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HFMEA-Fuzzy Model for Lean Waste Assessment in Health Care Units: Proposal and utilization cases

Harvey Cosenza¹[0000-0002-9291-2167], Nilra Silva¹[0000-0002-8276-5669], Olavo Neto²[0000-0001-6986-5369], Luis Torres³[0000-0002-5879-9455] and Robisom Calado¹[0000-0003-3349-0344]

1 Federal Fluminense University RJ, BR

harveycosenza@gmail.com

2 Ministry of Health – Secretariat of Specialized Health Care – Department of Hospital, Home and Emergency Care DF, BR

3 Campinas State University SP, BR

Abstract. The management of risks and failures in health systems is considered one of the most efficient solutions for providing care to patients. In practice, this activity also makes it possible to join new corporate opportunities, because it allows preventive measures resulting from social, scientific, and technological developments to be constantly evolving throughout the organization. The aim of the article is to present an application of the failure modes and their health effects analysis model (HFMEA) integrated with Fuzzy logic in three Emergency Care Units (UPAs) in Brazil. This mapping model analyzes and analyzes how failures occurred in the supply chain of UPAs. The methodology used included dividing the study into 4 stages, which were used to prepare the proposed model through the evaluation of failure modes integrated with Fuzzy logic. This work reports as one of the roots of the problems in the studied UPAs: the predominance of processing and creativity waste. These, associated with the factor Management and Leadership for a Lean environment, demonstrate that failures in leadership are linked to the dissatisfaction of management support professionals. In addition, a hierarchical analysis of the failure probabilities and evaluation of the eight Lean wastes found in the UPAs was presented.

Keywords: HFMEA-Fuzzy, Wastes, Lean Healthcare.

1 Introduction

Concern for patient safety has become a priority issue in recent decades. The methods and tools to carry out the exploration of risks that currently exist have been used extensively by industries, for example, aeronautics and nuclear. These have a complexity like that of health, where people and processes are exposed to human and technological failures, etc. The Failure Modes Analysis and Health Effects - HFMEA is one of the most used methods, being the best approach currently available, as mentioned by The Joint Commission [1] to map the steps of a process, identify possible failures

and their causes, and recommending measures to prevent failures and/or eliminate unnecessary risks and damages associated with health care. The Fuzzy linguistic model, on the other hand, consists of a tool capable of capturing vague and imprecise information, usually described in a natural language, and converting it to a numerical format, such as "high", "low" or "medium" enabling a more accurate and reliable interpretation. Its main objective is the computational modeling of human reasoning, imprecise, ambiguous, and vague. Therefore, it has been used as a strategy to support decision making for problems in the health area, using linguistic variables and the degrees of relevance that assume, respectively, the attributes and weights for the evaluation of each attributed factor, in order of importance.

Despite the advances already achieved, the following gap has not yet been filled: how to quantify a more accurate and reliable assessment of the probability of failures in emergency care units? As this problem involves failure mode analysis in the presence of qualitative variables that cannot be measured by binary evaluation mechanisms, this work proposes an unprecedented model.

The objective of this article is to present an integration model of HFMEA and Fuzzy logic to evaluate the eight lean wastes in three Emergency Care Units (UPAs) in Brazil, located in the municipality of Parque Vitória in Maranhão, Franco da Rocha in São Paulo and Trindade in Goiás. Therefore, the information used was collected through the internal reports of each UPA. This model proposed for failure analysis was specifically developed for this study, allowing the organization and assessment of the types of losses that do not add value to activities or processes considered important in UPAs. Thus, the data from this research show that the quality improvement processes are at different levels of maturity in the studied UPAs.

Therefore, this model is formulated to achieve the following secondary objectives:

- Classification of waste probabilities.
- Evaluation of the eight wastes found in the UPAs.
- Presentation of the predominant waste in the 3 UPAs.

2 Theoretical Framework

2.1 The 8 Lean Wastes

Lean mindset consists in continually reducing waste from activities that add value [2]. The waste or loss is capable of affecting what truly matters: the safety and quality of patient care. Therefore, a brief description the waste that can be found in the health care system: 1.Overproduction: Excessive monitoring of low-urgency patients, large number of patient visits, etc; 2.Defects: Wrong handling of medications, carrying out tests inappropriately and mistaken discharge of patients; 3.Waiting: Delays in attending in-coming patients, delays in collection and test results, delay in patient discharge, unavailability of resources, delay in accessing systems, etc; 4.Transportation: Medicines and materials moved unnecessarily; 5.Creativity/ Unused talent: Misuse of professionals' skills; 6.Overprocessing: Doublechecking the same process and asking the same questions consecutively; 7.Inventory: Ineffective distribution/allocation of mate-

rials, medicines and downtime information and 8.Motion: Long journey to be made by patients, employees and medical staff. Therefore, this visualization allows health organizations to observe the specific failures that generate waste.

2.2 HFMEA

The Healthcare Failure Mode Effect Analysis (HFMEA) is a prospective risk assessment tool that adopts measures aimed to prevent or avoid failures. Therefore, it is used in healthcare environments to map, evaluate, control and review the information of risk-generating processes in further detail. The steps for implementing the HFMEA are defining the topic to be analyzed; assembling a multidisciplinary team; describing the process and performing a risk assessment so as to identify possible failure modes, root causes and effects of failures. Thus, estimating the probability of occurrence, severity and failure detection determine the priorities and define action plans towards achieving the expected results aimed to reduce risks [3].

2.3 Fuzzy Logic

Fuzzy sets consist of a theory in which everything is graduated, that is, between the certainty of being and the certainty of not being, there are infinite degrees of uncertainty. In 1965, Zadeh [5] published an article on Fuzzy Sets that led to a series of studies on applications of fuzzy systems. Therefore, more objectively, Fuzzy Sets are, if necessary, better suited to dealing with information imperfections than probability theory. Therefore, the transition between belonging or not to a set is gradual, that is, it is not abrupt. An element can belong to more than one fuzzy set with different degrees of association. Association functions can be defined from the user's experience and perspective, but it is common to use standard association functions such as triangular, trapezoidal, and Gaussian functions.

The membership functions $\mu_{R_{ij}}(r_{ij})$ and $\mu_{w_j}(w_j)$ are assumed to be in the range of [0, 1]. All fuzzy sets are considered normalized, i.e., they have finite supports and assume the value of 1 at least once. For the evaluation of an X_j environment, a fuzzy set is assumed which is computed on the bases of r_{ij} and w_j , where vector $z = (w_1, w_2, \dots, w_m, r_1, r_2, \dots, r_n)$.

$$f(z) = \frac{\sum_{j=1}^m w_j r_j}{\sum_{j=1}^m w_j}$$

The membership function for weighted degrees is given by: $\mu_{\tilde{R}_i}(\bar{r}_i) = \sup \mu_{z_i}(z) \quad \bar{r}_i \in R; Z: (z) = \bar{r}_i$. The normalized value \bar{r}_i for alternative i is given by:

$$\bar{r}_i = \frac{\sum_{j=1}^m w_j r_{ij}}{\sum_{j=1}^m w_j}$$

If the final degrees are *crisp values*, r_1, r_2, \dots, r_n , then:

$$p_i = \bar{r}_i - \frac{1}{n-1} \sum_{j=1}^m \bar{r}_j.$$

Once r_{ij} 's and w_j 's are fuzzy variables and p_i is also a *fuzzy* variable with membership function $\mu_{p_i}(p) = \sup_{\bar{r}} \mu_{\bar{r}}(\bar{r}_1, \bar{r}_2, \dots, \bar{r}_n) \mid p_i \in R; \bar{r}_1, \bar{r}_2, \dots, \bar{r}_n: \mu_{\bar{r}_i}(\bar{r}_1, \bar{r}_2, \dots, \bar{r}_n) = p_i$.

3 Methods and Data

The stages comprise: 1. Theoretical Framework: mapping the research topics in the context of available literature and providing theoretical support; 2. Data analysis: document analysis of reports received from the Emergency Care Units; 3. Data Treatment: considerations used for elaborating the proposed modeling through an analysis of failure modes HFMEA and fuzzy logic; 4. Results: the effects of aligning the proposed objectives. It is worth mentioning that the quantitative data offered herein have been collected from the internal diagnoses of each UPA, which have used a maturity scorecard to find what was the probability of occurrence of good management practices, important points that should be addressed so that there was quality management in throughout processes.

Table 1. Characterization of the degree of importance.

Xi	Degree of importance
1	Very Important
0,8	Important
0,6	Relatively Important
0,4	Slightly Important
0,2	No Importance

The first stage consists in characterizing the importance of factor in linguistic terms. The second stage was to recruit trained and experienced Lean professionals, out of which 5 specialists were invited to assess the degree of importance of the 8 wastes that were listed on a scale of 0.2 to 1 (Table 1), i.e., those that the specialists believed to be more important.

3.1 Supply Matrix Compilation

A Supply Matrix was compiled for each of the three UPAs based on the analysis performed as regards occurrence, severity and detection following the linguistic terms of the HFMEA. Probability of Occurrence: What is the probability of this type of failure to occur? a) Very High: up to one missed score; b) High: between 1 and 3 missed scores; c) Average: between 4 and 5 missed scores; d) Low: between 6 and 7 missed scores; and e) Very Low: all scores were missed. Severity: if the failure occurs, what damage can be inflicted? a) Very Little: failure will have little noticeable effect on discontent patients and/or professionals; b) Little: slight deterioration in performance with slight discontent from patients and/or professionals; c) Average: significant deterioration in performance of a system with patient and/or professional discontent; d) High: system stops working and there is great discontent from patients and/or professionals and e) Very High: same as the above, however. It affects/compromises the safety of patients and/or professionals. Detection: If failure occurs, what is the chance of being detected? a) Almost Certain; b) Alta High; c) Moderate; d) Remote; and e) Nearly impossible.

3.2 Demand Matrix Compilation

A Demand Matrix was also compiled based on the opinion of specialists. Grades were assigned to the degrees of membership by considering each of the 5 factors (Table 2) in order of importance. The result consisted in relating the factors of diagnoses received from each UPA to the Lean wastes associated according to their characteristics.

Table 2. Factors and degrees of membership of the Demand Matrix.

Demand matrix	Degrees of membership				
Factors	VI	I	RI	SI	NI
1. Management and Leadership in a Lean environment	0.67	1	0	0	0
2. Adherence to communication and interaction among staff members	1	1	0.50	0	0
3. Management through indicators	0.67	1	0	0	0
4. Physical and technological infrastructure	1	1	0	0.50	0
5. Clear and well-defined processes	1	0.67	0	0	0

3.3 Cross-checking of Data from Supply and Demand Matrices

Table 3 represents the cross-checking of data from the demand (Table 2) and supply matrices which allows observing the HFMEA failure analyzes according to occurrence, severity and detection criteria. The cross-evaluation form divides the set into 5 subsets, respecting proportionality.

Table 3. HFMEA of Supply and Demand Matrices

Demand X Supply (Occurrence, Severity and Detection)					
	Supply				
Demand	Very Low	Low	Average	High	Very High
Very Important	1	1-1/N	1-2/N	1-3/N	1-4/N
Important	1+1/N	1	1-1/N	1-2/N	1-3/N
Relatively Important	1+2/N	1+1/N	1	1-1/N	1-2/N
Slightly Important	1+3/N	1+2/N	1+1/N	1	1-1/N
No Importance	1+4/N	1+3/N	1+2/N	1+1/N	1
N = 5					
Demand X Supply – Occurrence					
	Supply				
Demand	Very Low	Low	Average	High	Very High
Very Important	1	0,80	0,60	0,40	0,20
Important	1,20	1	0,80	0,60	0,40
Relatively Important	1,40	1,20	1	0,80	0,60
Slightly Important	1,60	1,40	1,20	1	0,80
No Importance	1,80	1,60	1,40	1,20	1
N = 5					
Demand X Supply – Severity					
	Supply				
Demand	Very Low	Low	Average	High	Very High
Very Important	1	0,80	0,60	0,40	0,20
Important	1,20	1	0,80	0,60	0,40
Relatively Important	1,40	1,20	1	0,80	0,60
Slightly Important	1,60	1,40	1,20	1	0,80
No Importance	1,80	1,60	1,40	1,20	1
N = 5					
Demand X Supply – Detecion					
	Supply				
Demand	Almost Certain	High	Mod-erate	Re-mote	Nearly Impossible
Very Important	1	0,80	0,60	0,40	0,20
Important	1,20	1	0,80	0,60	0,40
Relatively Important	1,40	1,20	1	0,80	0,60
Slightly Important	1,60	1,40	1,20	1	0,80
No Importance	1,80	1,60	1,40	1,20	1
N = 5					

4 Result and Discussion

4.1 Ranking waste probabilities

The results shown throughout this section are based on Table 4 - Evaluation of expectations from data summarized in Table 3. It is worth mentioning that the present arguments are based on an Average - Fuzzy Index. Where, 1 - fully meets the expectation; close to 1 - slightly meets expectations and above 1 - exceeds expectations.

Table 4. Evaluation of expectations.

Demand x Supply Matrices Results									
Factors	Parque Vitória - MA			Franco da Rocha - SP			Trindade - GO		
	O	S	D	O	S	D	O	S	D
Management and Leadership in a Lean environment	0,8	0,8	1,2	0,8	0,8	1	0,6	0,8	1,2
Adherence to communication and interaction among staff members	0,4	0,6	1	0,4	0,8	1	0,4	0,6	0,8
Management through indicators	0,4	0,8	1	0,6	0,8	1,2	0,4	0,8	1,2
Physical and technological structure	0,6	0,4	1	0,6	0,6	0,8	0,6	0,6	0,8
Clear and well-defined processes	0,4	0,6	1	0,4	0,6	0,8	0,8	0,6	1
Total - Fuzzy Index	2,6	3,2	5,2	2,8	3,6	4,8	2,8	3,4	5
Average - Fuzzy Index	0,52	0,64	1,04	0,56	0,72	0,96	0,56	0,68	1

It is found that UPAs of Trindade - GO and Franco da Rocha - SP are the most sensitive in terms of occurrence, i.e., 56%, to failures concerning the 5 factors and/or precursors of waste; as for severity, the Franco da Rocha - SP UPA has a 72% chance of the generated damage, thus disrupting and impacting the whole system of the unit and, finally, the detection criterion in the Parque Vitória - MA UPA has over 100% chances of being detected. In short, the rankings of HFMEA criteria as to occurrence, severity and detection rates provided the possibility of failures in relation to how often, how, and when they can occur, so that there are preventive measures to combat waste.

4.2 Assessment of 8 Lean wastes found in the UPAs

The assessment of the eight Lean wastes was correlated with situations found in the UPAs. This analysis allows assessing whether failures described in UPAs are the causes of the wastes found. Table 5 reports the causes, modes and effects of presented failures. Caption: Causes of failure: Why would the failure occur? Failure mode: What can go wrong? Effects of failure: What would be the consequences of failure?

Table 5. Cause, mode and effect of wastes.

Cause of Failure	Mode of Failure (Waste)	Effect of Failure
Lean Management/Leadership	Over-processing/Creativity	Dissatisfaction with Leadership support
Adherence to communication and interaction among staff members	Defects	Failure of staff communication and interaction
Management through indicators	Waiting/Inventory	Lack of management through indicators
Physical and technological infrastructure	Overproduction	Failure in physical and technological structure
Clear and well-defined processes	Transport/Motion	Lack of Clear and well-defined processes

Therefore, relating Lean Management/leadership to the waste of over-processing and creativity is affected by presenting redundant or unnecessary steps in processes from the perspective of professionals and/or the patient, and it does not involve the perceptions of professionals about the identification and resolution of the problems which they deal with daily; relating adherence to communication and interaction among staff members to the waste of defects demonstrates the need to redo something due to incorrect or incomplete information, i.e. poor communication due to the fact that meetings for staff alignment do not exist or are inefficient. In addition, ranking Management through indicators of the wastes of waiting and inventory refers to demonstrating that waiting time is mostly associated with failures by some of the teams responsible for a part of the process, information that does not flow, and being unnecessarily stuck in the middle of the process; ranking the physical and technological structure with the waste of overproduction represents the losses derived from waiting for the process due to the lack of organization, quality and efficiency of the health environment. It is also due to loss of medication in addition to what was requested and/or surplus of products due to waiting for their moment of use in certain stages of the production process. In addition, relating clear and well-defined processes to the wastes of transport and motion represents demonstrating the loss of transporting products, medications and patients from one place to another unnecessarily. Therefore, this mapping allowed describing and analyzing the failures occurring in the supply chain of the UPAs, which are the causes of the wastes found. Observing these wastes is going to make it possible to eliminate what does not add value to the user/patient and all professionals involved from the processes.

4.3 Presentation of the predominant waste at the 3 UPAs

The HFMEA allows calculating the Risk Priority Number – RPN, indicator which is a product ($O \times S \times D$) to the three items: occurrence, severity and detection, which allows prioritizing the worst failures. Table 6 shows a quantitative visualization of the highest RPN values for the UPAs in Parque Vitória – MA, 0.77; Franco da Rocha – SP, 0.64, and Trindade – GO, 0.58, in which it was commonly found the element of Management and Leadership in a Lean environment, which is related to the waste of processing and creativity. The effect exerted by these wastes is dissatisfaction with leadership support. For this reason, although UPAs have different difficulties, however, they have the predominance of the same waste in common.

Table 6. Fuzzy HFMEA of UPAs waste.

Results of Demand X Supply Matrices												
	Parque Vitória - MA				Franco da Rocha - SP				Trindade - GO			
Factors	O	S	D	CPR	O	S	D	CPR	O	S	D	CPR
Lean Management/Leadership	0,8	0,8	1,2	0,77	0,8	0,8	1	0,64	0,6	0,8	1,2	0,58
Adherence to communication and interaction among staff members	0,4	0,6	1	0,24	0,4	0,8	1	0,32	0,4	0,6	0,8	0,19
Management through indicators	0,4	0,8	1	0,32	0,6	0,8	1,2	0,58	0,4	0,8	1,2	0,38
Physical and technological infrastructure	0,6	0,4	1	0,24	0,6	0,6	0,8	0,29	0,6	0,6	0,8	0,29
Clear and well-defined processes	0,4	0,6	1	0,24	0,4	0,6	0,8	0,19	0,8	0,6	1	0,48

The waste of creativity corresponds to a misuse of human talent. Not fully using people's capacity is associated with the current culture of Emergency Care Units (UPAs), therefore, it is necessary to improve health services seeking to better learn management and leadership tools and practices so that there is a reduction in the chances of error in management, information, activities, people, materials, among other actions.

5 Conclusion

The purpose of this article was to present an integration model of HFMEA and Fuzzy logic to evaluate the eight Lean waste in three Emergency Care Units (UPAs) in Brazil, located in the municipality of Parque Vitória in Maranhão, Franco da Rocha in São Paulo and Trindade in Goiás. Thus, three secondary objectives were achieved: classification of waste probabilities; evaluation of the eight waste found in the UPAs; and presentation of the predominant waste in the UPAs under analysis. This mapping

allowed us to describe and analyze the failures that occurred in the supply chain of the UPAs, capable of eliminating what does not add value to the user/patient and to all professionals involved in the processes. The HFMEA/Fuzzy analysis quantitatively showed that among the eight wastes, the main ones among the UPAs were processing and creativity, which was associated with the generators factor of Lean Management and Leadership. The spread of the effect of these wastes generates dissatisfaction with leadership support. Therefore, although UPAs experience different difficulties, however, they have the predominance of the same waste in common. In short, a new lean culture must be fostered in the three UPAs used as the object of study so as to achieve efficient management. The application of HFMEA/Fuzzy model allowed identifying the failure modes belonging to the system in question through the eight wastes presented. However, the entire management team must be committed to experiencing a collaborative environment with the other professionals in their work units in such a way as to target continuous improvement. This work provides knowledge that points out the need of developing new studies and research focusing on the Health Safety Leadership and Management errors, as the main gap to be filled by future work. Thus, measures can be taken on time so as to ensure continuity of improvement within the organization, which is going to allow the implementation and improvement of patient safety practices based on strategies to prevent failures for maximum reduction and/or elimination of unnecessary risks and damages associated with health care.

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