ESCALATOR FAULT TREE STUDY

Final Report

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Notice

Executive Summary

Baker Engineering and Risk Consultants, Inc. (BakerRisk®) has completed the escalator fault tree workshop, which was conducted on April 23-24, 2018 at the offices of Technical Safety BC (TechSafeBC). During the course of this workshop, three separate fault trees were generated, covering different risks associated with escalator operation.

The three fault trees (escalator runaways, escalator brake failures, and entrapment scenarios) all appear as attachments in Appendix A. Due to the size of the fault trees, they cannot be included in the main body of the report.

There were fourteen recommendations made by the working group for further action after the fault trees were generated. These recommendations appear in full in Section 3 of this report.

There were two key causal factors identified during the fault tree sessions:

1. Original equipment manufacturer (OEM) data for escalators is not shared with third party maintenance contractors, including data that could be considered safety critical. This was frequently cited as a potential source of hazard, as maintenance is not exclusively done by equipment manufacturers.
2. Misuse of the escalator systems, either by operators, third party maintenance groups, or by the public was repeatedly cited as a causal factor in many areas. There is a strong belief that a lack of knowledge on the part of both the public and the escalator owners/operators contributes to the risks in operating this equipment.

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1 INTRODUCTION

On April 23-24, 2018, a two-day workshop was conducted by BakerRisk with TechSafeBC personnel to create a fault tree that studied the risks associated with escalator operation in BC. This workshop was a follow-up to a fault tree that had been internally generated by TechSafeBC in 2017, and the first of four workshops conducted by BakerRisk in 2018 covering four different risk topics of interest to TechSafeBC: escalator operation, electrical shock, ammonia exposure, and carbon monoxide exposure.

At the beginning of the escalator session, the working group decided to split the fault tree into three different scenarios, each covering different portions of escalator risk. Fault trees covering escalator runaways, escalator pile-ups, and escalator entrapments were generated during the two-day workshop. These fault trees are included in Appendix A. The original fault tree created in 2017 is included in Appendix B. A full list of causal factors identified appears in Appendix C.

Section 2 of this report includes a brief overview of fault tree methodology. Section 3 includes a full listing of all recommendations made by the working group, and Section 4 provides a summary and conclusion for the project.

2 FAULT TREE ANALYSIS

2.1 History

Fault tree analyses were first created and performed in the 1960's by Bell Laboratories in the U.S. in order to evaluate the risks associated with the potential inadvertent launching of Minuteman missiles and the potential unauthorized arming of nuclear devices. In the 1970's, the fault tree system was adopted by the U.S. nuclear industry as a method to evaluate the reliability of reactor safety, including potentials for reactor runaway and the release of radioactive materials. It is still used in the U.S. nuclear industry to analyze risks and failure rates of critical systems.

Through the 1980's and beyond, fault trees have occasionally been used in chemical and petrochemical companies to provide detailed risk analyses where less detailed methods such as hazard and operability studies (HazOps) have not provided a clear resolution to risk decisions.

2.2 Basic Method

A fault tree is generated by choosing a specific final event of interest – such as a chemical release in a specific location, or an explosion from a reactor that leads to a fatality. After choosing the final event, the participants in the fault tree study work backwards to identify all of the causes that could lead to that particular final event happening. In most fault tree studies, each initiating cause is assigned a specific probability, allowing the organization creating the fault tree to identify the dominant cause or groups of causes that led to that final event so that they can be addressed.

Fault trees use logic gates to create a map of sub-causes from the original event to the multiple potential root causes for that event. In Figure 1, the logic gate symbols used in fault trees are shown.

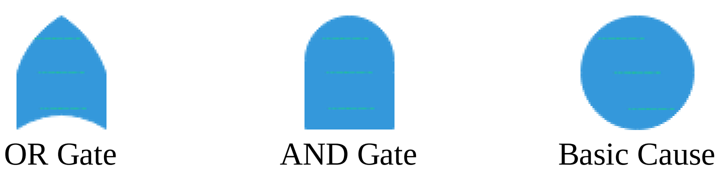

Figure 1. Logic Gate Symbols

Figure 2 shows an example tree created to demonstrate the fault tree map that could be used to understand the failures that could result in a light bulb not turning on.

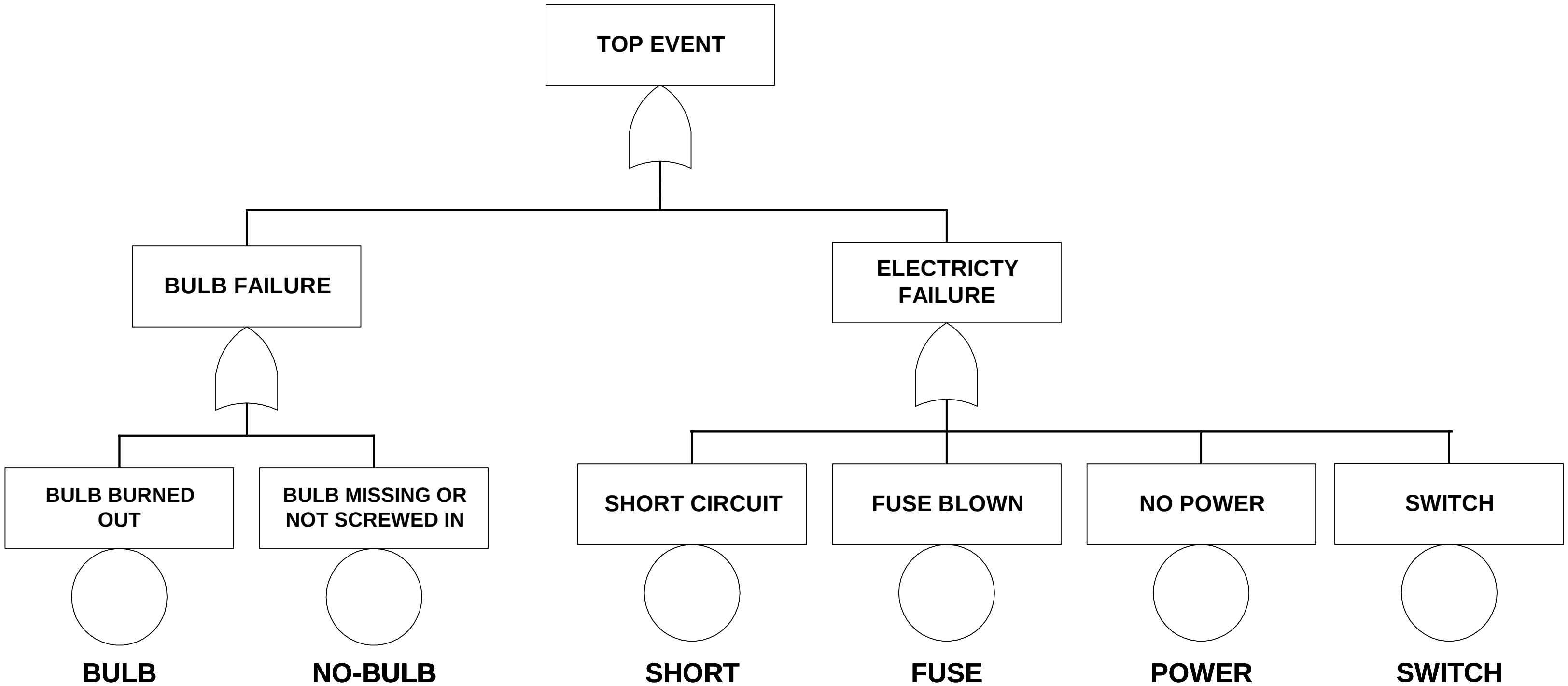

Figure 2. Fault Tree Example – Light Bulb Fails to Light

3 RECOMMENDATIONS

At the conclusion of the workshop, the working group reviewed the fault trees that had been created and identified the key common causal factors that appeared in each of the three trees. The group then held a brainstorming session to develop actions and recommendations that could be carried forward by TechSafeBC to attempt to reduce the risks associated with escalator operation. These recommendations appear in full, below:

1. Continue with the implementation of the currently planned safety order to institute daily start-up inspections and yearly brake servicing for all escalators in BC. There is data from Ontario's Technical Safety and Standards Authority (TSSA) that indicates this will reduce the level of incidents related to mechanical failures within the province.
2. Ensure that a suitable education program is developed to support the implementation of the safety order cited in recommendation one, above.
3. Consider requiring skirt index testing for new and existing escalator installations (i.e. make the change retroactive) to mitigate public misuse. Note that this requirement will be added if the 2016 code adoption goes forward, unless it is specifically written out.
4. Consider developing an awareness campaign targeting the public to mitigate misuse, playing, and inattention on escalators. There is an existing campaign in place with the TSSA that could be leveraged, and the Escalator Foundation also has material available. The campaign should be targeted to areas where the escalator user base has a low median age (i.e. shopping malls, schools) or presented using media where the user base is of lower median age (i.e. apps, games, video channels). A partnership with other organizations should also be considered as a viable method of getting exposure for this material.
5. Consider requiring stanchions or bollards at the top and bottom of escalators, where this protection is warranted, such as in shopping malls or airports. Note that this recommendation is site specific and not intended to be generic for the entire industry.
6. Consider creating regulation that requires original equipment manufacturers (OEMs) to share data on safety critical set-points and procedures to allow for third party maintenance and servicing of their equipment. Note that the lack of availability of manufacturer specifications and standards was repeatedly cited as a causal factor in all three of the fault trees generated in this workshop.
7. Review the maintenance, servicing, and repair components of the existing apprenticeship syllabus/exams and skills passport for escalators and ensure that it adequately supports these areas. The opinion of the workshop participants was that the current syllabus is strong on installation, but weak on maintenance and repair.

8. Review the continuing education requirement of the escalator/elevator certification to incorporate relevancy of training targeted to mechanics who hold escalator scope of work as part of their certification. There is a concern that some certificate holders will lose currency on escalator repair due to the small amount of work they are actually doing in the field.
9. Consider moving forward with the implementation of maintenance control plants (MCP), including the requirement that a maintenance contractor develop equipment-specific procedures for all equipment being serviced by their organization, and that the MCP be registered in order to ensure compliance.
10. Consider improving the structure and frequency of regulatory compliance audits being performed as an oversight activity, including refining and expanding audit protocols and ensuring that the same protocols are being used at all audits and that the developed audit protocol includes measures to develop baseline data. Verify that the existing audit program addresses a sufficient number of escalator operators per year (rather than just elevator operators).
11. Expand regulatory compliance audits to include asset owners, and not just maintenance contractors. This will allow TechSafeBC to identify where asset owners have a pattern of non-compliance or substandard maintenance, rather than just targeting single sites or maintenance contractors.
12. Consider developing a system whereby non-compliance issues identified in the field are made available and searchable for both asset owners and their contractors.
13. Enhance the existing TechSafeBC hazard mapping and assessment tools to allow improved baseline data to be gathered on escalator failures and compliance issues.

4 SUMMARY

On April 23-24, 2018, a working group formed by Technical Safety, BC met to update the fault tree analysis done in 2017 on escalator risks in the province of British Columbia. During this session, three fault trees were created: one on escalator pile-ups, a second on escalator runaways, and a third on escalator entrapments.

At the conclusion of the two-day workshop, recommendations to address the common or critical causal factors identified in the creation of the fault trees were made, as outlined in Section 3.

The most critical deficiency identified during these workshops was the lack of data supplied by OEMs to allow for maintenance of their equipment by third parties after installation. It appears that third party contractors can only gain competency in maintenance of vendor equipment by hiring personnel who have worked for that vendor. In the absence of qualified personnel, maintenance and adjustments of safety systems can only be done by the best judgement of the individual technician, which may or may not align with the OEM's design intent. Although a regulatory change would be required to ensure that this data is shared with maintenance contractors, this appears to be a significant industry shortfall and should be addressed.

APPENDIX A. FAULT TREES

Due to their large size, the three fault trees created during this workshop area attached as .pdf files to this report. The file names are *EscalatorPileups.pdf, EscalatorRunaway.pdf, and Entrapment.pdf.*

APPENDIX B. ORIGINAL FAULT TREE

The original fault tree developed by TechSafeBC is attached as a Microsoft Visio file. The file title is *Escalator Braking v3.pdf*

APPENDIX C. CAUSAL FACTORS

Causal Factor	Number of Appearances
Equipment Specific Issues	15
Inspection Failure	15
Inspection Interval	13
OEM Specifications not Available	12
Apprenticeship Program Issues	11
Continuing Education	10
Foreign Material	8
Misuse	8
Obsolete Equipment	6
Service Wear	6
Corporate Culture	5
Risk Tolerance/Complacency	5
Chemical Exposures/Contamination	4
Corporate Resourcing	4
Lack of Duty Holder Oversight	4
Water	4
3rd Party Parts	3
Excess Heat/Cold	3
Impact/Load Failure	3
Lack of Process/Procedures	3
Parts Availability	3
Step Misalignment	3
UV/Light Exposure	3
Cost/time Constraints	2
Lack of Knowledge/Training	2
Loose Fasteners	2
Lubrication	2
Manufacturer Defect	2
Client Pressure	1
Contamination	1
Demarcation Strip Missing	1
Escalator in Motion	1
E-stop Pressed	1
Excess Compression	1
Fatigue Weakening	1
High Use/Loading	1
Housekeeping	1
Inattention	1
Incorrect Length from Manufacturer	1
Incorrect Length on Replacement	1
Lack of Inspection	1
Load Present	1
Loose Clothing	1
Loose Footwear	1
Low Design Tolerance	1
Manufacturer Specialization	1
Manufacturer Tolerance	1
Material Issues	1
Misadjustment at Setup	1
Normal Wear	1
Oxidation	1
Playing	1
Power Failure	1
Safety Switch Activated	1
Spring Weakening	1
Step Riding High	1
Step Tread Worn	1
Temperature Cycling	1
Unit Age	1
User Damage	1
User Present	1
Worn Rollers	1