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RESEARCH ARTICLE OPEN ACCESS

RISK EVALUATION OF BELT CONVEYOR ACCIDENTS USING FAILURE MODES AND EFFECTS ANALYSIS AND EVENT TREE ANALYSIS

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ABSTRACT

Belt conveyor haulage is an often-preferred haulage method in raw material transport of industrial facilities. Main components of the system often subject to breakdowns are belt, drums, roller systems and belt tension drum systems. Among these components, belt breakdowns are belt ruptures due to corrosion, inability of rotation due to corrosion and dust in cylinders and mechanical failures in drum systems and components. In this study, risk evaluation was carried out on probable risks due to breakdowns and faults in a bad conveyor facility. Realized accidents in industry are considered to specify risks. In the first step of the study, Failure modes and effects analysis was employed. Upon results of FMEA, event tree analysis was carried out for each risk to display and decrease severity degrees of risks.

I. INTRODUCTION

Belt conveyors are haulage systems used to transport large amount of stock materials to short, medium, or long distances in horizontal or inclined surfaces through an infinite belt between two drums. Material is transported on the belt. The belt is pulled by one or more drums, which is driven by one or more electrical engines and moves on pulley groups. Material is moved forward on the upper side of the belt and the belt returns to the beginning point empty on the lower side (Figure 1). Since belt conveyor haulage provides economical and efficient transportation of large capacities in long distances, there are many application areas even in today's mining industry [1].

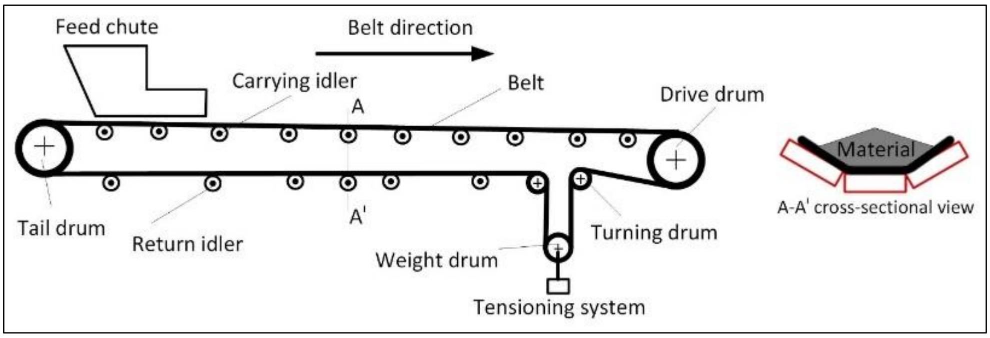


Figure 1: Schematic View of Belt Conveyor.
Source: Authors, (2022).

Belt conveyor is a strong machine with thousands of moving parts. These moving parts contain the risk of injuring a worker seriously. In addition, this injury may occur instantaneously. A regular belt conveyor moves with a constant speed of about 0.5 m/s to 10 m/s [1]. In fact, Conveyors load large amount of mechanical energy to an enormous elastic belt surrounded by tensioned structures. Tensioned belt carries tons of materials and usually up to 600 HP (450 kW) engines are used. When weight, inertia and kinetic energy are considered, enormous amounts of force may appear. Human body can produce power less than 1 HP. Therefore, it is impossible for human body to overcome forces produced by belt conveyor.

Two thirds of fatal belt conveyor accidents occur when belt is moving. Usually, worker's body is grabbed or squeezed by the conveyor during maintenance or cleaning near a moving belt conveyor [2]–[4]. Fatal accidents are usually caused by union of two unsafe applications. First one is maintenance without careful lock down, labelling, blocking, and testing of belt conveyor. Second one is contact with the belt conveyor with a tool or equipment. When these two unsafe behaviours come together, results are unfortunately very serious or fatal. Working around a closed but unlocked belt conveyor can even result in very serious accidents.

In a study of [3], 44 fatal accidents of belt conveyors are analysed according to the reasons of the accidents. It is seen that 96% of the accidents are due to human error. Therefore, it is very important to train workers in order to take and apply precautions. [5]–[9] used main principles and methods of risk analysis and work safety in their studies to decrease and prevent work accidents. [4], [10]–[14] explained in detail hazard sources, physical risk factors and necessary precautions to decrease work accidents in underground mines. Especially, [11] handled work safety applications in underground belt conveyors, which is also the main subject of this study.

In this study, risk factors were examined for underground belt conveyors using a Failure Mode and Effect Analysis (FMEA) and Event Tree Analysis (ETA) methods. In the first step of the methodology, five major risk factors were identified and analyzed using FMEA. In addition, preventive actions were determined, and each risk factor was evaluated together with preventive actions by FMEA. However, since belt conveyor accidents may cause disastrous results in terms of human health, interruption of haulage and production, residual risk of each risk factor was also examined using ETA.

II. DEFINITION OF THE RISK ANALYSIS METHODS USED IN THE STUDY

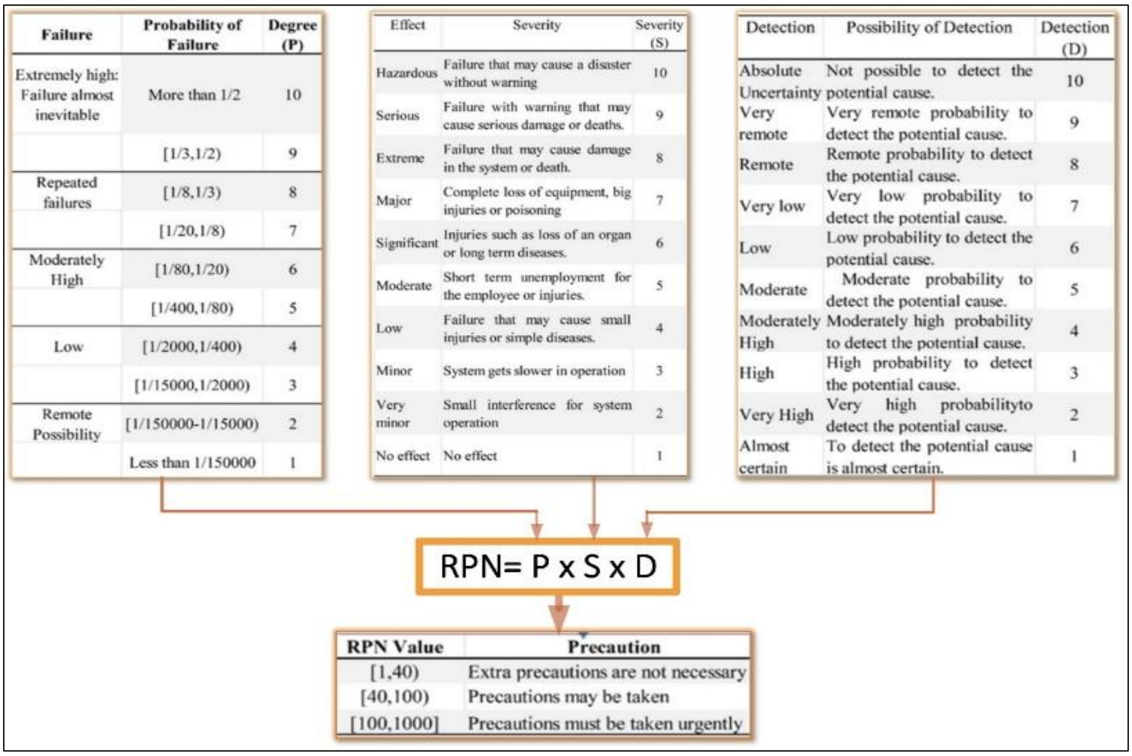
II.1 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Failure Modes and Effects Analysis (FMEA) is one of the frequently used methods in risk analysis and evaluation. Basically, FMEA depends on failures of systems and parts of systems and examines the effects of defined failures. Finally, results are evaluated which may occur due to a failure [15]. FMEA can be applied in many different industries. Failure mode is identified as a potential failure factor in the system [16]. Until now, FMEA has been used in many industries such as mining, aviation, automotive, electronics, chemistry, and production [17]–[27].

FMEA can be considered as a method of safety engineering. It is a quantitative method which handles the three parameters of the risk. These parameters are probability, severity and detectability. Risk probability (P) is the probability of occurrence of an event. Severity (S) is the seriousness degree of results. Detectability (D) is the level in which the risk can be realized before it happens. Risk priority number (RPN) is calculated by multiplying the three parameter values as in Equation 1.

$$RPN = P \times S \times D \quad (1)$$

When determining P, S and D values, FMEA scales given in Figure 2 are used [8], [12], [16].



Failure	Probability of Failure	Degree (P)
Extremely high: Failure almost inevitable	More than 1/2	10
	[1/3,1/2)	9
Repeated failures	[1/8,1/3)	8
	[1/20,1/8)	7
Moderately High	[1/80,1/20)	6
	[1/400,1/80)	5
Low	[1/2000,1/400)	4
	[1/15000,1/2000)	3
Remote Possibility	[1/150000-1/15000)	2
	Less than 1/150000	1

Effect	Severity	Severity (S)
Hazardous	Failure that may cause a disaster without warning	10
Serious	Failure with warning that may cause serious damage or deaths.	9
Extreme	Failure that may cause damage in the system or death.	8
Major	Complete loss of equipment, big injuries or poisoning	7
Significant	Injuries such as loss of an organ or long term diseases.	6
Moderate	Short term unemployment for the employee or injuries.	5
Low	Failure that may cause small injuries or simple diseases.	4
Minor	System gets slower in operation	3
Very minor	Small interference for system operation	2
No effect	No effect	1

Detection	Possibility of Detection	Detection (D)
Absolute Uncertainty	Not possible to detect the potential cause.	10
Very remote	Very remote probability to detect the potential cause.	9
Remote	Remote probability to detect the potential cause.	8
Very low	Very low probability to detect the potential cause.	7
Low	Low probability to detect the potential cause.	6
Moderate	Moderate probability to detect the potential cause.	5
Moderately High	Moderately high probability to detect the potential cause.	4
High	High probability to detect the potential cause.	3
Very High	Very high probabilityto detect the potential cause.	2
Almost certain	To detect the potential cause is almost certain.	1

RPN Value	Precaution
[1,40)	Extra precautions are not necessary
[40,100)	Precautions may be taken
[100,1000]	Precautions must be taken urgently

Figure 2: Probability, severity and detectability scales in FMEA.
Source: [8], [12] and [16].

After computing RPN, risks are categorized according to RPN level. If RPN value is greater than 100, precautions must be taken immediately to reduce P, S, D levels. If RPN value is found to be between 40 and 100, precautions should be taken, and risks should be kept under control. If it is less than 40, available precautions should be continued and risk is said to be tolerable [16]. RPN levels easily display the factors with highest risks, and precautions must be taken immediately for the highest priority risks. After taking precautions P, S and D values are evaluated and RPN is computed for the risks again. The cycle should be a continuous process until all risks are under control and within limits. In this study, FMEA procedure is integrated with ETA procedure. The flow of the algorithm can be seen in Figure 3.

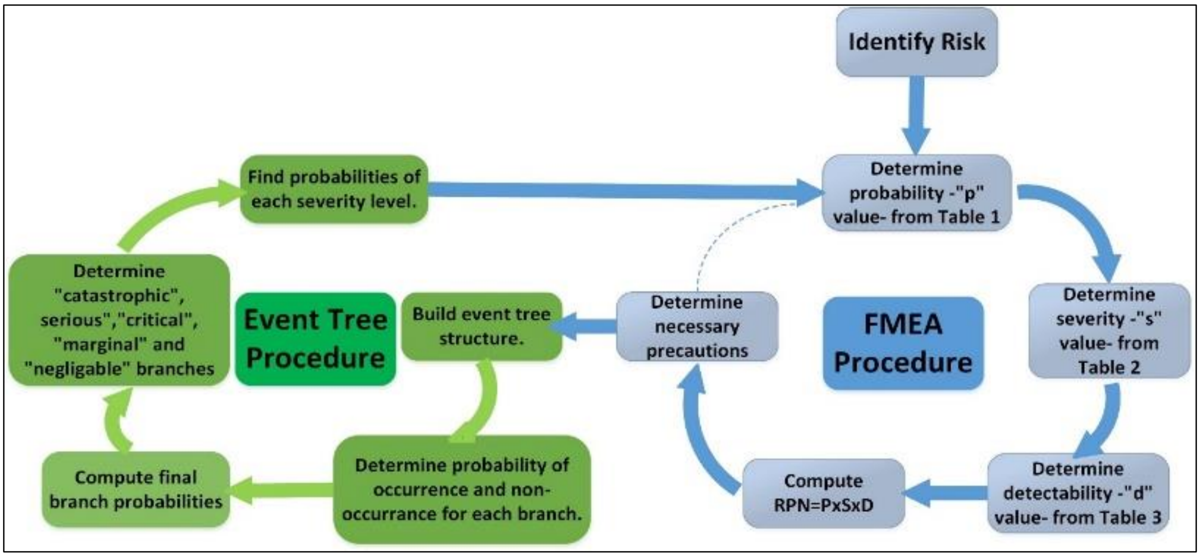


Figure 3: FMEA and ETA are integrated together for further analysis of risk severity degrees and probabilities.
Source: Authors, (2022).

As seen from Figure 3, in FMEA, the process is a continuous loop. The loop is closed by defining precautions and analysis restarts. However, in this study, after determining the precautions in FMEA, ETA is applied for each risk to analyze the severity degrees and their probabilities in further detail. However, risk analysis process is a continuous cycle. The cycle restarts after finding the probability levels of each severity level (catastrophic, serious, critical, marginal, negligible accidents) in ETA.

II.2 EVET TREE ANALYSIS (ETA)

ETA is a risk analysis method which defines root causes of an event, occurrence probabilities of undesired events, probabilities of precautions to avoid the event and classifies the degrees of results (disastrous, critical, serious, marginal, negligible) [13], [14], [28], [29]. ETA has found applications in many different industries. Event tree can be developed in five steps. These steps are defining the initiating event, defining the precautions, developing the tree, evaluation of the tree and classifying risks.

Event tree analysis starts with an initiating event. The tree splits into two branches as the occurrence of the event and non-occurrence. The probabilities of two branches can be stated as "p" and "1-p". The tree continues branching similarly for all precautions defined. Therefore, for "n" barrier there will be "2n" branches at the final level. Probability of a branch at the final level is found by multiplying probabilities of all previous level branches which is connected to the final branch considered. In the evaluation of the tree, each branch at the final level is classified as disastrous, critical, serious, marginal, and negligible. Finally, probability degrees of all disastrous branches are added to give the probability of occurrence of a disastrous risk. Similarly, probabilities for critical, serious, marginal and negligible risks are calculated. A schematic representation of an event tree can be seen in Figure 4.

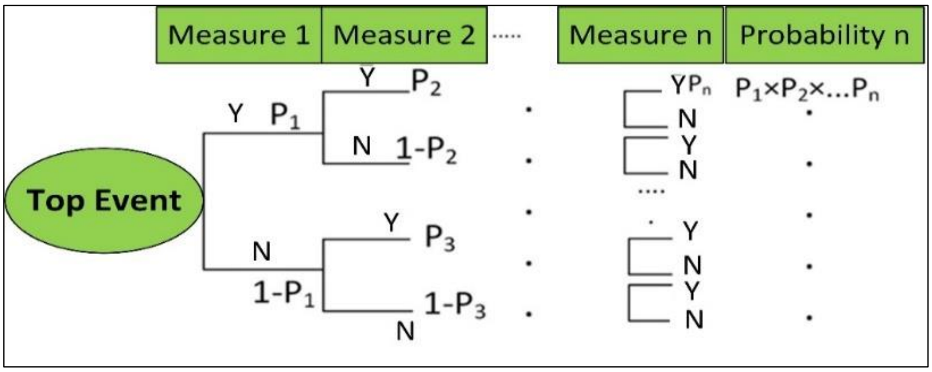


Figure 4: Structure of ETA.
Source: [4].

III. HAZARD IDENTIFICATION DURING BELT CONVEYOR OPERATION

Use of belt conveyors in human transportation is quite hazardous. Lack of emergency stop wire or assuming conveyor energy is cut off when emergency stop wire is pulled are among hazardous events. Another possible hazardous behaviour is inaccurate passing to the other of the side conveyor.

Belt conveyors are long systems, which split the production facility into two areas. Often operators may need to pass to the other side of the conveyor due to maintenance or service. An operator may attempt to pass over or below the conveyor to save time. There are several hazards that may be incurred when passing below the belt conveyor. Operations carried out near belt conveyors involve risks, which may result in serious injury or fatality. One of the mostly incurred accidents is being stuck in the moving belt conveyor or drum. A major proportion of these accidents occur during control, lubrication, maintenance, cleaning of belt conveyor and around area. Working below or around unprotected equipment, using hands to take out material between rollers, trying to turn rollers by hand, putting on/off protective cover of a working conveyor are very hazardous events. In addition, trying to remove materials drive or tail drums while conveyor is working, having loose clothes around belt conveyors, trying to stop a conveyor before cutting off energy are other hazardous behaviours. Among these hazards, five main events were considered and analyzed by FMEA.

III. 1 FMEA FOR BELT CONVEYOR ACCIDENTS

Five hazardous events in belt conveyor haulage were identified and analyzed by FMEA. These events are worker passing below the belt conveyor (F1), faults occurring during belt and drum cleaning (F2), unpermitted boarding on the belt conveyor (F3), insufficient maintenance of pulleys (F4) and no planned cleaning (F5). Calculations of risk priority numbers (RPN) and precautions are given in Table 1.

Table 1: FMEA table for belt conveyor accidents.

Failure Type	Current				Precautions to be taken	After precautions			
	P	S	D	RPN		P	S	D	RPN
Worker passing below the belt conveyor (F1): Worker may stuck in the belt conveyor	8	9	8	576	Cleaning operations or passing below the belt should not be permitted when the belt is in operation. If there is an obligatory case, belt should be stopped. Passing below the belt must be forbidden. Bridges should be placed in appropriate locations to provide passing over the belt.	4	9	1	36
Faults occurring during belt and drum cleaning (F2): Worker may stuck between drum and belt.	8	10	8	640	Workers should not be allowed near drums when belt conveyor is moving. Drums should be covered with protective covers.	3	10	3	90
Unpermitted boarding on the belt conveyor (F3).	6	10	5	300	Boarding on the belt should be stopped regularly to lubricate pulleys and make necessary maintenance. Belts should be made of non-flammable material.	3	10	1	30
Insufficient maintenance of pulleys (F4): Pulleys may tear up belt due to corrosion or belt fire due to friction.	6	7	9	378	Belt conveyor should be stopped regularly to lubricate pulleys and make necessary maintenance. Belts should be made of non-flammable material.	2	7	2	28
No planned cleaning (F5).	8	8	6	384	Training should be given to stop belt conveyor before cleaning. Cleaning operations should be show to the operators during training.	5	8	2	80

Source: Authors, (2022).

In Table 1, RPN values both for the current situation and after precautions are calculated. The decrease in RPN values can be seen in Table 2.

Table 2: Improvement rate of risks after corrective / preventive action.

Failure	Current Situation RPN Value	After corrective/preventive action RPN Value	Improvement rate %
F1	576	36	93.75
F2	640	90	85.94
F3	300	30	90.00
F4	378	28	92.59
F5	384	80	79.17

Source: Authors, (2022).

III. 2 EVENT TREE ANALYSIS OF EACH HAZARD (ETA)

Each of the five hazards defined in Table 1 was also considered using ETA.

III. 2.1 THE WORKER PASSES UNDER THE BELT CONVEYOR (F1)

Event tree is developed for event F1 (Figure 5). The precautions defined are:

- Building bridge to prevent people from passing under the belt conveyor: Probability of an accident decreases to 0.2.
- Regular cleaning under the belt conveyor: Probability can be decreased to 0.3.
- Putting a warning sign to prevent passing under the belt conveyor: Probability of an accident decreases to 0.3.
- Having belt conveyor stop wire: Probability of an accident decreases to 0.3.

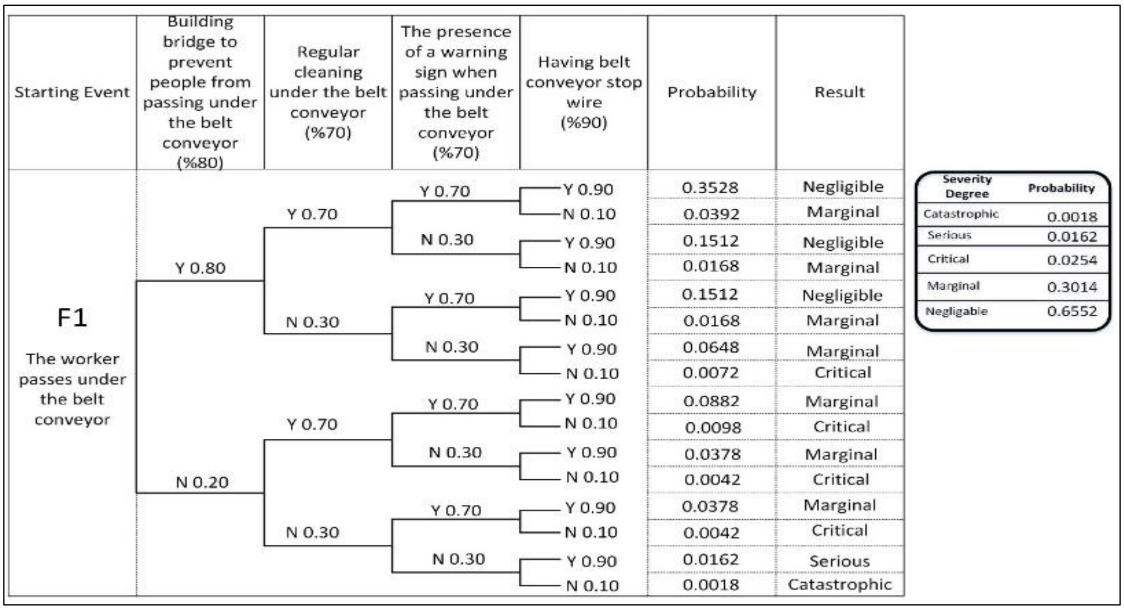


Figure 5: Event tree analysis diagram of F1.
Source: Authors, (2022).

It can be seen from Figure 4 that when these precautions are applied, probability of a catastrophic accident is 0.0018, which is very small. Probabilities of serious, critical, marginal, and negligible accidents are 0.0162, 0.0254, 0.3014, 0.6552, respectively. Therefore, severity of accidents is decreased considerable with the suggested precautions.

III. 2.2 FAULTS IN DRUM AND BELT CLEANING (F2)

F2 event is also considered using ETA. The tree developed can be seen in Figure 6. The suggested measures for event F2 are:

- Belt conveyor should be stopped during operation: Probability of accident reduces to 0.05.
- There should be backup workers (e.g., observers) during work.: Probability of accident reduces to 0.1.
- Belt conveyor stop wire: Probability of accident is decreased to 0.1.
- Planned maintenance: Probability of accident is decreased to 0.1.

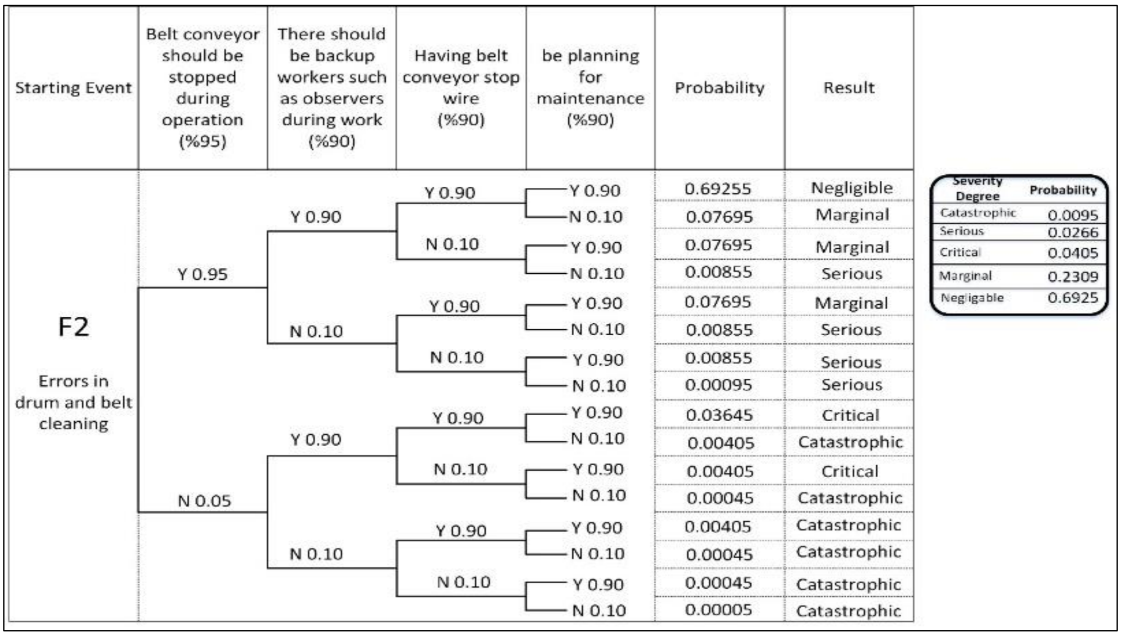


Figure 6: Event tree analysis diagram of F2.
Source: Authors, (2022).

As seen in Figure 6, in the result of ETA, probability of catastrophic and serious accidents is decreased considerably whereas probability of negligible accidents increases. Therefore, severity of accidents are taken under control with the suggested measures.

III. 2.3 UNPERMITTED BOARDING ON THE BELT (F3)

Similar to events F1 and F2, event F3 is also analyzed using ETA. Event tree is given in Figure 7. The defined measures for event F3 are:

- There should be an observer for belt conveyor boarding: Probability of accident reduces to 0.1.
- Boarding on the belt conveyor should be prohibited: Probability of accident reduces to 0.2.
- Prohibition of belt conveyor boarding should be clearly stated in trainings: Probability of accident reduces to 0.1.
- Observation cameras should be placed in certain points: Probability of accident reduces to 0.2.

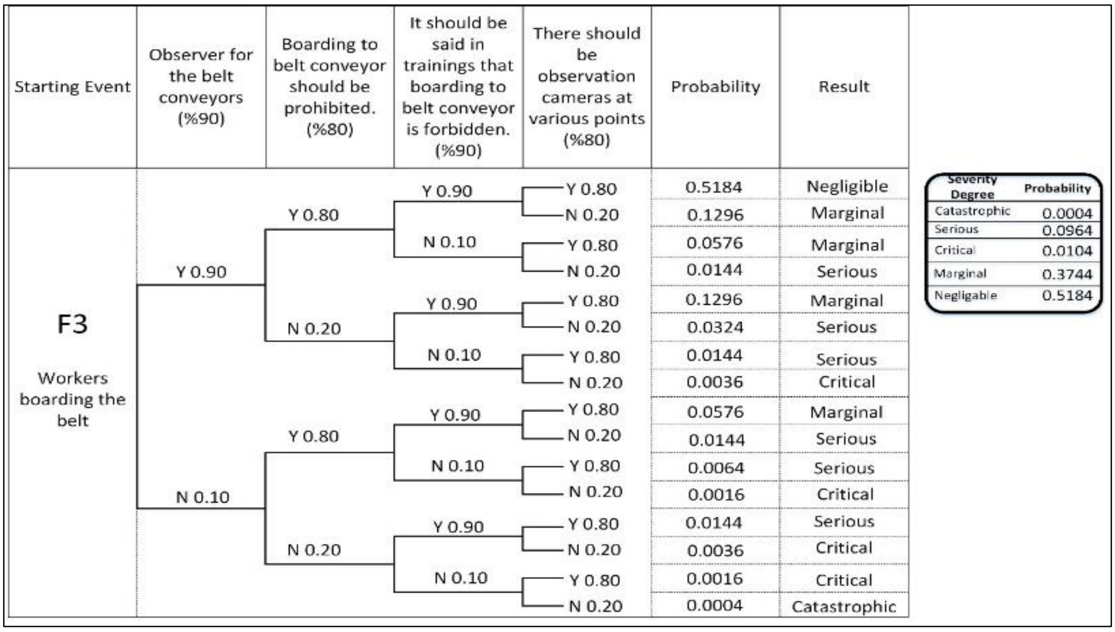


Figure 7: Event tree analysis diagram of F3.
Source: Authors, (2022).

It is seen from Figure 7 that probability of catastrophic accidents decreases to 0.0004. Also, as severity of accidents increases, probability decreases.

III. 2.4 INSUFFICIENT MAINTENANCE (F4)

Event tree developed for event F4, and the analysis can be seen in Figure 8. The measures that should be taken are:

- Rollers should be regularly lubricated and maintained: Probability of accidents decreases to 0.1.
- Belts must be fireproof (ex-proof material): Probability of accidents decreases to 0.1.
- Rotation of the belt conveyor should be smooth and aligned: Probability of accidents decreases to 0.2.
- Correct technical calculations should be done such as capacity and speed: Probability of accidents decreases to 0.2.

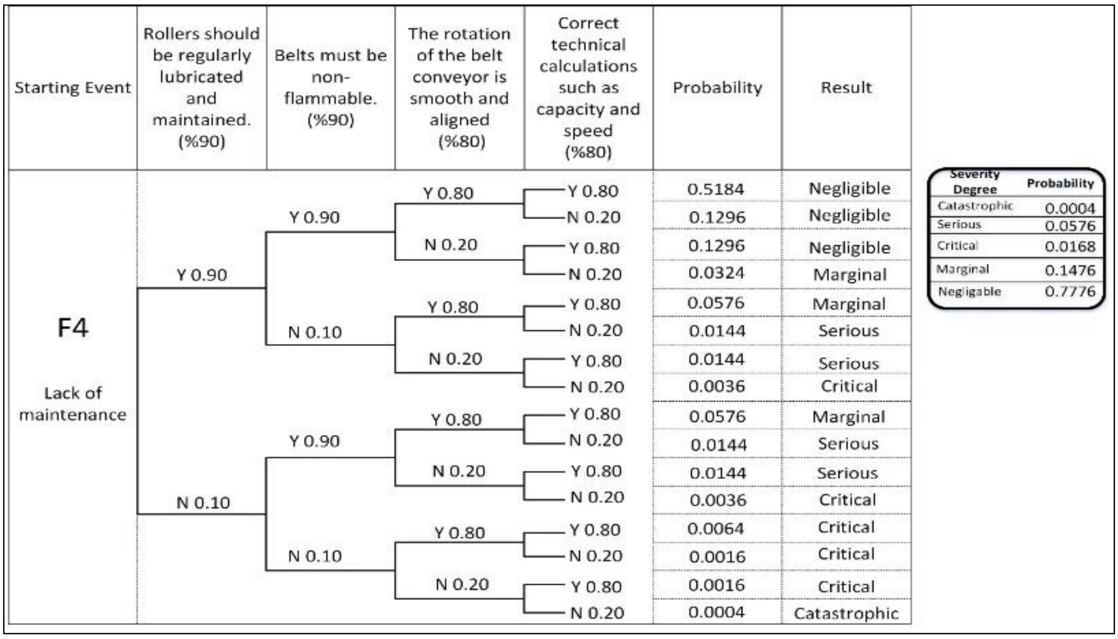


Figure 8: Event tree analysis diagram of F4.
Source: Authors, (2022).

Similar to previous event trees, it can be said for event F4 that severity and probability inversely changes, which is important to keep severity of accidents under control. Among the suggested measures, roller maintenance and non-flammable belts are especially important since they are proactive measure and can be able to prevent the initiating event.

III. 2.5 NO PLANNED CLEANING (F5)

Finally, event tree developed for event F5 and the analysis can be seen in Figure 9. The suggested measures are:

- Planning should be made regularly for cleaning operations: Probability of accidents decreases to 0.05.
- Belt conveyor should be stopped during cleaning: Probability of accidents decreases to 0.05.
- Cleaning area should be separated by a safety strip: Probability of accidents decreases to 0.1.
- Maintenance and cleaning records should be kept, and information should be provided: Probability of accidents decreases to 0.2.

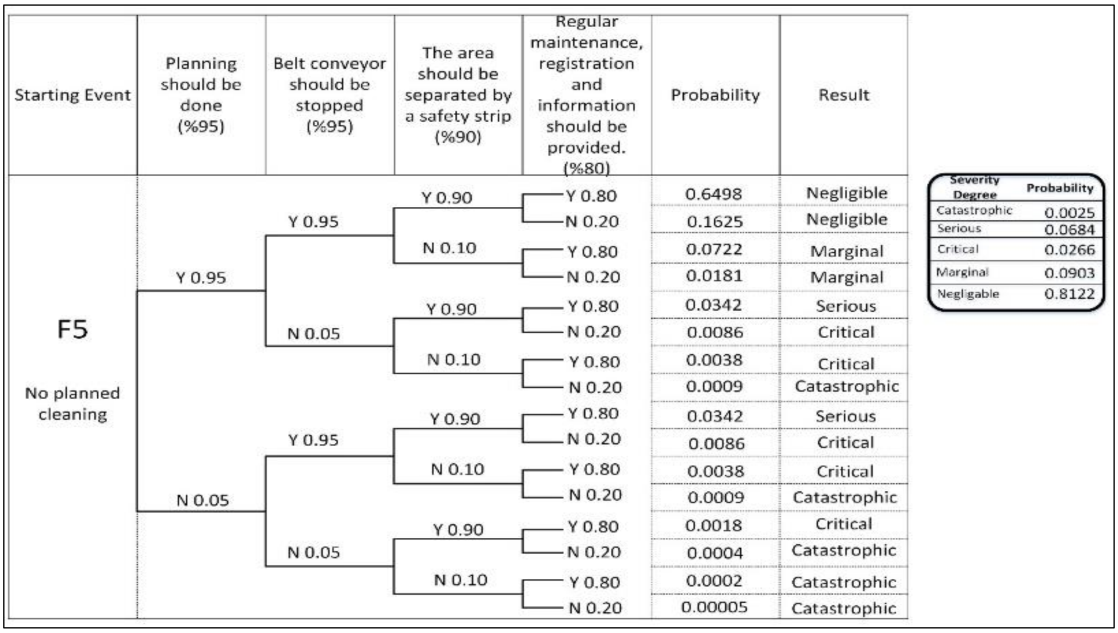


Figure 9: Event tree analysis diagram of F5.
Source: Authors, (2022).

In Figure 9, it is also shown that as severity of accident increases, probability decreases. Especially, planning and safety strip measures are proactive. In other words, these measures are important to prevent the initiating event.

IV. RESULTS AND DISCUSSIONS

Belt conveyors are always risky elements in work safety since they are moving equipment. Even when someone presses the stop button, it takes time until the conveyor stops. Therefore, it is more important to use proactive measures to prevent accidents. Even if all necessary measures and precautions are taken, risk cannot be decreased to zero but it can be kept under acceptable limits.

In this study, five major risks were identified in use of belt conveyors. In the first step of risk analysis, FMEA was used to find risk priority numbers of each risk. Then, each risk was further handled with ETA to examine the severity levels of possible work accidents and the corresponding probabilities.

In FMEA application, the risk value of all five risks were found to be intolerably high without any precautions (Table 1). By defining all the necessary preventive and corrective actions, RPN values were decreased by 90% on the average (Table 2) and all the risks were taken under control. However, to see the detailed effects of suggested measures, ETA was carried out for each risk. In other words, scenario analysis was carried out for cases success and failure in suggested measures. By this way, severity degrees and their probabilities for each case were computed. The summarized results of ETA are given in Table 3.

Table 3: Results of ETA for the five initiating events.

Event	F1	F2	F3	F4	F5	Average
Risk Class	Probability					
Catastrophic	0.0018	0.0095	0.0004	0.0004	0.0025	0.0029
Serious	0.0162	0.0266	0.0964	0.0576	0.0684	0.0530
Critical	0.0254	0.0405	0.0104	0.0168	0.0266	0.0239
Marginal	0.3014	0.2309	0.3744	0.1476	0.0903	0.2289
Negligible	0.6552	0.6925	0.5184	0.7776	0.8122	0.6912
Total	1	1	1	1	1	

Source: Authors, (2022).

In Table 3, five types of risk classes in ETA can be seen. These are catastrophic, serious, critical, marginal, and negligible risks. For all of the five events, it is clearly shown that as severity of the accidents increases, probability decreases under the defined measures. In addition, probability of an accident with catastrophic results is 0.29% on the average which is quite small and tolerable. When catastrophic, serious, and critical accidents are considered together, the total probability turns out to be 7.98% on the average. This situation shows that the suggested measures are very effective in taking the risks under control and they should be applied and followed appropriately.

V. CONCLUSIONS

This study serves to be a unique example in belt conveyor applications which encompasses FMEA, being a milestone risk analysis method in safety and ETA, which is a crucial qualitative and quantitative risk analysis method in engineering sector. In this study, risk analysis was carried out for belt conveyors, which is one of the mostly used haulage methods in industry. Firstly, risks that may occur in belt conveyor haulage were identified and FMEA was applied. Then to analyze the initiating events in more detail, ETA was used for each defined risk. In the results of the study, by use of suggested measures and barriers, it is shown that occurrence of severe accidents can be decreased considerably. In addition, it is important to make risk analysis continuously in belt conveyor facilities to keep risks under control and prevent accidents. By this way, it can be possible to keep operators safe and healthy as well as to prevent production and economical losses.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Methodology: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Investigation: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Discussion of results: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Writing – Original Draft: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Writing – Review and Editing: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Supervision: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.
Approval of the final text: Pınar Mızrak Özfırat, Muharrem Kemal Özfırat, Mustafa Emre Yetkin and Çağatay Pamukçu.

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