JOURNAL OF MARITIME RESEARCH

Vol. X. No. 2 (2013), pp. 43 - 50

ISSN: 1697-4040, www.jmr.unican.es

Failure Mode and Effects Analysis (FMEA) for Reducing the Delays of Cargo Handling Operations in Marine Bulk Terminals

J. Sayareh[1,2,*] and V. R. Ahouei[1,3]

ARTICLE INFO

Article history:
Received 18 March 2013;
in revised form 28 March 2013;
accepted 08 June 2013

Keywords:
Failure Mode and Effect Analysis (FMEA), Cargo Handling Operation, Bulk Terminals, Cause and Effect Diagram, Pareto Analysis.

ABSTRACT

So far as dry bulk cargoes are concerned, million tones of different varieties of these cargoes being moved and handled in marine bulk terminals around the world every day. Undoubtedly, this massive movement can impose serious cargo handling issues for dry bulk terminals in seaport. The problems associated with handling of dry bulk cargo in marine terminals can be in terms of both infrastructure and superstructure.

This research attempts to use a combination method comprising Failure Mode and Effect Analysis (FMEA) in conjunction with the Cause and Effect Diagram and Pareto Analysis to firstly reduce the delays in cargo handling operations, and secondly to smooth the loading/unloading activities in marine bulk terminals.

To achieve these objectives, this paper also aims to initially surface the major factors causing delays in cargo handling operation by focusing on the quantification of risk assessment through determining the Risk Priority Numbers (RPN) per identified processing of cargo handling operation, and then suggest solutions to resolve the problems.

1. Introduction

Over the last decade, global economic developments have had an increasing influence on supply and demand trend in the dry bulk market. This increase has impacted on the shipping industry, dry cargo handling, bulk terminal operations and transportation industries (Schott and Lodewijks, 2007).

Capacity of dry bulk terminals generally depends on the number of berths available to ship traffic and cargo handling capacity. Occurring some natural phenomena such as heavy rains, stochastic changes in water and land transport, failure in the progress of loading/unloading mechanisation and other involved equipment (Bugaric and Petrovic, 2007), weak cooperation of ship's crew with port operators, weak documentations, wrong cargo stowage and problems with labours can be regarded as factors which affect the cargo handling capacity negatively.

Several reliability engineering approaches have been proposed to identify and recover from failures. A well-known and mature approach is the FMEA (Sozer et al., 2007), which was originally designed to address safety concerns. However, FMEA is now used throughout the industry to prevent a wide range of process and product problems and thereby making the system robust (Ookalkar et al., 2009).

This paper employs a novel model, based on the FMEA in conjunction with the Cause and Effect Diagram, aiming to assist marine bulk terminal operators in reduction of delays in cargo handling operations, and smoothing their loading/unloading activities.

To date, no study has adequately examined the philosophy of FMEA in marine bulk terminals as a decision-making optimisation tool at strategic/operational levels. The challenging issues inherent this problem, and the limitation of existing research, robustly motivates this study.

For the first time in the literature, this research provides a novel decision-making framework for port operators to smoothing the bulk terminal's cargo handling activities and reducing the delays inherent it.

2. FMEA

FMEA is known as a systematic procedure for the analysis of a system to identify the potential failure modes, their causes and effects on system performance. It is vitally important to

[1] Chabahar Maritime University, Daneshgah Avenue, 9971756499, Chabahar, Iran.
[2] Assistant Professor, Email: J.Sayareh@gmail.com, Tel +989151954755, Fax +985452223304.
[3] Lecturer, Email: vrahouei@gmail.com, Tel +989124741960, Fax +985452223304.
[*] Corresponding author.

know that a failure mode is not the cause of a failure, but the way in which a failure has occurred (Hoseynabadi et al., 2010).

Conducting a FMEA, the reviewed product/process/service/system is normally broken down into smaller items/subsystems. For each item, the following seven steps are performed:

1. Define the item being analysed.
2. Define the functions of the item being analysed.
3. Identify all potential failure modes for the item.
4. Determine the causes of each potential failure mode.
5. Identify the effects of each potential failure mode without consideration of current control.
6. Identify and list the current controls for each potential failure mode.
7. Determine the most appropriate corrective actions and recommendations based on the analysis of risk.

After going through all the items for each failure, a rating for severity, occurrence and detection are assigned. Severity, in this context, refers to the magnitude of the end effect of a system failure. Similarly, occurrence refers to the frequency that a root cause is likely to occur, described in a qualitative way. Finally, detection refers to the probability of detecting a root cause before a failure can occur (Hoseynabadi et al., 2010). The severity, occurrence and detection factors are rated using a numerical scale, typically ranging from 1 to 10.

After these steps, the RPN should be determined for prioritising the recommendations. The severity rating should be based on the worst effect of the potential failure mode. The RPN is the product of the failure mode severity, failure cause probability, and control detection effectiveness ratings.

3. Case study

The objective of this research is the reduction of delays in cargo work operation, loading/unloading operation in both the quayside and landside, in the dry bulk terminal of port of Imam Khomeini (BIK); the main Iranian marine bulk terminal.

Among Iranians commercial ports, BIK with its 11 million square meters area is one of the largest and leading port complexes of the country, particularly being active in bulk operation. The port handles the largest quantity of bulk cargo (in terms of import and export) amongst all Iranian commercial seaports. Statistics indicate that almost half of the country's non-oil exports are transported via this port annually.

4. Data analysis

When applying the FMEA, a cross-functional and multidisciplinary team identifies failure modes, evaluates their risks and prioritises them so that appropriate corrective actions can be taken (Chin et al., 2009). Following steps have been perused solutions for removing delays by empirical analysis methods.

4.1 Definition of Process

Dry bulk terminals are transshipment and transport systems, consisting of different subsystems that enable a division of functions according to place, time, personnel and means (Schott and Lodewijks, 2007).

Definition of process and data analysis was conducted in a workshop with operational managers of the BIK, wherein the analysis was based on the annual BIK reports gathered from July 2009 to July 2010.

4.2 Definition of Components Functions

Like all marine bulk terminals, the case study has the following three main components:

— Port: must be fit to load and discharge vessels, at all times, whenever they are berthed.
— Ship: must be fit to receive or deliver cargoes from/to the port.
— Cargo owner: must be fit to receive or deliver cargoes from/to vessels throughout the port, after completing all the port and custom formalities.

4.3 Identify all Failure Modes

Failure modes are conditions which each of components could not be fit with their tasks and thus operation is stopped or performed slowly (less than standard norms), and cause delays in cargo handling process.

4.4 Determining the Causes of each Failure Mode by Cause and Effect Diagram

Cause and effect diagram is an analysis tool that provides a systematic way of looking at the effects and at the causes that create or contribute to those effects (Kumar, 2006). The cause and effect diagram is used to explore all the potential or real causes that results in a single effect (Arvanitoyannis and Varzakas, 2009).

As shown in Figure 1, causes are arranged according to their level of importance or detail, resulting in a description of relationships and hierarchy of events.

As illustrated in the Figure, there are four main factors which cause delays in cargo handling operations in the BIK, including:

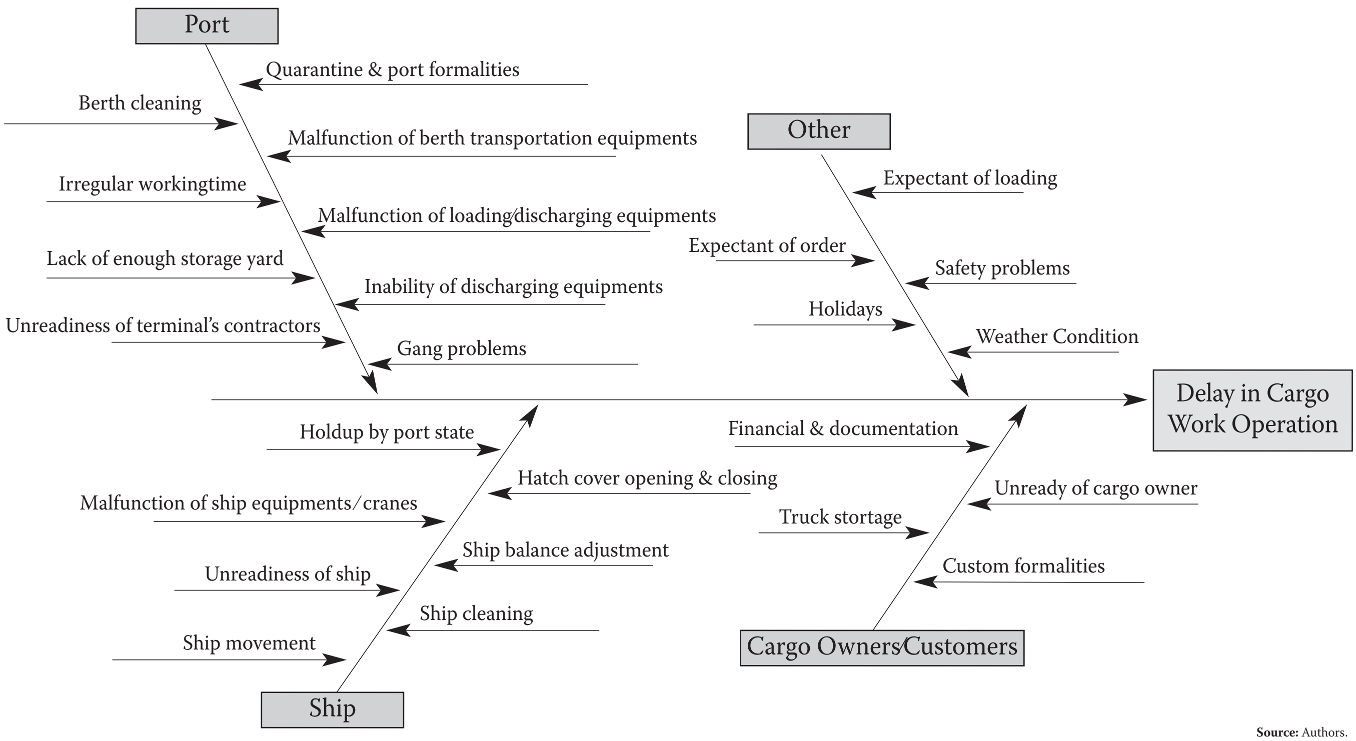
— Customers and cargo owners,
— Port and its operators,
— Ships, and
— Others.

Obviously, each of these factors has its own sub-factors which will be discussed in the next sections.

4.5 Identification of the Effects of each Failure Mode

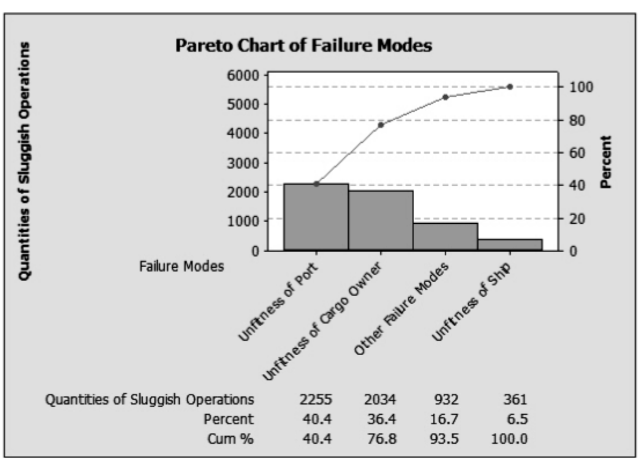
Pause in cargo handling operation and sluggish process are effects of failure modes; usually named delays. Pareto analysis is the process of ranking opportunities to determine which of many opportunities should be pursued first. It is also known as separating the vital few from the trivial many (Pyzdek, 2003). Pareto analysis is exploited to find what types of failure modes are effective.

Figure 1: Cause and effect diagram for the BIK problem.



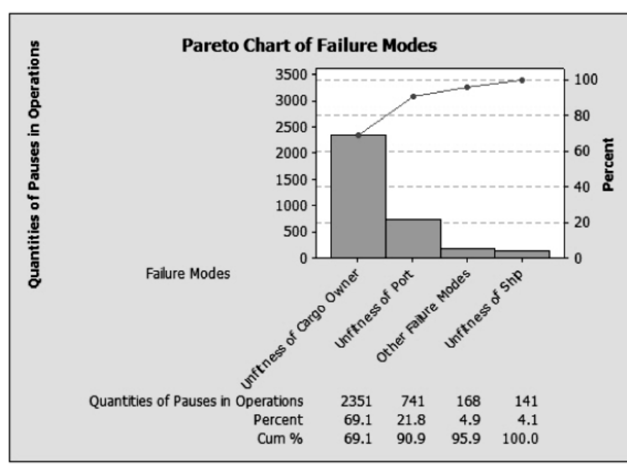
Source: Authors.

Figure 2: Pareto chart of failure modes and their roles at sluggish operation.



Source: Authors.

Figure 3: Pareto chart of failure modes and their roles at pauses in operations.



Source: Authors.

Evaluation and assessment of BIK performances by Pareto analysis, which is performed on the reports of delays at slow cargo work operation, indicated that more than 76% of failure modes are caused by unfitness among cargo owners and port. As illustrates in Figure 2, ships create failure modes only 6.5%.

Unfitness of cargo owner has also created more than 69% of total pauses in cargo handling operation (Figure 3).

According to both Figures above, it can be resulted that unfitness of cargo owner is the most important failure mode, and ship plays a minor role in creation of delays in cargo handling operations.

4.6 Identification the Current Controls for each Failure Mode

The first step in determining the current control of each failure mode is the identification of their causes. Table 1 extracts causes of each failure mode conducted from cause and effect diagram and, as well indicates the total and average quantity of delays as the results of both effects and number of occurrences in measured period of time. These help evaluating current controls and their effects for each failure modes.

There is no control on cargo owner to prevent the delays. High extent of delays confirms the coordination of cargo owner with port authority, and also ship owner and custom. In addition, inability for payments and truck preparation are very important issues that must be regarded.

Implementation of maintenance planning management programs is a sound method of controlling and preventing damage to port equipment. Cargo handling contractors are checked by daily statistics and statistical process control programs. Quarantine and port formalities need to be more and more in coordination with port authority, custom, agricultural and health organisations, wherein port authority plays more important role. Also gangs and working time should be supervised by operational employee.

Vessel is controlled by ship's chief officers and there is no special instruction for prevention of delays. Weather forecasting organisation helps port authorities to prepare requisite conditions for exceptional circumstances.

4.7 Analysis of Risk and Determination the most Appropriate Corrective Actions and Recommendations

As stated by Kumar (2006), FMEA is a structured and qualitative analysis of a system or function which identifies potential system failure modes, their causes, and the effects on the system operation associated with the failure mode's accuracy.

Table1: Causes of failure modes.

Failure	Effect of Failure	Cause of Failure	Tot.	Ave.	N
Unfitness of Ship	Pauses in Operations	Malfunction of ship's equipment	20.5	20.5	1
		Unreadiness of ship	24	24	1
		Holdup by Port State	85.5	14.25	6
		Ship cleaning	11.5	11.5	1
	Sluggish Operations	Malfunction of ship's equipment	231.75	5.4	43
		Unreadiness of ship	2	2	1
		Ship movement	32	6.4	5
		Ship balance adjustment	35	3.18	11
		Hatch cover opening and closing	60	7.5	8
Unfitness of Port	Pauses in Operations	Malfunction of loading and discharging equipment	48	24	2
		Movement of equipment	15	15	1
		Lack of enough storage yard	72	72	1
		Unreadiness of terminal's contractor	24	24	1
		Quarantine and port formalities	582	4.73	123
	Sluggish Operations	Malfunction of berth transportation equipment	241.5	3.05	79
		Malfunction of loading and discharging equipment	279	3.2	87
		Movement of equipment	20.5	0.89	23
		Inability of discharging equipment	121	2.47	49
		Berth cleaning	211.5	2.9	73
		Lack of enough storage yard	270.5	8.19	33
		Irregular working time	128	1.77	72
		Unreadiness of terminal's contractor	86.75	1.93	45
		Gang Problems	321.5	2.61	123
		Quarantine and port formalities	526	3.55	148
		Others	49	1.96	25
Unfitness of Cargo Owner	Pauses in Operations	Financial and documentation problems	1276	60.76	21
		Unreadiness of cargo owner	1064	11.44	93
		Custom formalities	11	11	1
	Sluggish Operations	Financial and documentation problems	690.5	14.09	49
		Unreadiness of cargo owner	628.5	5.56	113
		Truck shortage	662.5	12.74	52
		Others	53	6.62	8
Other Failure Modes	Pauses in Operations	Weather condition	120	24	5
		Expectant of order	24	24	1
		Expectant of loading	24	24	1
	Sluggish Operations	Weather condition	702.5	11	64
		Holidays	96	24	4
		Safety problems	44.5	11.12	4
		Others	89	6.36	14

Source: Authors.

The RPN is an important tool for ranking failure mode and their causes. Analysis of risk and determination of RPN need to rank severity, occurrence and detection, usually done in a 10-point scale. It is calculated for each failure mode by multiplying the severity times the occurrence time the detection ranking. Problem ranking system for each of the scales is provided in tables 2 to 4.

Table 2: Process FMEA severity evaluation criteria.

Rank	Effect	Criteria: severity of effect on process
10	Very Long delay	Period of stop is often more than 24 hours
9	Long delay	Period of stop is often less than 24 hours and more than 12 hours
8	Moderate delay	Period of stop is often less than 12 hours and more than 6 hours
7	Moderate delay	Period of stop is often less than 6 hours or period of sluggish operation is more than 18 hours
6	Moderate delay	Period of sluggish operation is often less than 18 hours and more than 12 hours
5	Minor delay	Period of sluggish operation is often less than 12 hours and more than 6 hours
4	Minor delay	Period of sluggish operation is often less than 6 hours and more than 3 hours
3	Slight delay	Period of sluggish operation is often less than 3 hours and more than 2 hours
2	Slight delay	Period of sluggish operation is often less than 2 hours
1	No delay	There is no stop or sluggish operation

Source: Authors.

Table 5 presents the FMEA of the BIK problems, obtained according to the results of group analysis of statistical performance of BIK and brainstorming among the experts and operational managers of the BIK.

Table 3: Process FMEA occurrence evaluation criteria.

Rank	Likelihood of failure	Criteria: occurrence of causes – incidents per items
10		> 36%
9	Very high	30 - 36%
8	High	24- 30%
7		18- 24%
6		12 - 18%
5	Moderate	6 - 12%
4		3 - 6%
3	Low	1.5 - 3%
2		< 1.5%
1	Very low	Failure is eliminated through preventive control

Source: Authors.

Table 4: Process FMEA detection evaluation criteria.

Rank	Effect	Criteria: severity of effect on process
10	Extremely unlikely	Controls will almost certainly not able to detect the existence of a defect
9	Remote likelihood	Defect is detectable after operation & port operators won't be able to correct it
8	Very low likelihood	Port operators will be able to correct the de fect with limitations after operation
7	Low likelihood	Port operators will be able to correct the defect after operation
6	Moderate low likelihood	Port operators will be able to correct the defect during operation
5	Medium likelihood	Controls have medium effectiveness for detection
4	Moderate high likelihood	Defect is detectable prior operation
3	High likelihood	Controls have high effectiveness for detection prior operation
2	Very high	Controls have a very high probability of detecting the existence of delay prior operation
1	Extremely likely	Controls will almost certainly detect the existence of the defect and correct it

Source: Authors.

Table 5: FMEA for the BIK problems.

Line	Component and Functions	Failure Mode	Effect(s) of Failure	Severity	Cause(s) of Failure	Occurrence	Current Controls, Detection	Detection	RPN
1	Cargo Owner; delivers or receives cargo to/from port	Unfitness of Cargo Owner to deliver or receive cargo from/to port	Pause of cargo work operation	10	Financial and documentation problems	5	None	10	500
2				8	Unreadiness of cargo owner	8	None	10	640
3			Sluggish cargo work operation	6	Financial and documentation problems	6	None	10	360
4				4	Unreadiness of cargo owner	9	None	10	540
5				6	Truck shortage	6	None	10	360

6	Port; transfers cargo from berth to ship or vice versa	Unfitness of Port to deliver or receive cargo from/to port	Pause of cargo work operation	7	Quarantine and port formalities	10	Coordination between responsible organisations by port authority	8	560
7			Sluggish cargo work operation	4	Malfunction of berth transportation equipment	7	Implementation of PM and CM programs	3	84
8				4	Malfunction of loading and discharging equipment	8	Implementation of PM and CM programs	3	96
9				3	Inability of discharging equipment	6	None	9	162
10				3	Berth cleaning	7	None	8	168
11				5	Lack of enough storage yard	5	Control by warehouse employees	6	150
12				2	Irregular working time	7	Check by operational section (visual)	7	98
13				2	Unreadiness of terminal's contractor	6	Check by statistical process control (SPC)	5	60
14				3	Gang Problems	10	Supervision	6	180
15				4	Quarantine and port formalities	10	Coordination between responsible organisations by port authority	8	320
16	Ship; carriages cargo from/to port	Unfitness of ship	Pause of cargo work operation	9	Holdup by Port State	3	Pteort sta	3	81
17			Sluggish cargo work operation	4	Malfunction of ship's equipment	6	None	6	144
18				4	Ship balance adjustment	4	None	6	96
19				5	Hatch cover opening and closing	3	None	7	105
20	Others	Cargo work operation is impossible	Pause of cargo work operation	10	Weather condition	3	Weather forecasting organisation	3	90
21			Sluggish cargo work operation	5	Weather condition	7	Weather forecasting organisation	3	105
22				10	Holidays	2	Annual holiday at calendar	3	50

Source: Authors.

According to the results of the FMEA, followings are the main roots of delays in cargo handling operations in the BIK:

— Unreadiness of cargo owners,
— Quarantine and port formalities,
— Financial and documentation problems, and
— Truck shortage.

A high RPN needs an immediate attention as it indicates that the failure mode can result in an enormous negative effect, its failure cause has a high probability of occurring and there are insufficient controls to catch it.

As stated above, RPNs obtained from the FMEA table, denote unreadiness of cargo owners, is the main factor increasing the delays within the cargo handling operations. Unfortunately, there is no control plan on the fore mentioned problem.

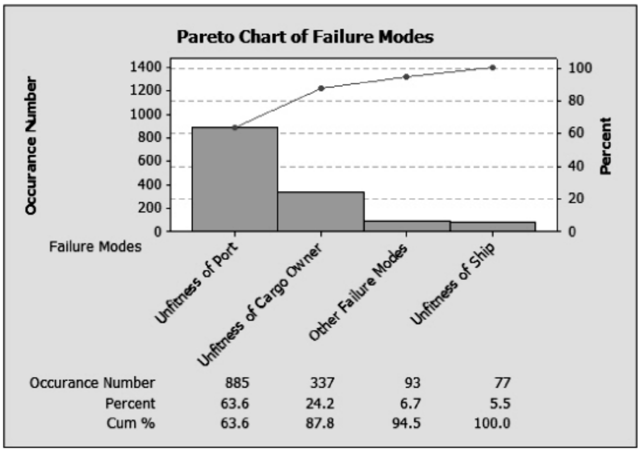
5. Failure mode and root cause hierarchy

A final useful analysis from the FMEA results is the occurrence frequency of the different failure modes and root causes (Hoseynabadi et al., 2010). As illustrated in previous tables, there are lots of failure modes and root causes. Counting these over the whole FMEA gives histograms for each, identifying the top failure modes and the same root causes shown in Figures 4 and 5, respectively.

Identifying the most frequent failure modes and root causes is a vital decision making tool, especially at improvement phase.

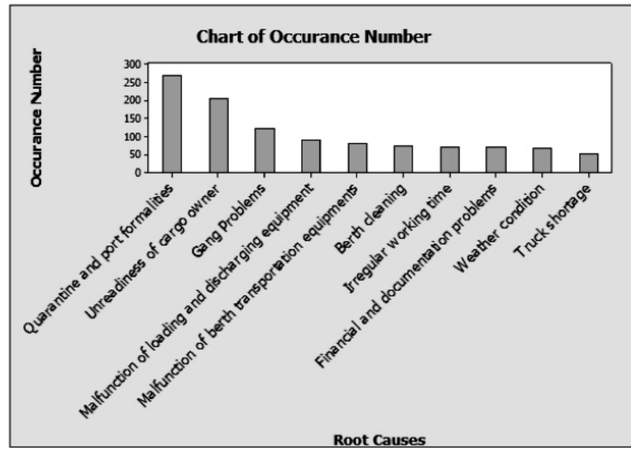
As it can be seen from Figure 4, the most significant failure modes are unfitness of port and that of cargo owner. Hence, improving the unfitness of both the port and cargo owner is the key point in implementing the strategy at improvement phase.

Figure 4: Pareto chart of top failure modes based on occurrence number.



Source: Authors.

Figure 5: Top 10 root causes.



Source: Authors.

Based on Figure 5, the most frequent root causes are quarantine and port formalities, and unreadiness of cargo owner. Both of these root causes are the results of weak cooperation among port authority, port contractors, cargo owner, and custom, which should be looked upon at the improvement phase.

6. Conclusions

FMEA is known as a systematic procedure for the analysis of a system to identify the potential failure modes, their causes and effects on system performance. Firstly, this paper discussed the FMEA and the Cause and Effect Diagram in the context cargo handling operation. Secondly, it attempted to draw links between cargo operation in a bulk terminal and other activities in port environment through utilisation of the FMEA in conjunction with the Cause and Effect Diagram, and Pareto analysis. The overall aim was to improve the efficiency and productivity a marine bulk terminals by reducing the delays of cargo handling operations, and smoothing their loading/unloading activities.

Based on the obtained results, followings should be taken into consideration for reducing the delays in loading/discharging operations in the BIK:

— Since unreadiness of cargo owners is one of the main causes of failure, there should be a plan for its reduction. Unfortunately, it is an external factor which is not directly related to port authorities, thus there is no control over it.

— Providing a systematic cooperation between contracting companies working in the port area and the port authorities is one of the solutions for reducing the port formalities via implementing standard documents.

— Since malfunctions of port equipments is one of the main root causes of failure, implementation of periodic maintenance planning management programs is a sensible process for monitoring and prevention of damage port equipment.

— Quarantine and port formalities are the two main root causes in bulk cargo work operation. Using standard and electronic documents and implementing Electronic Data Interchange (EDI) should be at the top of agenda, which definitely will reduce port formalities.

Acknowledgement

The authors would like to express their gratitude to the Chabahar Maritime University and R&D department of BIK for their financial and technical supports during this research.

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