	0	0
3.2 Meet target LOS		0	0	X	0	0	0	0		0	X	X
3.3 Manage Output		0	0	0	0	0	0	0		0	0	X

Analysis of the Coupling of Quality Improvement and Staff Satisfaction



- Mistakes in medical treatment and decisions do happen
- Sometimes the mistakes lead to severe effects
- Staff is afraid of being punished and might prefer to not report an incident
- Learning from mistakes needs proper intelligence

➢ E.g. instantly and honestly reported single mistakes are not being punished

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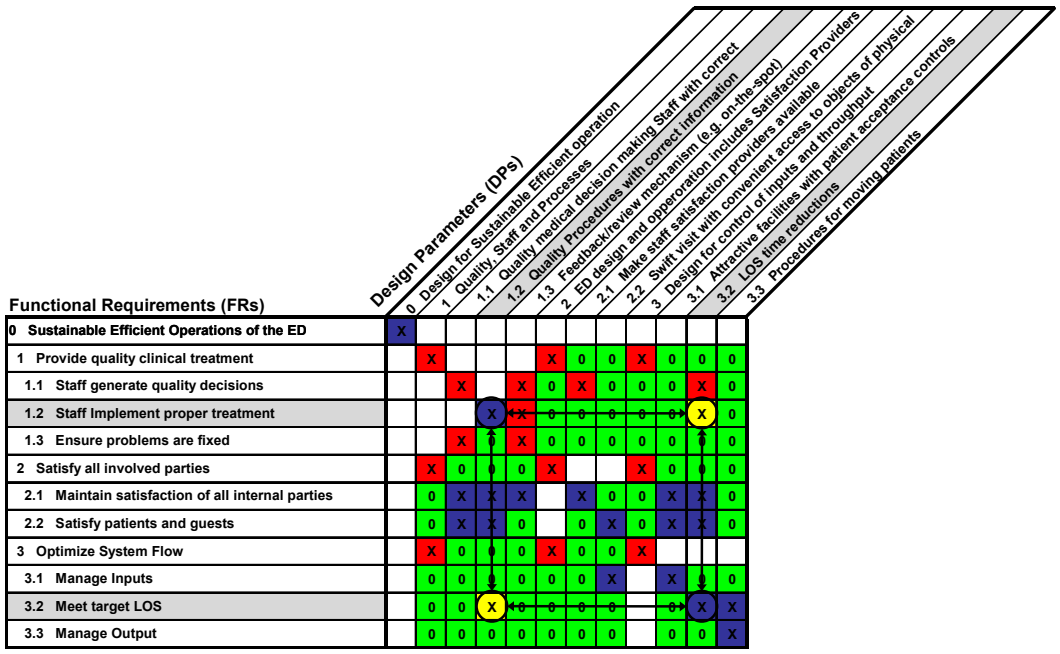
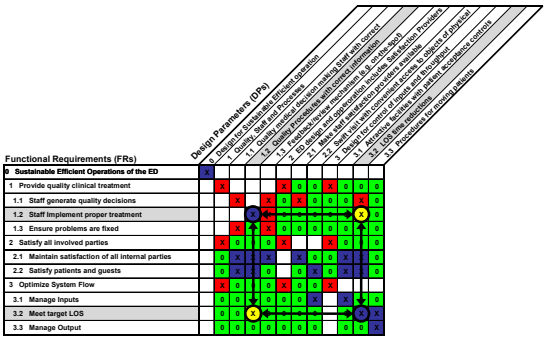
Coupling of FR1.2 Treatment Quality vs. FR3.2 Throughput



Analysis of the Coupling of Treatment Quality and Throughput



- Underlying system constraints
  - not harming patients demands for an increase of quality
  - limited monetary spending asks for reducing process times
  - ➢ Dichotomy
  - Severe situation of ED crowding being caused by the associated hospital
  - ➢ Research focus on a ‘smart’ solution for this coupling

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Conclusion and Future Research

Conclusion

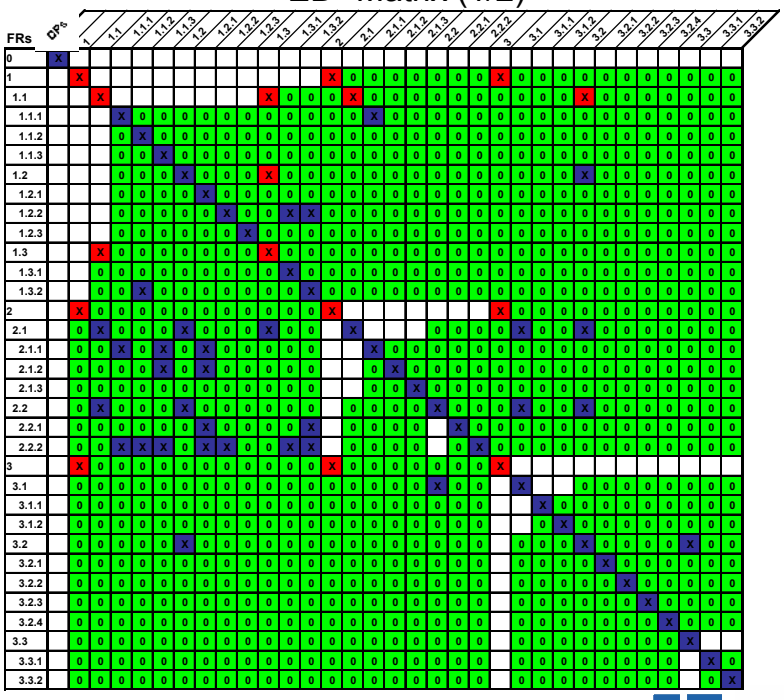
- The ED³ captures the Emergency Department in a clear way
- Showcase for applying AD to socio-economic systems
- Thereby it has the potential to significantly support
  - the communication about ED for any stakeholder,
  - highlighting the issues of single EDs when being compared to the ideal ED³, and
  - to anchor efforts to improve single EDs.

Future research

- Applying the ED³ for ED improvement projects
- Analyzing the system inherent couplings with respect to smart trade offs

Appendix

ED³ Matrix (1/2)



ED^3 Matrix (2/2)

No.	Functional Requirement	Design Parameter
0	Sustainable Efficient Operations of the ED	Design for Sustainable Efficient operation
1	Provide quality clinical treatment (decisions and implementations)	Quality, Staff and Processes
1.1	Staff generate quality decisions	Quality medical decision making Staff with correct
1.1.1	Maintenance of Staff commpetent at making decisions	Acquiring intelligent staff and continued education
1.1.2	Timely dissemination of accurate patient information	Clear Patient Information distribution system
1.1.3	Maintain functionality and access to testing facilities	Facility Maintenance and Design Planning
1.2	Staff Implement proper treatment	Quality Procedures with correct information
1.2.1	Accurate response to decisions	Attentive Staff with clear responsibilities
1.2.2	Timely dissemination of decisions	Decision Information distribution system
1.2.3	Maintain Functionality and access to treatment facilities	Maintenance and planning
1.3	Ensure problems are fixed through feedback/review	Feedback/review mechanism (e.g. on-the-spot)
1.3.1	Communication is encouraged	Communication tools and guidelines
1.3.2	Communication skills are developed	Training evaluation
2	Satisfy all involved parties	ED design for satisfied providers
2.1	Maintain satisfaction of all internal parties	Make staff satisfaction providers available
2.1.1	Employees are given competitive salaries/compensation	Pay employees based on workload and education
2.1.2	Distribute the employee work load evenly	Balanced Time Schedules
2.1.3	Hospital Success creates employee satisfaction	Promote feeling of ownership (autonomy)
2.2	Satisfy patients and guests	Swift visit with convenient access to objects of physical
2.2.1	Comfort of patients and support is provided	Objects of physical and mental comfort
2.2.2	Patients less aware of non action time (wait time)	Design for less noticible wait time
3	Optimize System Flow	Design for control of inputs and throughput
3.1	Manage Inputs	Attractive facilities with patient acceptance controls
3.1.1	Known Attractiveness of hospital to potential patients is maintained	Quality of Hospital and advertisement
3.1.2	Ability to divert patients to facilities that can accept them immediately	Ambulance diversion
3.2	Meet target LOS	LOS time reductions
3.2.1	Reduce Process delay	Process designed for quickness
3.2.2	Reduce Transportation delay	Patient flow oriented layout
3.2.3	Reduce systematic operational delays (A Balance between medical	System design to avoid interuptions
3.2.4	Reduce delays due to external entitees	Design to compensate for transfer problems and testing
3.3	Manage Output	Procedures for moving patients
3.3.1	Provide for further treatment outside of ED quickly	Admit to hospital
3.3.2	Remove patients that will not be admitted to hospital as soon as possible	ED discharge

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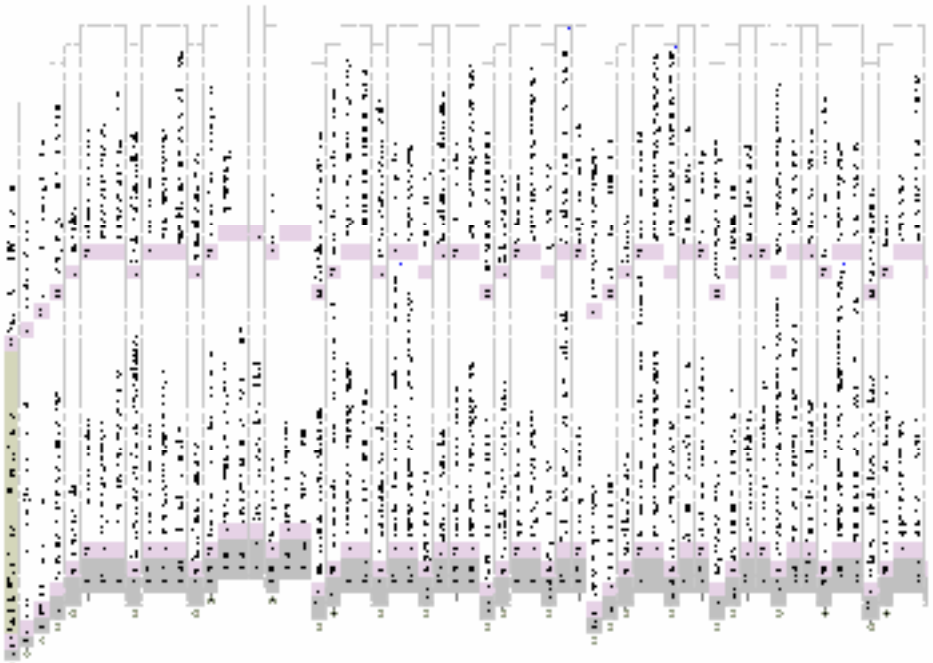
Functional Requirement and Design Parameter Decomposition (1/3)



Functional Requirement and Design Parameter Decomposition (2/3)

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Functional Requirement and Design Parameter Decomposition (3/3)