DEPARTMENT OF MANAGEMENT SCIENCE

University of Strathclyde Business School

"Modelling the impact of regulatory control on the risk and availability of elevator devices to users in Toronto, New York City and Mumbai"

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Except where explicitly stated, all the work in this dissertation – including any appendices – is my own and was carried out by me during my MSc course. It has not been submitted for assessment in any other context.

Signed: …………………………......

EXECUTIVE SUMMARY

The aim of the study is to investigate the elevator devices' (ED) regulatory control in Toronto, New York City and Mumbai. Hence, to develop an Influence Diagram that models the impact of the different degrees of regulations on the consequences failures of elevator devices have on users. The purpose of doing this project is to address a growing concern among users of EDs on the potential risk and unavailability issue it is causing in the community today.

Initially, a background review of the different types of EDs and safety steps to be carried out on EDs was studied, along with the currently available safety devices installed on EDs, as a best practice for ED authority to enforce and users to follow. Then a current account on the ED availability in each of the cities was studied. After that, a detailed review on the present situation of each region's EDs hazard occurrences; standards, laws, regulations and codes pertaining to buildings and EDs were explored. Quantitative and qualitative data relevant to the objective were gathered and presented in tables and diagrams. This constituted the first part of the objective, which was to be used as the input to the second part.

Various risk modelling methods such as Petri Nets, Bow-Tie, Fault Tree Analysis, Bayesian Nets, etc. were reviewed. Its applications and previous research done on modelling elevator risk were studied and evaluated. Their features and benefits were assessed, and BBN was chosen as the method to model the data, as it suited the type of uncertain and missing information present in the collected data. Upon further review, Influence Diagram, an extension of Bayesian Nets, was used to model the objective, as it involved making certain decisions and associated consequences. This was supported by Influence Diagrams.

'Netica' from Norsys Software Corp was the tool used to model the problem. The key variables, decision and consequence nodes were chosen from the data gathered, that represented the problem. The nodal probabilities were populated based on insights from research. The Influence Diagram was developed, and the model was tested using several scenarios relevant to the problem. It was found that the model was able to advice on a course of action, upon processing different inputs, by taking into account its consequences.

The model's benefits and limitations were assessed by reviewing the extent to which it achieved its purpose.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Professor Lesley Walls for believing in me, and for her never ending encouragement, guidance and extraordinary support in my journey through this thesis.

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To anyone and everyone else whom may have knowingly or unknowingly supported me with completing my dissertation, I take this opportunity to show my sincere appreciation.

I would like to dedicate this dissertation in the loving memory of the brave souls who were taken away from us during the catastrophic Kerala floods in August this year

In precious memories of our beloved grandmother, who is in God's care since July 16th this year

To our uncle, who left us on Jun 25th this year will forever live in our hearts

To my ever supportive and loving parents and sister, without whose blessings, affection and prayers, I couldn't have achieved this milestone

PREFACE

Elevators bring back a lot of memories to me. My first and worst experience of going on an elevator was with my dad, when I was about six years old. The reason I still remember this today is because the elevator had stopped, and it had become pitch dark. Being a toddler, I was so scared of the dark and the closed space, I had started crying out loud and just wouldn't stop. It had taken a while for the lift to be back on. After that incident, I was always afraid of going on an elevator, even if someone is with me. Even after nearly 25 years of my worst experience, I am still afraid of going inside elevators alone. I always need someone to accompany me. If I don't see anyone around, I would wait till someone comes so that we could get stuck together if something bad happens. However, now that I have done an entire project on elevators, I hope, I have become friends with it and going forward I will be more confident to get in them (alone).

My late grandmother used to call me every time she wanted to go downstairs by the elevator. The elevator door was one of those manual operated grill doors, where we had to pull it open. Since she was weak, she used to call me to help her open the door. We and many others in the flat had requested the building owner to change it to a power operated door so many times, but it never happened. The owner kept saying it is too expensive for him.

Having said a little about my personal motivation, on Jun 1st, I was thrilled when I received the email about my project allocation. It was my first-choice project and that was the project I was allocated with. At first, I couldn't imagine how exciting it would be to work on a project based on a mode of transport that most of us use almost every day but don't even realize its importance - it was not a car, bus or a train, but something much more important than these, needed for the fast pace at which the world is progressing today. When I first read the project description, I couldn't really imagine a project that could arise out of that, and more bizarrely, I never saw it as a means of travel until I sat for a moment and thought about it.

So, what exactly made me choose this project? Apart from a more of personal connection to elevators, there is a career perspective associated with it. In the project specification, I read the client name TSSA, Government of Ontario. That was the only non-UK external government-based project we had. That rang a bell for me. Lately, I have been watching and reading a lot of news about Canadian Prime Minister Justin

Trudeau and the respectable work he has been doing not just for Canada, but also for people abroad, such as the Syrians. Having several friends in Canada, I have always been fascinated by how welcoming they are towards foreign nationals and the enormous amount of opportunities they are providing for them. Currently, they are probably the only nation that is permitting the highest number of migrants into the country every year to strengthen their economy by bringing in foreign talent. I am hopeful of becoming one among them very soon! Therefore, I see this project in which a high-profile Canadian client is associated with, as a stepping stone in my career in terms of securing a bright future in Canada. I also aim to include it as an achievement in my CV, as elevator availability is a hot topic amongst the Canadians today.

Having spoken a little about the personal and career perspective surrounding this project, there is an academic side to it as well. Nearing completion of my MSc Data Analytics course, I want to work on a project that would allow me to use the knowledge I have gained over the past year through various subjects and put some of those into practice on a real problem. Through this, I want to give something back to the world to make it a safer and a better place for people to live in.

I faced some technical challenges in approaching the problem in a logical way. It is basically a messy 'socio-technical one'. This is because I was surprised to see that I was unable to find any useful 'datasets' from any regions to get a clearer picture of the situation. It would be better to say that the available empirical data is of poor quality and does not have the most useful variables for decision making. So, the scope for carrying out any advanced data analysis is limited. This was the challenge because as a Data Analytics student, I had always worked with only analyzing existing datasets. In this case, I had to create my own dataset.

However, the good side to this was that, it meant I had the opportunity to read several sources and gather my own data, rather than use readily available ones. This also meant I had the chance to increase my knowledge and understanding of the region-wise situation and hence frame my own set of variables. I did this by the means of a 'reverse engineering process', where I had a vision of what information I wanted, i.e., what an ideal dataset would be that helps me in deciding the suitable modeling method. So, I just had to work my way backwards and review the available information and check how far it matches with the variables I had in my mind. To achieve this, I first transformed the qualitative and quantitative data into individual tables and figures, and later took key information from these and put them into a comparative region-wise table. This made my modelling easier because I could find the information easily.

Having said that, what I enjoyed throughout the project is the never ending learning of new information about elevators, its associated concepts, ideas, and risk modelling methodologies and their benefits and weaknesses; ways to do research and make key notes; ways to gather and analyze limited amount of quantitative and qualitative data; ways to present information visually through tables and diagrams; different modelling software that exist, learning to work with them and understanding their limitations and usefulness. I learnt how to tackle some of the challenges on my own by making my own decisions and proceeded with the project the way I thought was correct, even if they were not the best decisions, without depending too much on Prof. Lesley’s advice or waiting for her response. After all, it is my project and I had the full control over it.

There were some terrible events that took place during the course of my project that mentally disturbed me quite significantly, due to which I was not able to fully concentrate on my project for a few days. The first was my uncle’s (65) death owing to Alzheimer’s Disease. After a few weeks, my grandmother (90) passed away in her sleep. The event that almost ripped me apart was the catastrophic Kerala floods, in August. It left the entire state of Kerala (my home state in India) in destruction. I felt so helpless just watching and not being able to do anything. My family, although safe; my house was badly affected. I wish I was there to help. However, in the midst of all these difficult circumstances, I am proud of myself for having achieved this important milestone.

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CLIENT REPORT

GENERAL

LIST OF ABBREVIATIONS

AECO	Accredited Elevator / Escalator Certification Organization
AEMA	Accessibility Equipment Manufacturers Association
ALARP	As Low As Reasonably Practicable
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
BBN	Bayesian Belief Networks
BIS	Bureau of Indian Standards
CECA	Canadian Elevator Contractors Association
CPT	Conditional Probability Table
CSA	Canadian Standards Association
DCAS	Department of Citywide Administrative Services
DOB	Department of Buildings
ECNY	Elevator Conference of New York
ED	Elevator Device
EESF	Elevator Escalator Safety Foundation
EESFC	Elevator Escalator Safety Foundation of Canada
EMANY	Elevators Manufacturers Association of New York
FDNY	Fire Department of New York
FTA	Fault Tree Analysis
IAEC	International Association of Elevator Consultants
IBC	International Building Code
IBEW	International Brotherhood of Elevator Workers
IEC	International Electrotechnical Commission
IEEMA	Indian Electrical and Electronics Manufacturers' Association
ID	Influence Diagram
IoT	Internet of Things
ISO	International Standards Organization
ISSEA	Indian Small-Scale Elevator Association
IUEC	International Union of Elevator Constructors
LCU	Load Carrying Unit
LED	Light Emitting Diode

MD	Managing Director
NAEC	National Association of Elevator Contractors
NBC	National Building Code
NEEA	National Elevator and Escalator Association
NEII	National Elevator Industry Inc.
NPT	Node Probability Tables
NYC	New York City
NYCHA	New York City Housing Authority
PN	Petri Net
SRA	Slum Rehabilitation Authority
REBNY	Real Estate Board of New York
SCC	Standards Council of Canada
SIL	Safety Integrity Level
TSSA	Technical Safety & Standards Authority
TPP	Tenant Protection Plan
USA	United States of America

PROJECT CONTEXT

CHAPTER 1

SCENE SETTING

1.1 Outline

In this chapter, I will be talking about the aim of the dissertation; my expected outcome by the end of the project; my research methodology; my action plan; choice of regions for investigation; problem context surrounding EDs; description of the elevator etymology; a brief history of the safety element of the elevator; major characteristics of EDs; the big players in the ED industry; the different types of EDs that exist in the world; a description on the elevator mechanism; diverse types of doors that are used in EDs. I have provided tables and figures for better interpretation where necessary.

1.2 The Objective

The purpose of this dissertation is to carry out an investigation exploring the EDs regulatory control in Toronto, Canada; NYC, USA and Mumbai, India. Hence, to develop an ID that models the impact of these different degrees of regulations on the consequences ED failures have for users.

1.3 Expected Outcome

What I aim to learn and achieve at the end of this dissertation is to master the BBN and ID modeling methods. I also intend to have expert knowledge about the extensive and complicated world of EDs, its associated benefits and risks, which cause availability issues for users. I aim to assist the respective regional EDs authority, e.g., TSSA, Government of Ontario, with visualizing the problem context, thereby enabling them to make sound tactical decisions to control ED risks and availability issues arising from them. Through this, my objective is to provide a safer and more reliable means of vertical transportation for ED users. Figure 1.1 below shows the beneficiaries of the project upon completion.

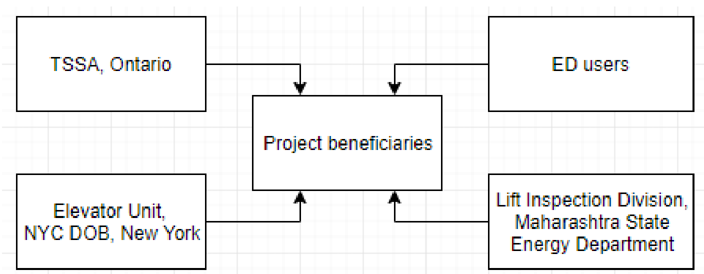


Figure 1.1: Project beneficiaries

1.4 Research Methodology

My research methodology for the literature review will primarily be only based on secondary research. Figure 1.2 shows the sources I will be using to gather relevant qualitative and quantitative data on the project objective presented in section 1.2

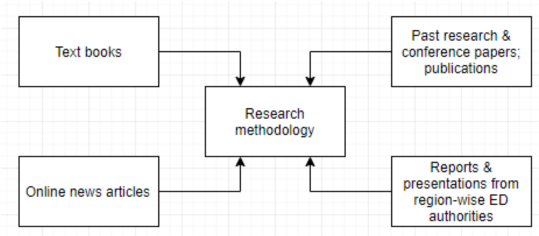


Figure 1.2: Secondary resources for research

1.5 Plan of Action

Figure 1.3 shows a flowchart of my action plan to carry out my thesis. Firstly, starting with the original project description, I framed it into my own project objective (see section 1.2) as there was flexibility to do so. I then would collate my secondary resources to perform my literature review (see section 1.4). I plan to split this into two. One is to review the available qualitative and quantitative region-wise ED data and the other is to review the various modelling methods that have been used in the past for evaluating ED risks. The data from the former would be the input to tabulate them region-wise, while the information from the latter would be the input that would be evaluated against the tabulated information from the former. The reason for doing this evaluation is because different modelling methods have different usages, according to the type of data available. So, I must decide the best modelling method that suits the tabulated data I have.

The next step after that would be to learn the selected modelling method deeply by using a certain software or tool. Then using the region-wise tabulated data as the input again, I will identify the degrees of regulations and their associated consequence of ED failures from the tabulated data. The desired output would be a visualization of the effect these different levels of protocols have on the significance of ED hazards for users. As a last step to end the project, I aim to create a PPT presentation on the model I have developed, along with any takeaways and send it to the region-wise ED authority, e.g., TSSA. This would be done with the guidance from Prof. Walls, as I would need to develop an individual version for them and another version for the Risk Consortium event to take place on 9th October, for which I was invited to participate and present my topic of research.

Figure 1.4 shows a Gantt chart of my project timeline. This is how I planned and allocated a time period to work on each part of my dissertation.

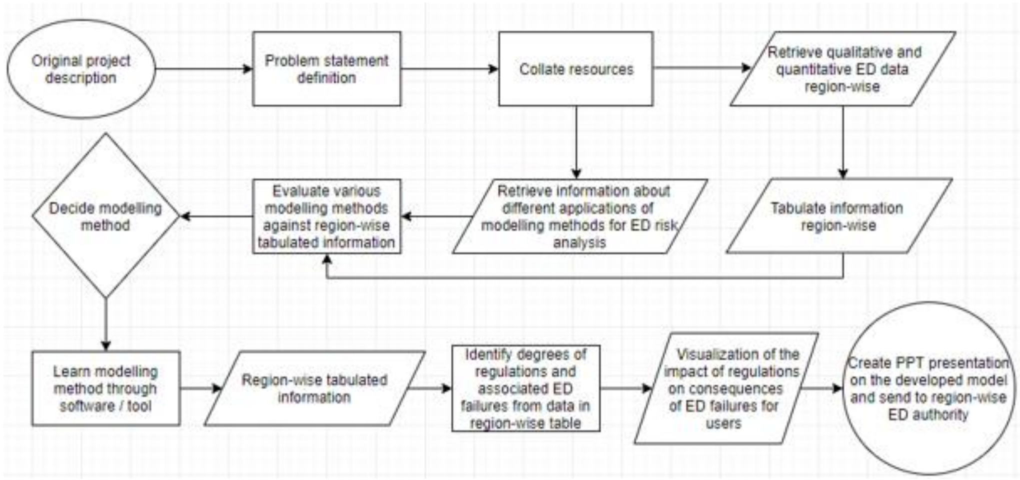


Figure 1.3: Dissertation plan of action

Task Name	Start Date	End Date	Duration (Days)
Project Planning	6/1/2018	6/11/2018	10
Write-Up - Project Title / Problem Statement / Objective	6/12/2018	6/14/2018	2
Write-Up - Introduction	6/15/2018	6/25/2018	10
Write-Up - General Literature Review	6/26/2018	7/1/2018	5
Write-Up - Specific Literature Review (ED regulations)	7/2/2018	7/12/2018	10
Write-Up - Specific Literature Review (Modeling methods)	7/13/2018	7/23/2018	10
Write-UP - BBNs & IDs	7/24/2018	7/31/2018	7
Learning Netica software	8/1/2018	8/11/2018	10
Implementing ID Model in Netica	8/12/2018	8/22/2018	10
Write-Up - ID model in Netica	8/23/2018	8/30/2018	7
Write-Up - Results discussion	8/31/2018	9/5/2018	5
Write-Up - Conclusion / Recommendation	9/6/2018	9/11/2018	5
Appendices	9/12/2018	9/15/2018	3
References	9/16/2018	9/20/2018	4
Cover Page/Abstract/Table of Contents/Acknowledgements, etc	9/21/2018	9/23/2018	2
Proofreading / Editing / Final changes	9/24/2018	9/27/2018	3
Project Diary	6/1/2018	9/27/2018	118

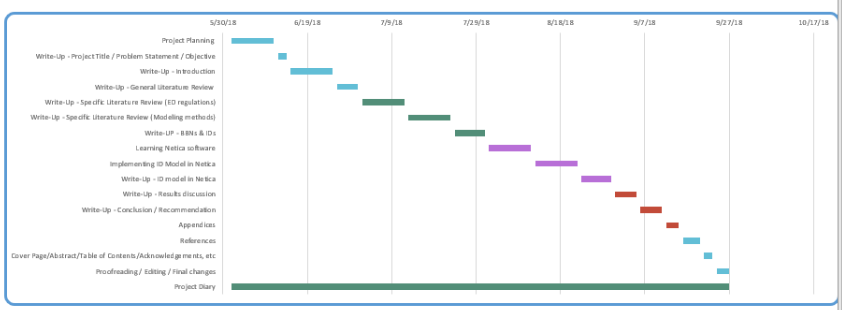


Figure 1.4: Gantt chart showing project timeline

I have split my dissertation into two documents (Figure 1.5). It follows a certain order that forms a story. The first document is the ‘Project Context’ which would be read by anyone who is not familiar with the background of the project. It has an introduction chapter on the general aspects of elevator devices (EDs). Chapter two talks about the general ED safety measures that ought to be followed by users and authorities; and the current region-wise availability issues. The readers can continue reading the second document, which is the ‘Client Report’. This is the document client(s) would read because it contains the crux of the project (data collection, model implementation and analysis). The first chapter talks about the data I have gathered (quantitative and qualitative) pertaining to the ED safety regulations, laws and standards and the hazard occurrences. Second chapter reviews the elevator system risk modelling methods that have been studied in the past. In the third chapter, I use information from the previous two chapters and select Influence Diagram (extension of Bayesian Belief Networks) to model the problem, and also brief on the modelling tool. Fourth chapter is the most important, where I develop and discuss the model for the problem. In the following two chapters, I present and talk about my findings and conclude the project with key takeaways for the users of the model and scope for further research.

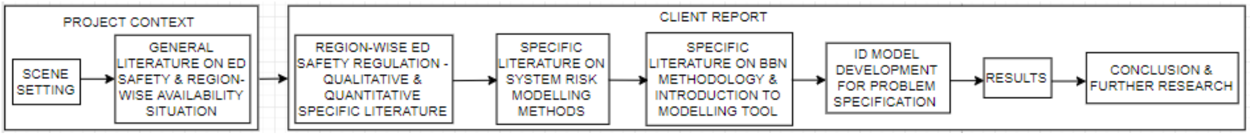


Figure 1.5: Document & Chapters layout

The project offered flexibility in a way I could do it the way I want to. So, I did a region-wise comparative study of ED availability and developed a single model representing the overall elevator risk and availability situation, and its consequences. So, it can be used by any of the elevator authorities of these regions.

'Figures represent a thousand words'. So, throughout this document, I have provided numerous spider diagrams, graphs and tables to visually represent information and to basically avoid text cluttering. I took that extra effort to help me structure my findings and improve my understanding of the information.

1.6 Choice of Regions

I will discuss the ED risk and availability situation in three cities, namely Toronto, NYC and Mumbai.

The reason for choosing Toronto is because the Canadian territory of Ontario is the region of study in the original problem specification (see Appendix, Figure 1.6). However, within Ontario I have chosen to focus only on Toronto (see Appendix, Figure 1.7 for location in the world map [80]). Toronto is home to the 5 tallest buildings in Canada. For e.g., 'The One', which is under construction and will be completed in 2023, will be the tallest building in Canada at 1005 feet (See Appendix, Figure 1.8 shows the model [81]) [45].

NYC, being the world's most powerful country's financial capital in the American state of New York, hosts some of the world's most famous skyscrapers (see Figure 1.9 for location in the world map [82]). NYC, otherwise known as the 'City of Skyscrapers' of the USA has the tallest building in America, the 'One World Trade Centre', at 1776 feet (See Appendix, Figure 1.10 [83]) [45].

Similarly, Mumbai being the financial capital and a major metropolitan city in the Indian state of Maharashtra that houses some of the tallest buildings in the country, is also close to my home state (Kerala) in India (see Appendix, Figure 1.11 for location in the world map [84]). 9 of the 10 tallest buildings in India are in Mumbai. For e.g., 'Palais Royale' which is under construction and to be completed in 2020, will be the tallest building in India at 1050 feet (See Appendix, Figure 1.12 [85]) [18].

1.7 Problem Context

I see elevators as a complex world unexplored. Especially in today's world where the earth is getting depleted of land to construct, for the want of saving natural resources, companies are taking it to the skies. 'Vertical cities' are being built everywhere, to which not cars, buses or trains can take the millions of people up and down a building – only elevators can. So, it is a must that regional elevator safety regulations and standards be followed to ensure hazards are avoided, enhancing passenger safety.

However, as with all systems, elevators certainly have risks and hazards that follow it before, during and after elevator installation. Each country in the world may have different regulations and standards for elevator availability and maintenance. I feel that elevators deserve more care and attention than what they are getting at the moment, especially since they are very important for vertical commuting. So, it is about time to shed some light on my point of view of handling this problem of elevator risk and availability.

The sky is no limit when it comes to tall buildings, high-rises and more popularly, 'skyscrapers'. According to a source in Elsevier, 'high-rise' does not have a clear definition as it varies between countries depending on the building codes, region, etc. However, generally it is defined as a 'building that has between seven to ten stories or has a height between 75 feet and 100 feet'. Whereas, the same source says that the word 'skyscraper' is 'just a fancy term that is exaggerated to communicate people's excitement about tall buildings' [72]. The Council on Tall Buildings and Urban Habitat further classified 'tall buildings' (buildings less than 980 feet high), into 'supertall' and 'megatall'. The former is defined as buildings that is 'at least 980 feet or higher', and the latter ones are defined as buildings that are at least '1968 feet or higher'. As of 2018, there are '136 supertalls and only 3 megatalls globally' [73].

However, builders these days are competing among themselves to see who builds the tallest building. In almost every corner of the world, there will be a high-rise building used for official or residential purposes. An article in a magazine shows that nearly 70% of the world's population will be living in cities by 2050, i.e., approximately 7 billion people [38]. The world is rather at a stage where there are "more cities being built in the sky", as rightly said by Amit Gossain, MD of Kone, India. Thus, it is inevitable that there exists vertical transportation, to move people and goods up and down the building [20].

However, the interesting part here is that as tall buildings continue to be built for residential and commercial purposes in all parts of the world, the safety and availability concerns arising around the EDs built within and outside of these buildings are becoming a major topic of discussion for the public. People are not feeling safe enough while traveling up and down the high-rises. Modern EDs are fitted with several safety devices that prevent EDs from free-falling and crashing. Despite this, various reports and news articles show that ED related hazards are at a rise and necessary steps with respect to ED safety, reliability and maintenance need to be taken by the ED authorities to prevent future hazards and to improve availability [38].

The problem here is that, each region's authority handles ED installations, repair and maintenance activities differently, giving it varying degree of regulations based on the significance of the hazard. However, if they are not repaired, maintained or even upgraded in a timely manner, it can lead to accidents. As various elevator and escalator companies use different technologies for their assemblies, controls and components in their EDs, it is important to get certification, knowledge and experience working with them. Hence, only trained and certified professionals must be hired to maintain them [22].

It is important to ask a few important questions regarding this varying level of regulations. Could this be related to the popularity or the number of EDs available in a country or region? Are there communication gaps between stakeholders responsible for repairing faulty EDs or maintaining them? Is there any time limit as to how long it should take to repair this? Should any priorities be given to care homes and hospitals, over residential or commercial buildings? How do these regulations impact the hazards caused by ED failures? Finding answers to these questions at the end of the study would make this research more interesting.

Another area of concern to the public is the availability of EDs when they are functional. Time is precious and EDs help us save time. However, people are concerned that the number of elevators available in residential and official buildings are far less in number than what is required, as per the occupancy and size of the building. This is increasing their waiting time for the next available ED to arrive, and hence causing delays for meetings and other purposes. Not just that, people are also concerned that there are no multiple EDs available when one fails [23].

In my opinion, anyone before buying a flat or apartment, takes time to learn about how tall the building is and if elevators are available to commute. Some might even take a step further to look at the model and make of the elevator to make sure it is manufactured by a renowned name such as Otis, KONE, etc. From personal experience, use of elevators is not as popular in India compared to the western world, for some members of the Indian public, it is gradually becoming a status symbol to show their friends and family that vertical transportation is available in their building.

Decades ago, buildings were hardly even four stories high. Today, with a growing population and the birth of skyscrapers, malls, complexes, vertical transportation is a need of the hour. Not just that, ground-level and up to two-story older buildings are getting rebuilt into taller buildings, so that more people can be accommodated. This has seen a rise in the demand for vertical transportation, which today despite having its own risk and safety concerns, is more efficient, reliable and fast, than those available years ago [38].

1.8 Elevator Etymology

When we hear the word "elevator", we always think of the elevator that takes us up and down a building. There is more to it. The word "elevator" came into existence in the mid-17th century from a Latin word, "*elevare*", which means 'to raise'. In the commonwealth nations, elevators are known as "lifts". A popular dictionary defines elevator as "a platform or compartment housed in a shaft, for raising and lowering people or things to different levels" [33]. So, an ED is any vertical transportation system that raises or lowers passengers or goods within or outside a building [13]. The key words here are 'raise and lower people or things'. This means EDs can be used to transport people and things. The elevator shaft is the vertical space through which the elevator moves between floors in a building (See Appendix, Figure 1.13 [86]).

1.9 History of Safety Elevator

Elevators and escalators have long been the safest and the most reliable means to travel within buildings. According to an article in an encyclopedia, "In 1853, American inventor Elisha Otis (See Appendix, Figure 1.14 [87]) designed and installed the first safety elevator, which was then called the 'safety hoist', that had an automatic safety device to prevent it from falling if the lifting chain or rope broke. He demonstrated to a public gathering his free-falling safety lock mechanism in 1854 (See Appendix, Figure 1.15 [88]) when he ordered the rope be cut. The public were astonished when the lift fell only a few inches before it came to a complete stop. In 1857, he installed the first safety elevator for passengers at a building in New York."

Later, his invention laid the foundation for what today is one of the largest elevator manufacturing companies in the world, Otis Elevator Company. Otis also discovered the fact that "if an ED is descending faster than its normal operating speed, it causes a copper or silicon nitride brakes to slow the ED down the rails in the shaft, halting the ED smoothly not causing any injuries. This device was called 'governor'" [34].

1.10 Characteristics of EDs

According to me, an ED must possess certain characteristics for it to serve its intended purpose of transporting people and goods (Figure 1.16). I have provided a description of these in Table 1.1.

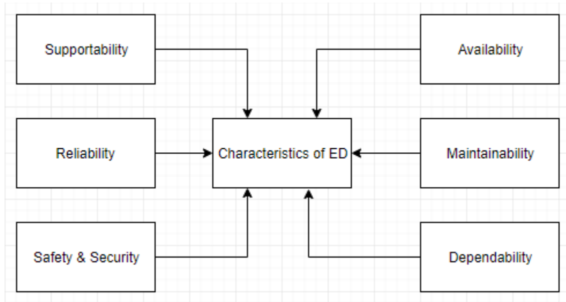


Figure 1.16: Characteristics of EDs

Characteristic	Description
Supportability	the ED must function normally without frequent repairs or maintenance issues
Reliability	the ED must be functional, with no outages or malfunctions, for a certain period, given certain conditions. In other words, the uptime (the period when a system is being used without any problems [75]) must be the maximum possible time
Maintainability	Is the probability of a repair being done within a time frame, yielding positive outcome. Essentially, this measures how easily and quickly an ED can be fixed once it has been found that it is malfunctioning
Dependability	is the ability for an ED to function when it is necessary. It is in fact a superclass of the above three characteristics
Availability	is the accessibility of an ED for transporting passengers and goods. The right number of EDs should be made accessible at a premise to minimize waiting time
Safety & Security	the ED must be safe and secure for passengers and/or goods to be transported without risks

Table 1.1: Characteristics of EDs and their description

1.11 Big Names in ED Industry

When we think of EDs, there are a few manufacturer names that immediately come to our mind. In India, it is Johnson Lifts that is most popular. However, there are a few other major globally popular manufacturers that provide services in Toronto, NYC and Mumbai. Table 1.2 shows the largest ED manufacturers and their profiles, including data on their ED sales / revenue as of their respective available dates [26] [38].

Company Name	Headquarters	Revenue (US$ billions)	Number of Employees	Data (Year)
KONE	Helsinki, Finland	9.31	52,000	2016
Otis	Farmington, Connecticut	12	66,000	2015
Schindler	Ebikon, Switzerland	9.56	58,271	2016
ThyssenKrupp	Essen, Germany	7.62	50,000	2016
Toshiba	Tokyo, Japan	2.12	12,000	2014
Fujitec	Hikone, Japan	1.57	9,486	2016
Mitsubishi	Tokyo, Japan	11.1	138,700*	2017

Table 1.2: Major ED manufacturer profiles

*Mitsubishi employee count includes their staff in elevator units and their other electrical and electronic units.

For better interpretation, I created a graphical representation of the revenues, as shown in Figure 1.17. It is clear the top four elevator manufacturers by revenue (US$) are Otis, Mitsubishi, Schindler and KONE.

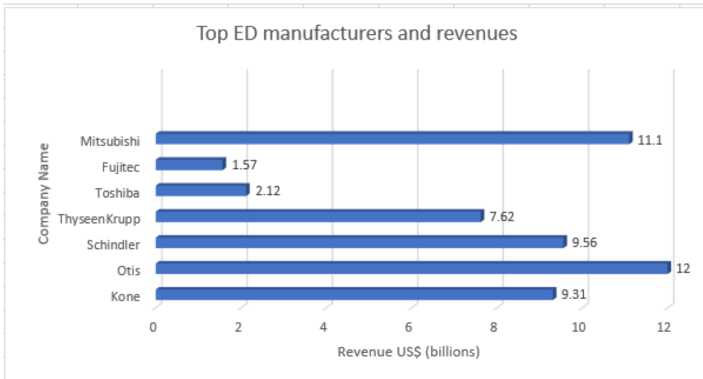


Figure 1.17: Revenue of top ED manufacturers

1.12 Types of EDs

It is important to note that there is a whole family of EDs that use the mechanism of elevating and lowering people and things between levels. So, let us briefly talk about some of these devices, stating that in this thesis, the only EDs we will be using in examples and research papers are passenger elevators, escalators, and moving walks. This is presented in Table 1.3 below as Figures 1.18 [89], 1.19 [90] and 1.20 [91], respectively. Where the remaining are presented in Appendix Table 1.4. This is because the former ones are the most widely used EDs by the public, as opposed to other types which are used only by certain groups of people, owing to their occupation or physical condition.

ED type	Description	Image
Passenger elevator	Found in residential apartments, condos & commercial buildings to transport people between floors	 Figure 1.18: Passenger Elevator [89]
Escalator	Moving staircase that carry passengers between floors; found mostly in commercial buildings such as shopping malls; airports; railway stations, etc.	 Figure 1.19: Escalator [90]
Moving walk	Usually found in large airports to transport passengers and luggage quickly within the same level	 Figure 1.20: Moving Walk [91]

Table 1.3: Passenger elevator / escalator / moving walk, description and image

1.13 Types of Elevator Mechanics

Unlike section 1.12, which talked about the different types of EDs, this section talks about the different types of mechanics used to build elevators. According to an online article by ScienceStruck, "elevators work with the help of a powered electric motor which runs on either traction cables, counterweight systems or hydraulic fluids." The major types and subtypes of elevator mechanics are shown in Figure 1.30 [28].

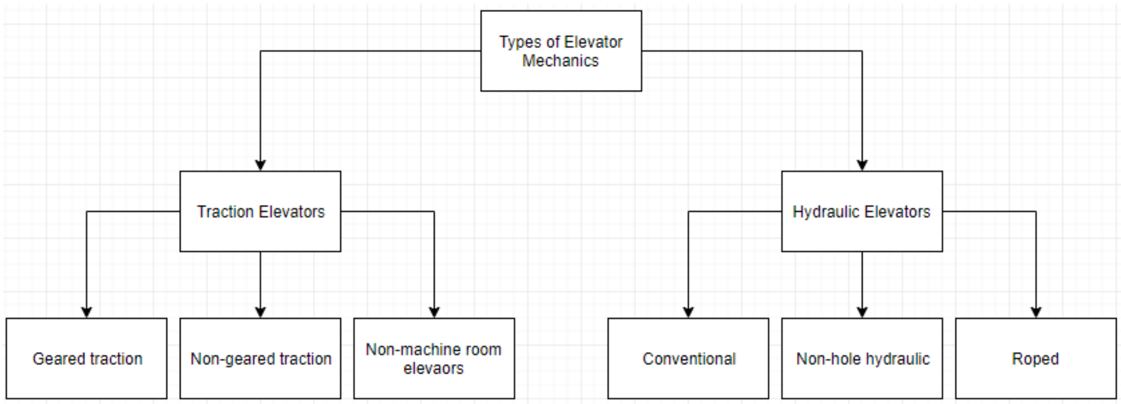


Figure 1.30: Types of elevator mechanics

1.13.1 Traction Elevators

"These elevators function with the help of a rope that passes over a wheel. This wheel is attached to an electric motor and when the motor is powered, the wheel moves, pulling the rope and lifting the elevator car. The wheel is placed in the machine room, at the highest floor of the building. The speed of the wheel and rope is increased by adding a counterweight to one of the ends of the rope, where the other end is attached to the car." There are three types of traction elevators as shown in Table 1.5: [28]

Type	Description
Geared traction	have a gearbox attached to the powered electric motor. This increases the speed, where the elevator can travel at almost 500 ft/min
Non-geared traction	do not have a gearbox, but the wheel is attached to the motor. This increases the speed, where the elevator can travel at almost 200 ft/min
Non-machine room elevators	in the above two types, the motor and the wheel are accommodated in the machine room. However, this type of traction elevator has both the wheel and motor above the elevator shaft, easing the access in case of repairs

Table 1.5: Types of traction elevators and their description

1.13.2 Hydraulic Elevators

"This type of elevator has a slower mechanism, as it includes a piston at the bottom of the elevator, which is controlled by an electric motor. This piston will push the elevator car (LCU) up or down upon pressing the floor button. It is very slow compared to traction elevators, because it can travel only to a maximum speed of 200 ft/min. Unlike traction elevators, the electric motor is placed in a machine room in the lowest level of the building. These types of elevators are normally used for buildings with less than 10 floors." There are three types of hydraulic elevators as shown in Table 1.6: [28]

Type	Description
Conventional	has a pulley that extends below the elevator pit. It provides support to the elevator while descending. The speed here is at 60 ft/min owing to the retraction provided to the piston
Non-hole hydraulic	hydraulic elevators have a hole below the pit for faster movement, but this type does not have a hole as their piston is on either side of the elevator car. This causes the speed to lower to 20 ft/min
Roped	in this, the piston and a rope on a wheel will move the elevator, which increases the speed to 60 ft/min

Table 1.6: Types of hydraulic elevators and its description

1.14 Elevator Door Types

The type of door being installed in an elevator is a critical aspect that plays a crucial part in enhancing safety of an elevator. There have been incidents owing to the use of manual doors, which are still functional in India and many other countries. For e.g., according to a news article online, a 12-year old girl died after being hit by lift as the swing door of the elevator had a broken window through which she stuck her neck out to see where the lift is [16].

1.14.1 Manual Doors

Manual door types are ones which involves human effort to open and close the elevator door once it reaches the desired floor. The different types of manual doors, their advantages and disadvantages, along with their image are provided in Table 1.7 [27].

Door Type	Advantages	Disadvantages	Image
Collapsible door	Robust; reliable; allows ventilation & natural light during power outages	Dangerous if children put their hands through the grills; difficult for children, the physically challenged or seniors to use their strength to open the door	 Figure 1.31: Collapsible door [101]
Swing door	Long life expectancy; durable; totally encloses shaft	Breakage of vision panel can lead to accidents	 Figure 1.32: Swing door [102]
Imperforate door	Fully closed; extra safe; small rectangular cut outs to see the other side	Hard to get ventilation or natural light in case of power outages	 Figure 1.33: Imperforate door [103]

Table 1.7: Manual door types and its advantages and disadvantages with images

1.14.2 Power-Operated Doors

Power operated doors are ones which automatically open without any human intervention when a desired floor arrives. The different types of power operated doors, their advantages and disadvantages, along with their image are provided in Table 1.8 [27].

Door type	Advantages	Disadvantages	Image
Center opening door	Opens from the center; safest and most widely used in the world; time-bound and closes automatically; sensor-based	Injury prone if the passenger does not get inside the lift before the door closes	 Figure 1.34: Center opening door [104]
Telescopic opening door	Opens from the left side; widely used; takes less space; rest of the features are the same as Center opening door	-do-	 Figure 1.35: Telescopic opening door [105]

Table 1.8: Power operated door types and its advantages and disadvantages with images

1.15 Summary

In Chapter 1, I started by talking about my thesis objective; what I expect to learn and achieve from the project; a brief description on who would benefit from the project; the sources I would be using to carry out my research; a flowchart which demonstrated my methodology to achieve my objective; a brief description of why I chose the selected regions; the problem context explaining why the chosen problem is interesting; the gist behind the word ‘elevator’; a brief history behind the first demonstration of safety mechanism; a brief description about the big names in the ED industry; brief description of the various types of EDs and their mechanisms; and ending with the different types of doors used in EDs.

CHAPTER 2

GENERAL LITERATURE ON ED SAFETY & REGION-WISE AVAILABILITY SITUATION

2.1 Introduction

In this chapter, I will be providing some general safety tips while exiting and entering passenger elevators, escalators and moving walks; safety devices that are included in elevators and escalators; use of sensors in ED; why ED maintenance is important; stakeholders and communication between them; ending with a discussion on the current ED availability situation in the selected regions.

2.2 Passenger Elevator Safety Tips

Before getting into the core literature review on the region-wise qualitative and quantitative data; and modelling methods, I want to give the readers and all users some basic safety tips while entering and exiting a passenger elevator (Figure 2.1). It is a known fact that an ED should never be overload (a load greater than what a machine is designed to carry). It should always be within the rated load (the load a machine is designed to carry) [71]. Apart from this, there are other important tips to be aware of as daily ED users. According to an online newspaper, there was a major elevator accident, where a 58-year old lady fell from the 7th floor and died, as she entered empty space when the elevator door opened, and she did not notice the car was not there [17]. Incidents like this can be avoided if passengers are more careful while using EDs.

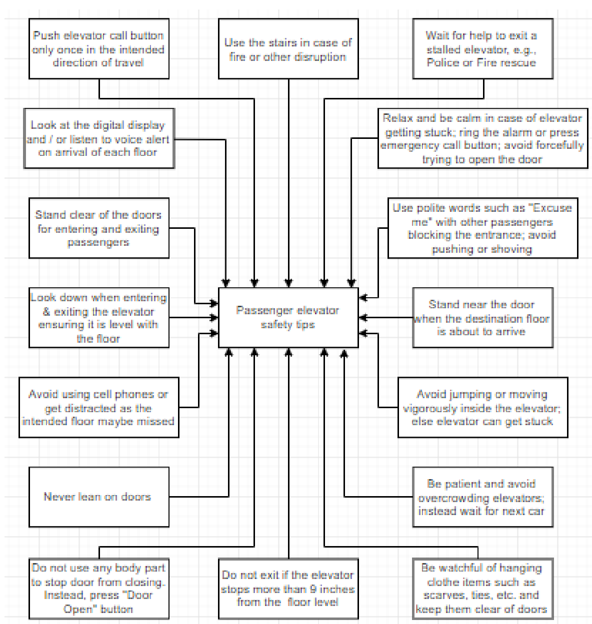


Figure 2.1: Passenger elevator safety tips

2.3 Escalator & Moving Walk Safety Tips

In this section, like section 2.2, I want to give the readers and all users some basic safety tips while entering and exiting an escalator and / or a moving walk. Let us look at this in Figure 2.2 below.

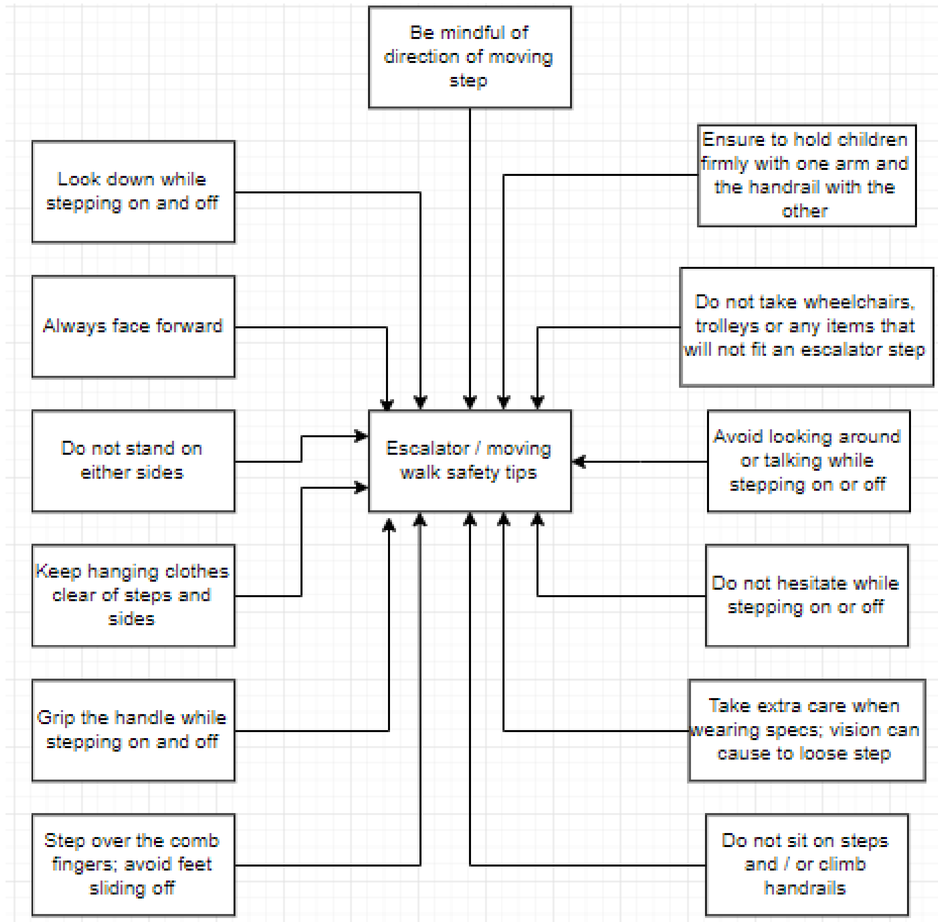


Figure 2.2: Escalator and moving walk safety tips

2.4 Safety Devices in EDs

All EDs are prone to risks and accidents, even if a commuter is careful, because there are other technical means by which an ED can be prone to risks. In view of this, it is crucial for ED manufacturers to affix all mandatory safety components into an ED and test to make sure they are functional. While the technology used to construct an ED is changing every day with new safety features being added and different ED manufacturers using different mechanisms to build EDs, there are some basic safety devices that must be present in elevators and escalators.

2.4.1 Safety Devices in Elevators

Table 2.1 shows information from an online source with some critical passenger security features that an elevator must have irrespective of the make or model [37]. Figure 2.3 below shows a diagram of the major devices and components used in elevators to enhance safety as reported in [11].

FEATURE	DESCRIPTION
Emergency back-up battery	Rechargeable back-up power; turns on automatically during power failure
Emergency lowering device	When turned on, passenger can select a lower level floor and exit when it reaches
Emergency lighting system	Turns on the lights in the elevator
Alarm	Activated to alert someone when a passenger needs help
Door interlocks	Installed at door entrance to prevent opening of door unless it is closed or level with the floor
Infrared light curtain (only for accordion doors)	Runs adjacent to the door and creates an invisible shield to the entrance; crossing this shield will halt the elevator
Elevator door contact	Located on top of elevator; stops elevator from operating unless door is closed
Flow control valve	Regulates speed of elevator
Handrail	To provide gripping support to passengers
Telephone	Landline telephone inside the elevator to use in case of emergency
Slack cable device	Halts the elevator and withstands the load if a cable loosens or snaps
CCTV camera	To capture any incidents or assaults taking place in the elevator
Levelling device	Two-way device which halts elevator within 13 mm of the floor level to avoid passengers tripping
Final limit switch	Stops all power to the elevator if the upper normal terminal stopping device fails
Separate open/close button for twin-door elevators [41]	Passengers may be unaware when a floor has two opening doors on a floor; to avoid incidents there must be separate buttons for each door
Imperforate doors	Safest type of elevator doors compared to other door types
Fire resistance	All elevator doors must have a fire resistance rating of 60
Cable-based EDs	Safest form of ED system compared to other types
Hoist cables	Build EDs with 6 hoist cables; 12 in high-rises & tall buildings; each cable can support full weight of ED + ~25% more weight; ED will not fall or crash even if a cable snaps [40]
Spring / Polyurethane / Telescopic oil / hydraulic buffer	Install this at the top or bottom of the elevator shaft to cushion any impact
Borehole jack	Installing this protects the ED from corrosion; removes tedious and expensive process of ground drilling
Vent	Lift shafts must have this at the top with an area of at least 0.2 meters^2

Table 2.1: Elevator safety features and their description

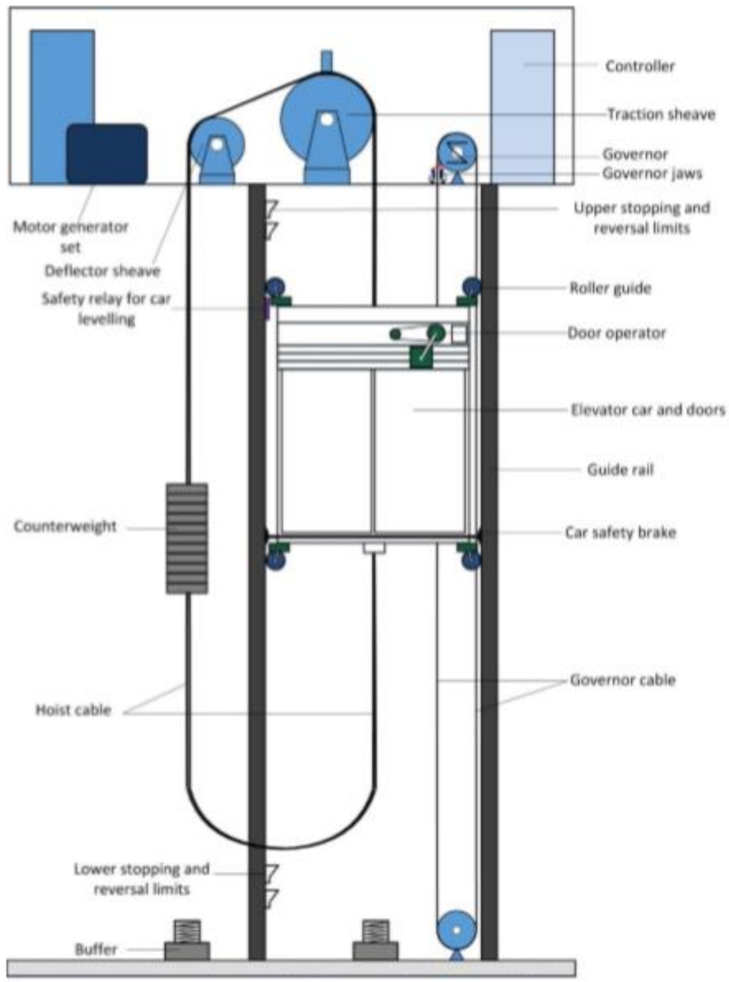


Figure 2.3: Elevator safety features [11]

2.4.2 Safety Devices in Escalators & Moving Walks

According to a research [11], escalators and moving walks were categorized as passenger conveyors and it discussed the safety devices an escalator has. The author writes that according to Mitsubishi Electric, there are 16 basic safety features in escalators. Figure 2.4 below shows the number labels [11], for which the label name and description are given below in Table 2.2.

Label number	Label name	Description
1	Emergency Stop Button	Used during emergencies, e.g., passenger falling; immediately activates escalator's breaking system
2	Step motion safety device	Activates braking system stopping the escalator in case of objects trapped, or dislocation or abnormality of step motion
3	Overload detection device	Stops the escalator if it is overloaded owing to abnormal temperature or current
4	Speed governor	Stops the escalator if the speed increases or decreases to 120% of the normal speed
5	Electromagnetic Brake	Stops the escalator if power fails or if any safety device is active
6	Drive chain safety device	Stops the escalator by applying the safety break if the drive chain breaks or stretches over a set limit
7	Handrail speed safety device	Stops the escalator if the handrail slips, loosens or breaks, or if there is a speed variation, it turns off the power
8	Step level device	Stops the escalator if the horizontal level of a step has dropped
9	Skirt guard safety device	Stops the escalator if a shoe lace or a long hanging piece of cloth is trapped between the steps
10, 11, 12, 13, 15, 16	Comb-safety switch; Handrail guard safety device; Missing step device; Step chain safety device; Door open switch; Three elements	Other safety devices installed in escalators; detect a specific problem and stops the escalator
14	Auxiliary breaks	Stops the escalator if the current speed exceeds normal speed

Table 2.2: Escalator safety features and their description

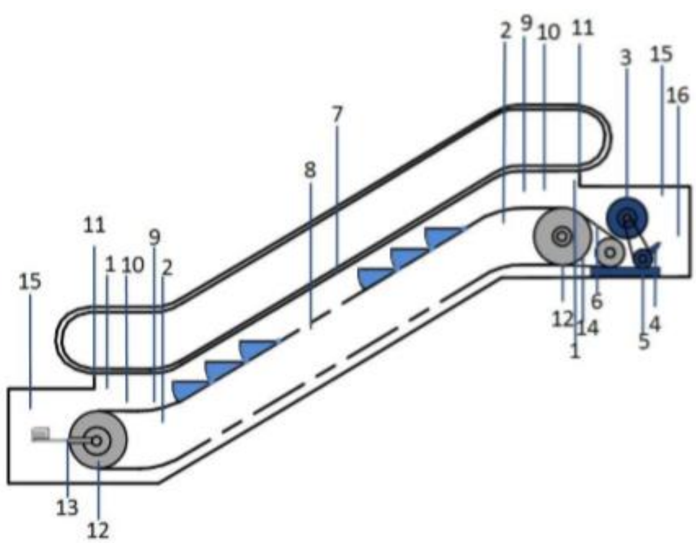


Figure 2.4: Escalator safety feature labels [11]

2.5 <u>Sensors in EDs</u>

Another interesting area to look at when it comes to EDs is the use of sensors. According to a research paper, "A sensor is a device which converts a physical quantity into a signal used by an observer or an instrument. It provides information about presence or absence of an object" [67]. There are various kinds of sensors that are used in EDs according to [67] [68] [69] as shown in Figure 2.5 below. These are briefly described in Table 2.3.

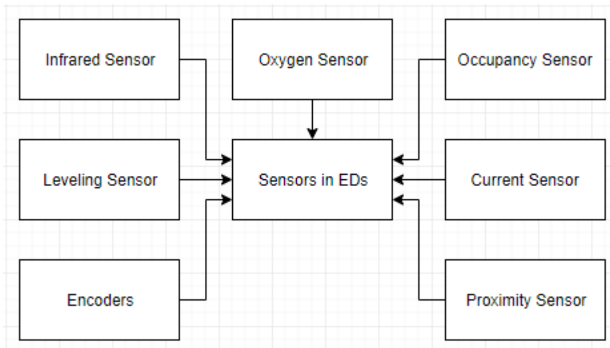


Figure 2.5: Sensors used in EDs

Sensor type	Description
Infrared Sensor	this is used as an 'Obstacle detector'. When the infrared transmitter (LED) emits radiation, it reaches the object and some radiation reflects onto the infrared receiver. This infrared transmitter is invisible to the human eye. Infrared receivers can be photodiodes, phototransistors, etc.
Oxygen Sensor	also known as a lambda sensor in an electronic device that measures the proportion of Oxygen in a gas or liquid. It is used in an ED to protect people during emergency when the lift is blocked and if the oxygen level in the car decreases. So, this sensor will detect if the oxygen level has reached a minimum level. In such a case the car will move to the nearest floor and it will open the door.
Occupancy Sensor	this sensor senses if the load in the car is at or less than the minimum level for enough time. If this is the case, then it will turn off the lights and fans. Contrarily, when there is overload, the motor will stop and will restart only when the load is below the maximum. When there is an overload, a buzzer will also ring to warn people about it.
Leveling Sensor	this transmits floor number of the ED car to control center to activate brake mechanism and ensure ED stops at the chosen level. This is done by 'smart positioning sensors' or 'optoelectronic sensors' which are mounted on elevator shafts or on top of the ED car [68].
Current Sensor	detect motor's working current based on which the power of moto could be adjusted to a proper level [68].
Encoders	are used to deter motor's rotation speed to control the motion and position of ED car [68].
Proximity Sensor	are round sensors with wire leads attached. They send signals to the door control panel which controls both when the door opens and closes and at what speed it should do this [69]

Table 2.3: ED sensors and their description

2.5.1 <u>Use of Data in ED Sensors</u>

According to a research [70], wireless sensors would have a key role to play, overtaking the wired systems currently in use in elevator devices. The challenge in the former is how the data transmission would take place from sensor nodes to the base station. The essence of the research is by using elevators itself to assist with data collection, where the elevator has a base station attached onto it. Then each floor has a representative node that collects and transmits data to the base station using short range communication when the elevator halts at or passes by any floor. So, the observations were made when the elevator was in motion. This way communication distance can be minimized.

The problem was formulated as an optimization problem. The data traffic was transmitted on time to maximize the gain and the lifetime of sensors, but to minimize the communication distance. So, the authors showed in the research that if the movement pattern of the elevator is known beforehand, they can solve the problem optimally. This would therefore improve the data collection performance. They also discussed how varying levels of knowledge of elevator movements could be used to collect data and develop algorithms based on this knowledge [70].

2.5.2 <u>Internet-Connected Elevators</u>

An online article [25] talks about how "elevators have entered the world of IoT. It is a collaboration between Microsoft and ThyssenKrupp. The focus of their work was based on using IoT technology to eliminate delays caused by maintenance requirements.

The gist of the technology is that the operating companies are alerted when faults happen or are about to happen, allowing lift operators to save time and money on repairs. This is done by attaching sensors that collate data about the elevators usage and other factors that impact the lifespan of elevator components. This information is passed onto Microsoft cloud-powered Azure IoT platform which processes the data and make predictions on when the maintenance would be needed accurately. This way, it would be easier to predict breakdowns before it happens and allows action to be taken well in advance" [25].

2.6 Importance of ED Maintenance

It is important to do regular and timely maintenance of an ED. Of course, different region's authorities have different intervals of conducting it, but it should be done for the advantages as explained in [29]. These are shown in Figure 2.6.

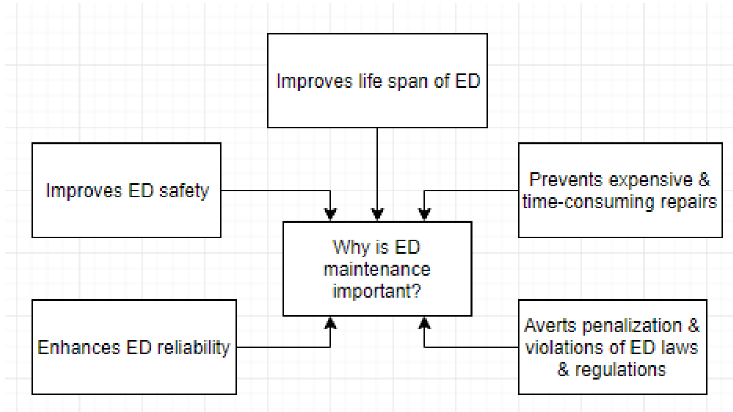


Figure 2.6: Benefits of ED maintenance

2.7 Stakeholder Entities

There are a set of stakeholder entities involved with the ED industry in all regions as given in [13]. These are shown in Figure 2.7. A brief description of these are also shown in Table 2.4.

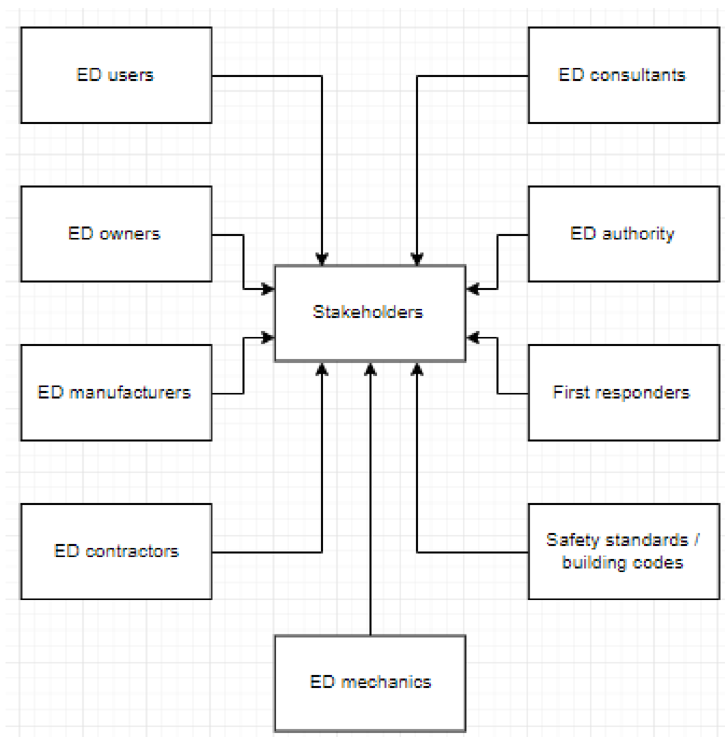


Figure 2.7: Stakeholders in ED industry

Stakeholder	Description
ED users	this cohort includes the public who use elevators on a day-to-day basis. For instance, patients, seniors, professionals, children, tenants, people with mobility issues, etc.
ED owners	all EDs have licensed owners. It could be the owner of the building, the owner of the rental property, manager of the building or a representative of the building manager
ED manufacturers	these are the big names in the ED industry, namely KONE, Otis, Schindler, ThyssenKrupp. In Mumbai, Johnson Lifts are very popular manufacturers. They are the ones who build EDs and its components. They constantly innovate EDs to improve their safety and reliability
ED contractors	these are the people who hire mechanics to repair and maintain EDs. They must be registered with the ED authority and report any faults or maintenance for EDs that are under their supervision
ED mechanics	they are the ones who repair and maintain EDs. They are usually trained and certified by the ED authority
ED consultants	they are the advisors to architects, building constructors and developers on the right choice of EDs, or even advise building owners about ED maintenance and upgradation
ED authority	the government body accountable for enforcing laws and standards to safeguard public safety, and those related to EDs. They are also responsible for investigating accidents arising from EDs and spreading general awareness about safety measures to avoid incidents
First responders	are the rescue personnel who are responsible for addressing emergencies in a timely manner. They include firefighters, police, paramedics, etc.
Safety standards / building codes & regulations	are the ASME / CSA / BIS standards and region-wise regulations, along with the IBC, NBC, etc. All the above-mentioned stakeholders must be aware of these for their respective regions.

Table 2.4: Stakeholders in ED industry and their description

Currently there are no laws or regulations governing the communication that takes place between these stakeholders and regulations in the chosen regions. It is my intention here to present an ideal two-way communication flow between the above entities, as shown below in Figure 2.8. Why this is important is because from my reading so far about the current ED situation in the regions, I understand that there is a lack in flow of information. So, for e.g., in Toronto (Ontario), the communication of ED faults and complaints from residents are not being passed to the the right authority at the right time by the building owners or representatives, for the reluctance of spending money, or to such an extent that there is a confusion on who holds responsibility of making arrangements for the repair. Hence there is significant delay in action taken, leading to ED availability issues [15].

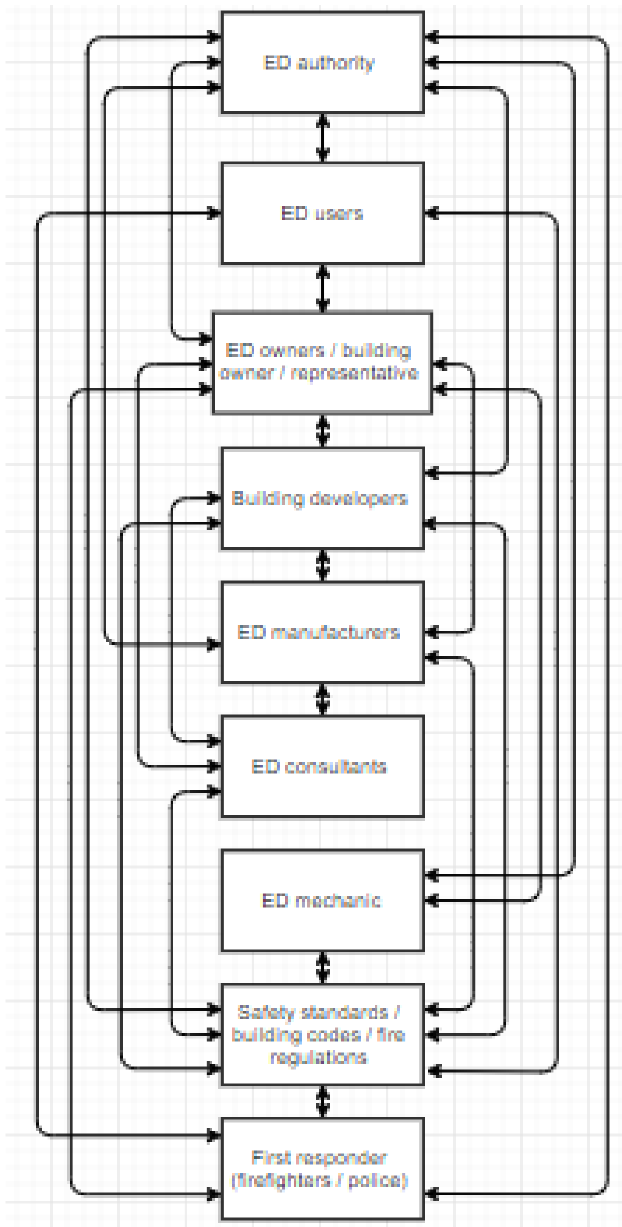


Figure 2.8: Communication between stakeholders and regulations

2.8 ED Availability Situation in Ontario

Figure 2.9 shows the current ED availability situation in Ontario [13] [14] [23] [24]. Information specific to Toronto is unavailable.

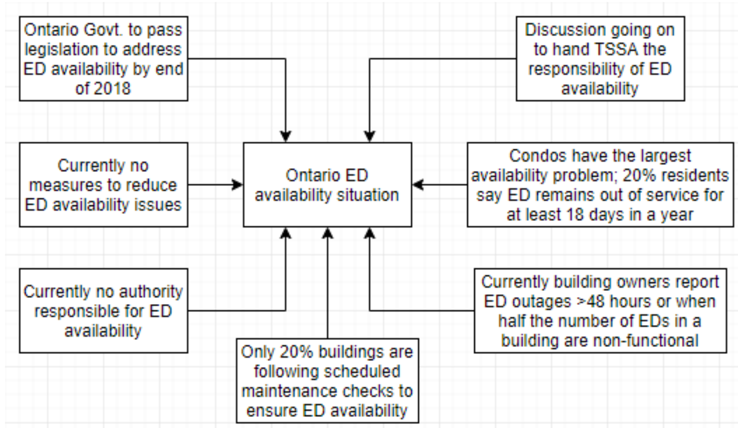


Figure 2.9: Ontario ED availability situation

2.9 ED Availability Situation in NY

According to a news article, "Escalators and elevators in New York's subways are constantly out of service because more than 80% of them don't get the timely maintenance. For e.g., out of 407 escalators and elevators, 65 were checked, out of which scheduled maintenance was performed only on around 50 of those. It says that the maintenance is a mess, with no proper planning, tracking, or authorizing any persons to be accountable for this. Seniors and disabled are not able to commute because of unavailable elevators and escalators". It says that the "government is failing them" [78].

Another news article says, "Private elevator inspectors in NYC are allegedly missing dangerous violations and allowing unsafe conditions to go unrepaired". During their audits, the DOB inspectors found false elevator inspections and safety hazards that were missed [79]. It is unacceptable that despite DOB's strong elevator regulations, in a well-developed vertical city such as NYC, where millions of people use elevators daily, false inspections are happening. This will lead to safety hazards and availability issues for commuters. The key here is to enforce stronger DOB regulations and monetary penalties to ensure private inspectors and building owners perform timely inspections thoroughly [79].

2.10 ED Availability Situation in Mumbai

According to a magazine [38], there are residential apartment buildings in Mumbai that have 12, 15 or even 18 apartments in a single floor. It is crucial to ensure that there is enough vertical transportation access and availability in these buildings. The number of floors in such buildings can go up to 12 floors. If there are not enough number of lifts, it is going to be like what the SRA is doing, by cramming almost 18 small-sized (~300 sq. ft.) tenement-type apartments in a single floor, and not installing enough lifts. This often leads to long waiting times, and therefore fights. Developers do this with the objective of saving money, but they fail to realize that it is not going to do any good to people, who are the prime users of the building and elevators [38].

The building height limit in Mumbai is 300 meters, owing to Civil Aviation policies. Infrastructure needs must be considered when building tall, such that issues arising from access to buildings can be avoided. More number of government-approved lift inspectors are required. Private consultants and other qualified personnel should also be allowed to take on elevator inspection and installation roles so that the process time can be minimized [44].

In a time where user safety is the primary focus as far as vertical transportation is concerned, most multinational elevator manufacturers follow international standards for their products. So, the government and associated ED stakeholders must ensure to take all the necessary steps to avoid any potential disasters.

Briefing on the overall EDs situation in India, according to the MD of Kone India, currently only eleven states in India have legislations and laws governing installation and maintenance of elevators. That means, almost 67% of the country has no elevator laws and hence no authorities. Moreover, different authorities administer these acts with no uniformity among states. Owing to this, even renowned lift manufacturers are finding it difficult to comply. Moreover, this attracts unreliable companies to install poor quality lifts that do not meet the required safety standards, putting many millions' lives at stake. This in turn attracts greedy investors towards investing into low cost products.

To resolve this problem, a feasible solution is to introduce a single suitable legislation governing the installation and maintenance of elevator devices throughout the country that obeys the BIS specifications. This will ensure uniformity of laws across the nation and hence the safety of the citizens. This will also keep away unreliable elevator manufacturers and improve product quality [44].

2.11 Summary

The purpose of this chapter was to educate readers and all ED users on some of the safety features and best practices that must be followed to prevent hazards on passenger elevators, escalator and moving walks. It was more of a preface to the entire thesis going forward. I also wanted to shed some light on the stakeholders involved so that readers and users know who all work behind the complicated world of EDs. I found it interesting to learn about the different sensors used in elevators and their applications in research and technology, such as IoT; a brief look at the benefits of maintenance and the elevator availability situation in each of the regions gave an understanding of the popularity, growth and extent of usage of EDs there.

CLIENT REPORT

SUMMARY

The aim of the study is to investigate the elevator devices' (ED) regulatory control in Toronto, New York City and Mumbai. Hence, to develop an Influence Diagram that models the impact of the different degrees of regulations on the consequences failures of elevator devices have on users. The purpose of doing this project is to address a growing concern among users of EDs on the potential risk and unavailability issue it is causing in the community today.

Initially, a detailed review on the present situation of each region's EDs hazard occurrences; standards, laws, regulations and codes pertaining to buildings and EDs were explored. Quantitative and qualitative data relevant to the objective were gathered and presented in tables and diagrams. This constituted the first part of the objective, which was to be used as the input to the second part.

Various risk modelling methods such as Petri Nets, Bow-Tie, Fault Tree Analysis, Fuzzy Approach, ALARP and Bayesian Nets were reviewed. Its applications and previous research done on modelling elevator risk were studied and evaluated. Their features and benefits were assessed, and BBN was chosen as the method to model the data, as it suited the type of uncertain and missing information present in the collected data. Upon further review, Influence Diagram, being an extension of Bayesian Nets was used to model the objective, as it involved making certain decisions and associated consequences. This was supported by Influence Diagrams.

'Netica' from Norsys Software Corp was the tool used to model the problem. The key variables, decision and consequence nodes were chosen from the data gathered, that represented the problem. The nodal probabilities were populated based on insights from research. The Influence Diagram was developed, and the model was tested using several scenarios relevant to the problem. It was found that the model was able to advice on a course of action, upon processing different inputs, by taking into account its consequences.

The model's benefits and limitations were assessed by reviewing the extent to which it achieved its purpose.

CHAPTER 1
REGION-WISE ED SAFETY REGULATIONS
QUALITATIVE & QUANTITATIVE SPECIFIC LITERATURE

1.1 Introduction

In this chapter, I will discuss about the region-wise authorities overseeing activities related to ED installation, maintenance, modernization and repair; ED code committee; inspection types; building types and codes; standards and regulations; components supply; current data and statistics associated with EDs and the violations and hazards that have occurred; a brief description of the role of ISO on ED safety; ending with a table comparing key aspects related to EDs in Toronto, NYC and Mumbai. I have provided tables and figures for better interpretation where necessary.

1.2 Why I am doing this

I am doing this comparative study between the three regions to learn and understand about the safety regulations that are followed in each of my selected region. Hence, what is the impact and consequence of this on the ED hazards and availability. I want to know if the situation is different in each region. I want to gather available data (qualitative and quantitative) on the regulatory authorities, their standards, an account of ED hazards that have taken place, and related information from these regions based on the current situation and the recent past (last few years). I want to study this to evaluate which modeling method would be apt to model the different levels of regulations and the consequence it has on ED failures for users.

1.3 ED Authority for Toronto

Table 1.1 below shows key information about the ED authority in Toronto [13] [51].

Topic	Description
Organization name	Technical Standards and Safety Authority
Region served	Territory of Ontario
CEO / President	Bonnie Rose
ED safety Act / Bill	Technical Standards & Safety Act, 2000
Founded	1997
Organization type	Self-funded / Not-for-profit
Head office	Toronto
Total employees	~ 400
Purpose & Area of Service	Ensure public safety in EDs, Ski Lifts, Amusement Parks, Upholstered & Stuffed articles; Fuels, Boilers, Pressure Vessels and Operating Engineers

Table 1.1: Toronto ED authority key information

1.4 <u>Ontario ED Statistics</u>

Table 1.2 below shows key data on the EDs available in Ontario as of 2016 [38]. Data specifically for Toronto is unavailable.

Topic	Count
Population	13,448,494
Existing passenger elevator	41,677
Existing freight elevators	2696
Existing escalators	2071
Existing moving walks	43
Existing dumbwaiters	1153
Passenger elevator installation	933
Freight elevator installation	30
Escalator installation	88
Dumbwaiter installation	4
Elevator Code	ASME A17.1-2010/CSA B44.10
Elevator Trade Association	CECA, EESFC, NEEA, CSA, TSSA

Table 1.2: Ontario EDs statistics as of 2016

1.5 <u>Toronto / Ontario ED Hazard Data</u>

Figure 1.1 shows some quantitative and qualitative data on ED hazards I found through Canadian news sources and reports that highlighted some crucial information about how devastating the hazards associated with EDs is [15] [22]. A Canadian News source says that the “Ontario firefighters responded to 4,461 calls in 2015 from passengers to rescue them from elevators”. An elevator consultant says that the “elevator crisis is already taking place, rather than coming soon. The reliability of a large number of elevators is the worst it’s ever been.” [21]

Some data are specific to Toronto, where the rest are for Ontario in general. The most crucial and interesting piece of information I found is the fact that Ontario is the first jurisdiction in the world to establish standards and regulations for passenger elevator repair timelines [14].

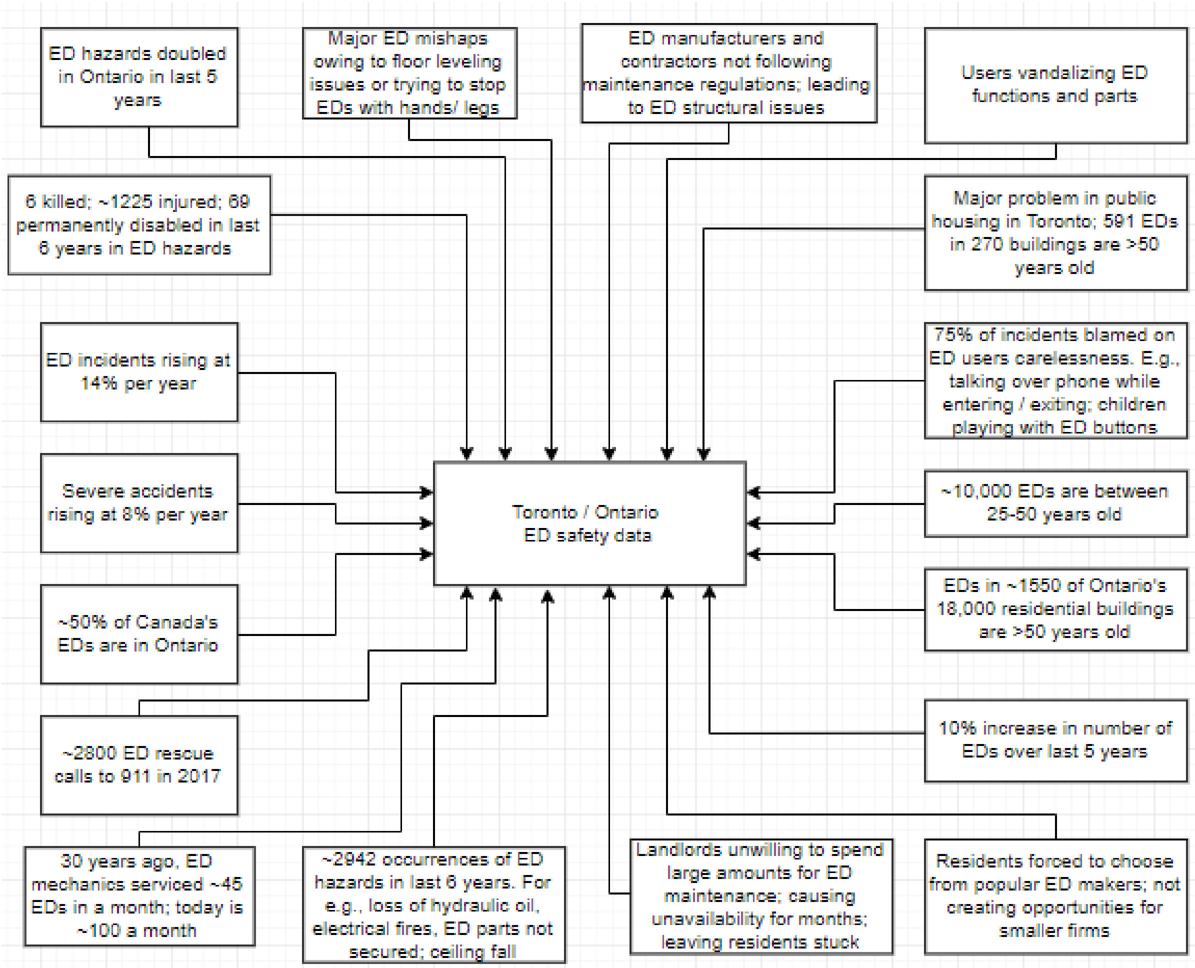


Figure 1.1: Toronto / Ontario ED safety data

1.6 ED Authority for USA

Table 1.3 and Figure 1.2 show key qualitative data I gathered about the overall ED authority for USA, i.e., NEII [39]. This includes its details and services. I am including this because I feel it is important to know how this authority regulates ED safety in comparison with the regional ED authority in NYC.

Topic	Description
Organization name	NEII
Region served	USA
Founded	1914
Purpose	National trade association of building transportation industry
Members	Firms that manufacture, install, repair and maintain EDs; including members of IUEC

Table 1.3: Key information about NEII

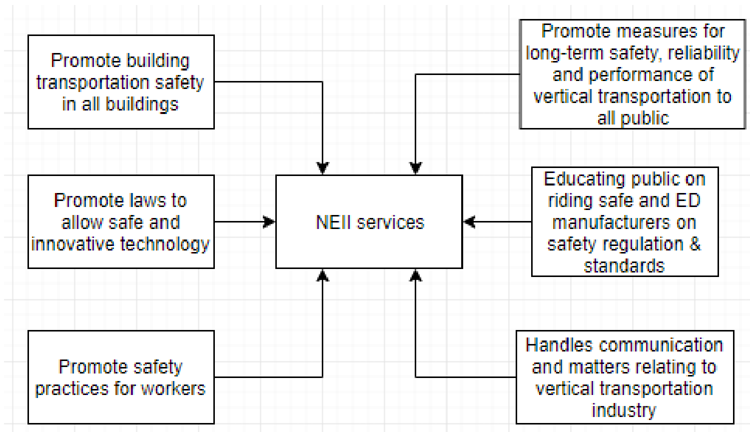


Figure 1.2: NEII services

1.7 ED Authority for NYC

Table 1.4 and Figure 1.3 shows the vital qualitative data I gathered about the ED authority for NYC [29] [50]. This includes its general features and its services.

Topic	Description
Organization name	New York City Department of Buildings
Region served	State of New York
Commissioner	Rick Chandler
Founded	1977
Total employees	~1200
Head Office	NYC
Purpose	Promote safety of all people that build, work and live in New York

Table 1.4: Key features of NYC DOB

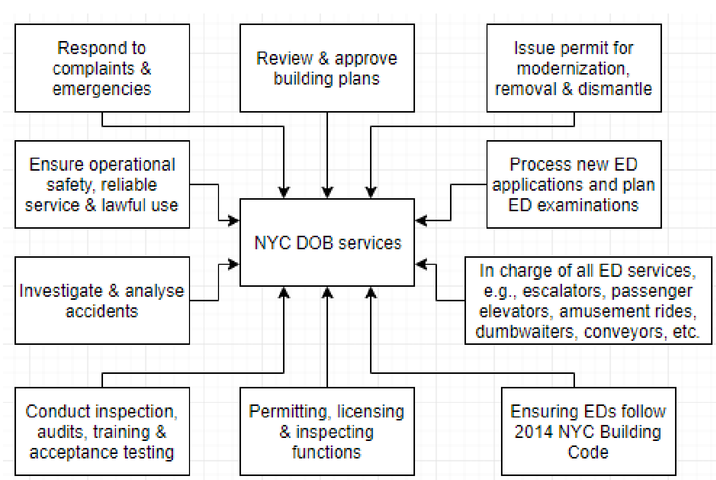


Figure 1.3: NYC DOB services

1.8 NYC ED Code Committee

The NYC Elevator Code Committee consists of various entities as shown below in Figure 1.4. This is the cohort of people who are responsible for keeping ED codes up to date and in line with building codes and standards [50] [52].

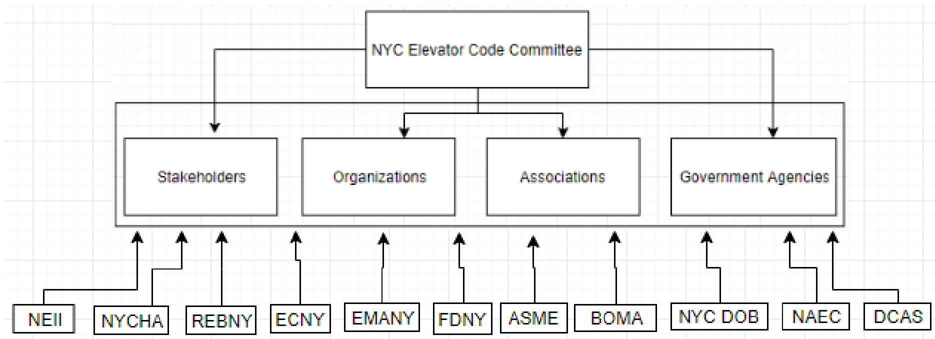


Figure 1.4: NYC ED code committee

1.9 NYC ED Violation Classification

Table 1.5 below shows how ED incidents arising from violations of ED regulations are classified according to severity of the violation [29].

Class	Description
1	Immediately Hazardous
2	Major
3	Lesser

Table 1.5: Class of NYC ED violations

1.10 ED Inspection Types & Categories

There are various types of ED inspections done by NYC DOB. Table 1.6 below shows this information. These inspections are done twice a year [50].

Inspection type	Description
Fast-track	For physically challenged & elderly care homes, high-rise and single-elevator buildings
In-depth	In case of hazards to passengers or death
Complaints	In case of any concerns raised by passengers or building owners or representatives
Acceptance	In case of approved applications for new ED installation
Amusement-ride	In theme parks, to ensure passenger safety
Violation	In case not abiding by ED regulations and or building codes, hence causing hazards
Quality assurance	To ensure proper functioning of EDs after installation

Table 1.6: Types of ED inspections

Apart from these types, Table 1.7 below shows the categories of ED inspections and its description. Inspections under these categories are performed by agencies licensed by NYC DOB. All other inspections are carried out by department inspectors [50].

Category	Description
1	Performed each year after installation with no load. Any defects found will be fixed in 120 days
3	Performed on water hydraulic elevators every 3 years from date of installation
5	Performed every 5 years from date of installation, with rated load and speed

Table 1.7: Categories of ED inspections

1.11 ED Installations, Modernization & Maintenance in USA

Below I have provided some qualitative data about the ED installations (Figure 1.5), modernization (Figure 1.6) and maintenance (Figure 1.7) for the whole of USA. Where available, information specifically for NY has been included [29] [50].

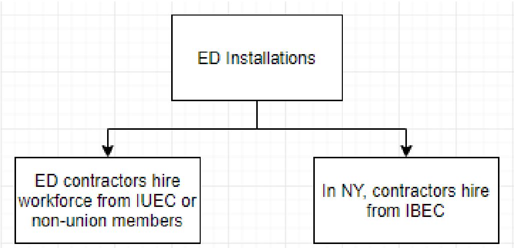


Figure 1.5: ED installation in USA

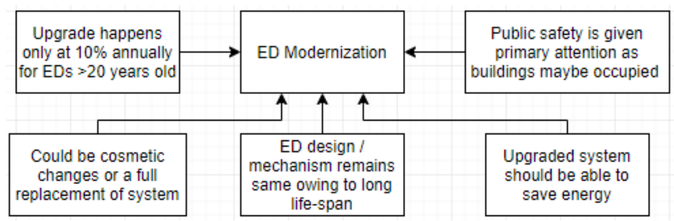


Figure 1.6: ED modernization in USA

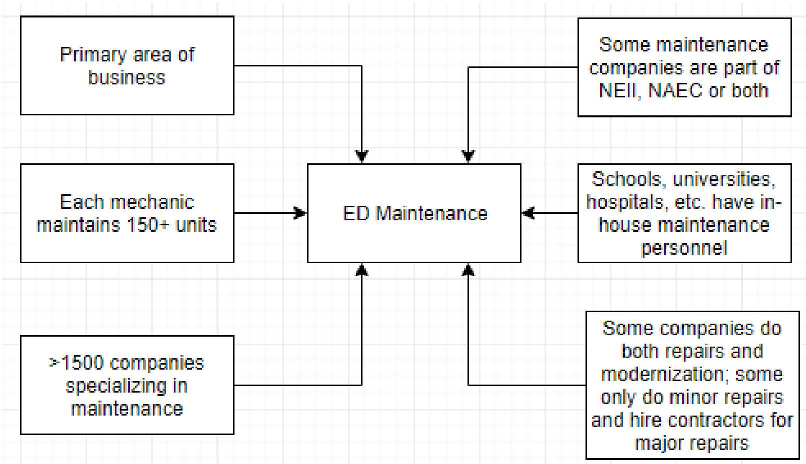


Figure 1.7: ED maintenance in USA

1.12 Components Supply

Some manufacturers supply equipment, rails, structures, machines, etc. Figure 1.8 and 1.9 below show the cost split of ED installed by a contractor and manufacturer, respectively [38].

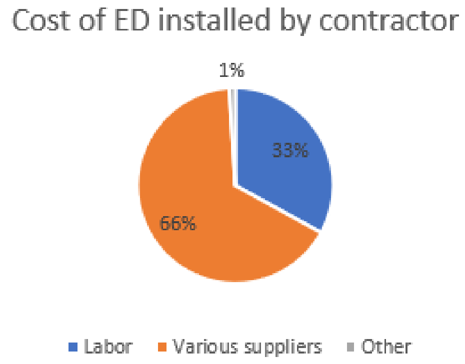


Figure 1.8: ED cost split if contractor installed

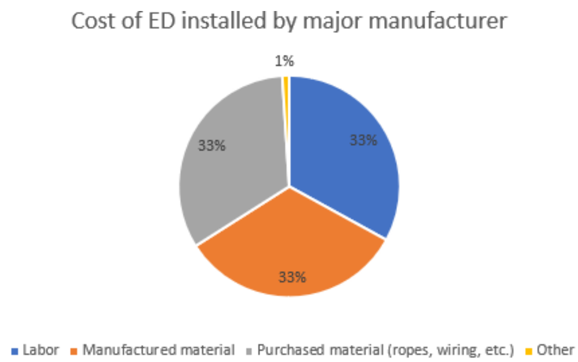


Figure 1.9: ED cost split if manufacturer installed

1.13 NY ED Statistics

Table 1.8 below shows key quantitative data on the EDs available in NY as of 2015 [29] [50]. Data specifically for NYC is unavailable. As per NYC DOB, in 2015 there were ~76,000 EDs in NY. In 2017, there were ~84,000 EDs [35]. The split is unavailable.

Matter	Count
Population	~19,820,000
Passenger elevator	66,602
Freight elevator	4,140
Escalator	2,663
Dumbwaiter	1,143
Sidewalk elevator	943
Private elevator	252
Handicap lift	227
Manlift	73
Public elevator	45
Elevator Code	ASME A17.1-2005
Elevator Trade Associations	NAEC, IAEC, EESF, AEMA, NEII, Elevator U

Table 1.8: NY EDs statistics as of 2015

1.14 NY ED Usage & Safety Violations

Figure 1.10 shows qualitative and quantitative information on the ED usage and safety violations that have taken place in NY as of 2017. Data specific to NYC is unavailable.

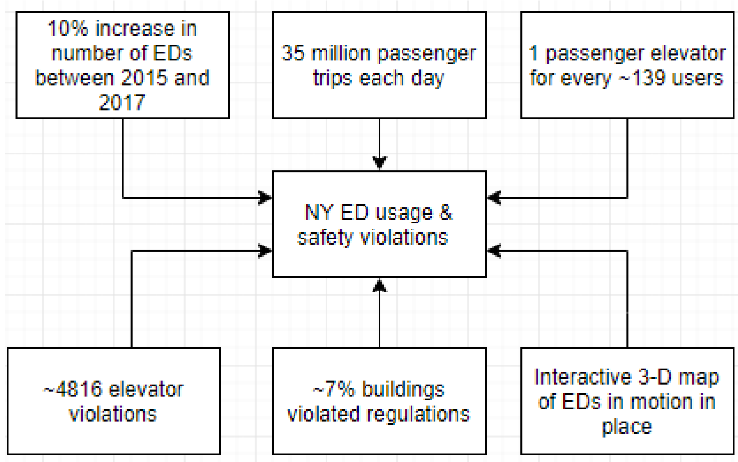


Figure 1.10: NY ED usage and safety violations

1.15 Building Codes Compliance (NYC & Toronto)

Building Codes Compliance are commonly followed by both NYC (NY) and Toronto (Ontario). It is crucial that all ED installations comply with these building codes. Another fact is that the IBC was formed in 2015 by combining NBC, Standard Building Code and Uniform Building Code [1] [52].

Table 1.9 below shows the Building Transportation Codes & Standards that exist for different types of EDs, the personnel and the equipment. The ASME and CSA needs all their ED equipment to be approved by AECO [1] [52].

Code	Description
ASME A17.1 / CSA B44	Harmonized Safety Codes for Elevator and Escalators in USA and Canada
CSA-B44.1/ASME A17.5	Standard for Elevator and Escalator Electrical Equipment
ASME A18.1	Safety Standard for Platform Lifts and Stairway Chairlifts
ASME QEI – 1	Standard for the Qualifications of Elevator Personnel
CSA-B355	Lifts for Persons with Physical Disabilities
CSA C22.1	Canadian Electrical Code
CSA-B613	Standard for Private Residences Lifts for Persons with Physical Disabilities
ASME A17.7 / CSA B44.7	AECO deals with product safety evaluation of conformance to this code; must be accredited by ANSI or SCC; must also comply with ISO

Table 1.9: Building Transportation Codes & Standards

1.16 ED Authority for Maharashtra

Table 1.10 below shows key qualitative information about the ED safety and regulation information in Mumbai, Maharashtra [19] [30] [36].

Matter	Description
Organization name	Lift Inspection Division, Maharashtra State Energy Department
Current Lift Act	Maharashtra Lifts, Escalators, Moving Walks Act, 2017
Law applicable	The phrases mentioned in the Act is applicable only to the state of Maharashtra
Previous Lift Act	Maharashtra Lift Act, 1939
Standard	All ED equipment to be in line with BIS 14665 and ISO, enhancing safety of public & personnel; all buildings must conform to these standards when upgrading or changing existing equipment
Maintenance	Compulsory annual checks
License	Mandatory for all buildings with escalators and / or lifts; valid for 20 years; manufacturers must renew license annually
Rescue	Automatic rescue device to be installed in all elevators
Permission	permission for installation and tests for elevators to be granted and conducted by the office of Chief Electrical Inspector, Electrical Inspector (Lifts) and Assistant Electrical Inspectors; compulsory to obtain permission before altering load capacity of lifts
Compensation for elevator hazard victims	Building owner responsible for the elevator must take third party insurance to compensate passengers who meet with elevator accidents
Penalizing ED manufacturer	ED manufacturing company to be penalized for elevator / escalator / moving walk accidents owing to equipment malfunctioning
Door type	All elevator doors must be imperforate; collapsible doors not to be allowed
Stakeholder committee	Maharashtra State Energy Department (Lift Inspection Division), Elevator Manufacturer representatives, ED contractors form the committee on strategies to eliminate lift accidents

Table 1.10: Qualitative information on ED safety and regulations

1.17 India ED Statistics

Table 1.11 below shows quantitative data on the EDs available in India as of 2016. Data specifically for Mumbai or Maharashtra is unavailable [30] [38].

Matter	Count
Population	1,266,883,598
Existing Elevators	440,000
Existing Escalator & Moving walks	12,500
Elevator Installations	58,500
Escalator & Moving walk installations	1900
Elevator Code	BIS
Elevator Trade Association	IEEMA, ISSEA

Table 1.11: India EDs statistics as of 2016

A magazine [38] reports that 77 units of escalators will be installed for use in several railway stations within Mumbai to ease commuters' strain of having to carry heavy luggage. As part of the "Mumbai Urban Transport Project", for the first time, a hybrid of foot over-bridge and escalators or lifts (50 nos.) are going to be installed at railway stations in Mumbai that would avoid commuters from trespassing railway tracks, in addition to ease with luggage [44].

1.18 Role of ISO on ED Safety

Figure 1.11 shows the role ISO plays on enforcing common safety of EDs [25] [42].

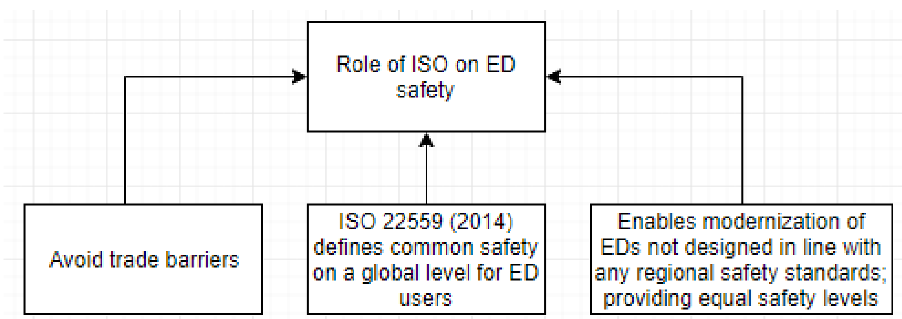


Figure 1.11: Role of ISO on ED safety

1.19 Region-Wise Comparison of Key Aspects

Taking the key information from the previous sections in this chapter, I did a comparison of the current situation of the various aspects related to EDs in Toronto, NYC and Mumbai. These were in terms of population, building count, density, purpose of the building, ED count, authorities involved in enforcing laws, regulation codes and standards for ED and building safety, minimum requirements for having EDs, the time constraints for repairing faulty EDs, and the responsible entities for repairing the faulty EDs, and any compensation that the ED manufacturer or the building owner may provide to those injured [24] [29]

[31] [36] [50]. This is shown in Table 1.12. I have split this into two pages owing to space constraints. 'Not Available' means no information regarding the matter is available for the region.

Pie charts in Figures 1.12 to 1.23 (see Appendix) show up-to-date data comparing the construction status, building function, number of stories and height range of buildings, respectively for NYC, Toronto and Mumbai [45].

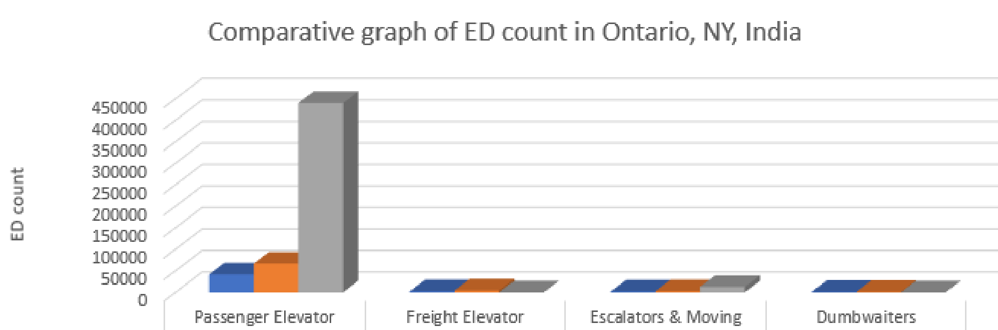
Matter	Toronto	NYC	Mumbai
Population (as of 2017)	~2,826,497 [48]	~8,622,698 [47]	~21,357,000 [49]
Population Density (mi²)	~10,750	~27,000	~73,000
High-rise count	251	635	56
Skyscraper count	284	888	82
High-rise & Skyscraper under construction	33	26	18
Building purpose (high-rise & skyscraper) [45] [Refer appendices Figure 1.12 – 1.14]	82% Residential 15% Office 3% Hotel & Other	52% Residential 39% Office 9% Hotel & Other	85% Residential 12% Office 3% Hotel & Other
ED count (elevators, escalators, moving walks, etc.)	Not Available	~85,000	Not Available
Authority for enforcing building requirements	Ministry of Municipal Affairs	NYC DOB	Government of Maharashtra
Min requirement for elevator in buildings	Seven stories or more	Five stories or more	Not Available
Authority for enforcing fire requirements	Ministry of Municipal Affairs	NYC DOB	Government of Maharashtra, Electrical Inspector (Lifts)
ED requirements in case of fire	Residential buildings more than 18m high need at least one firefighter elevator and at least one in the case of care homes	Buildings with five or more floors, one elevator for Fire Department personnel to access all floors	Not Available
Authority for ED safety, availability	TSSA, Ontario (Provincial)	Elevator Unit, NYC DOB	Electrical Inspector (Lift Inspection Division), Maharashtra State Energy Dept., BIS
National regulation & standard for elevator safety	NBC of Canada, A17.1 / CSA B44	ASME A17.1 safety code for elevators & escalators	NBC, BIS
State / Provincial regulation for building & elevator safety	Ontario Building Code, Ontario Fire Code, Building Code Act	New York State Building Code, Elevator Code	Government of Maharashtra, National Building Code, BIS

Table 1.12: Comparison of key aspects relating to EDs (1/2)

Municipal regulation for building & elevator safety	Ontario Fire Code, Building Code Act, Ontario Building Code	NYC Building Code, Elevator Code	Government of Maharashtra, National Building Code, BIS
Minimum time for repairing faulty ED	7 days for long-term care homes; 14 days for all other buildings	Based on approval of report submitted to Elevator Area Chief; If approved, time is approved as mentioned in the report; otherwise 45 business days plus 15 business days to certify correction	No time constraints; as decided by lift owner, his representative or contractor
Responsibility of making sure maintenance and repair of EDs happen	building owner and elevator contractor having license from TSSA [15]	Building owner	Government approved contractor possessing license from Chief Electrical Inspector
Safety precautions for members of public & compensation for injured or inconvenienced	Primarily keep building occupants informed well in advance of faulty elevators; no information on compensation in case of injuries	Keep building occupants informed as stated in the TPP; no information on compensation in case of injuries	Through third party insurance

Table 1.12: Comparison of key aspects relating to EDs (2/2)

Figure 1.24 below shows a 3D bar graph that compares the count of some of the major EDs in Toronto, NY and India. Rest of the ED count were not available fully for all the regions. '0' in the graph below means 'Not Available'. The data was taken from the tables presented earlier (Table 1.2, 1.8, 1.11). Data specific to Ontario, NYC and Mumbai was unavailable. The ED count for Ontario and India are as of 2016, whereas for NY it is as of 2015. This graph helps view to a certain extent on a comparative scale, the number of EDs that are in place in each of the regions. However, this may not be entirely reliable as the data is first of all, outdated and second of all, the scale varies quite significantly owing to lack of specific data for Mumbai.



	Passenger Elevator	Freight Elevator	Escalators & Moving Walks	Dumbwaiters
Ontario (2016)	41677	2696	2114	1153
New York (2015)	66602	4140	2663	1143
India (2016)	440000	0	12500	0

Figure 1.24: Comparative graph of ED count in Ontario, NY and India

1.20 Summary

In this chapter, I did a detailed and thorough investigation of the ED regulatory control in the three regions, which is the first part of my objective. I explored various secondary sources and gathered as much relevant information as possible about the regulations to make my analysis simpler. I transformed the ‘messy’ quantitative and qualitative data I obtained into individual tables and figures. I later took the key information from these and put them into a comparative region-wise table so that I could use them for modelling purposes (more details in the following chapters).

CHAPTER 2
SPECIFIC LITERATURE ON SYSTEM RISK MODELLING METHODS

2.1 Introduction

Ensuring safety of EDs is the most important measure that must be taken while manufacturing and during installation to avoid risks associated from it. There have been various research and studies conducted in the past using various modeling methods and frameworks to evaluate system risk and reliability with respect to EDs. In this chapter, I will be discussing some of this previous research work done using PN; Bow-tie; BBN; ALARP; FTA, and Fuzzy Network models and frameworks.

2.2 Why I am doing this

Why I am doing analysis of system risk modeling methods is to learn and understand about the various ways in which ED risks have been studied and implemented. At the end of this section, I want to find out what the limitations and benefits were of using these methods and hence evaluate and apply one of these methods for my own data in Chapter 1. I will be talking about how these methods are inter-related in terms of a probabilistic manner and how they have been applied to analyze ED risks, availability and reliability.

2.3 Combination of PN, Bow-tie & FTA Models

A research was conducted where a risk and reliability framework was developed using a combination of PNs, Bow-Tie and FTA models [2].

PN model was established by Carl Adam Petri in 1962 [4]. It provides a graphical representation of dynamic processes in a discrete event simulation framework. It has two types of nodes, named places (represented by circles) and transitions (represented by squares). These nodes are connected through directional arcs (represented by arrows). A simple net containing all components of a PN (Figure 2.1) and collection of primitive structures that occur in real systems, which can be found in PNs (Figure 2.2) are given in an online source [58]. It is constructed based on the ED's condition, deterioration, components, operation and maintenance. ED specific features, like operational usage, degradation process of components, human error in inspection and maintenance can be easily included. This will help with using updated information about the ED to estimate risk, rather than using generalized data [2]. Hence, PNs have applications in ED risk analysis as done in this research.

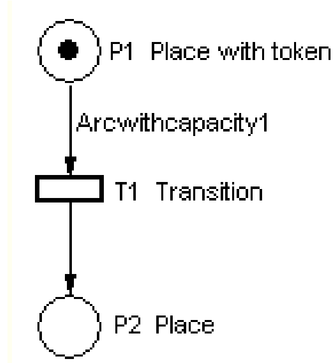


Figure 2.1: Components of a PN [58]

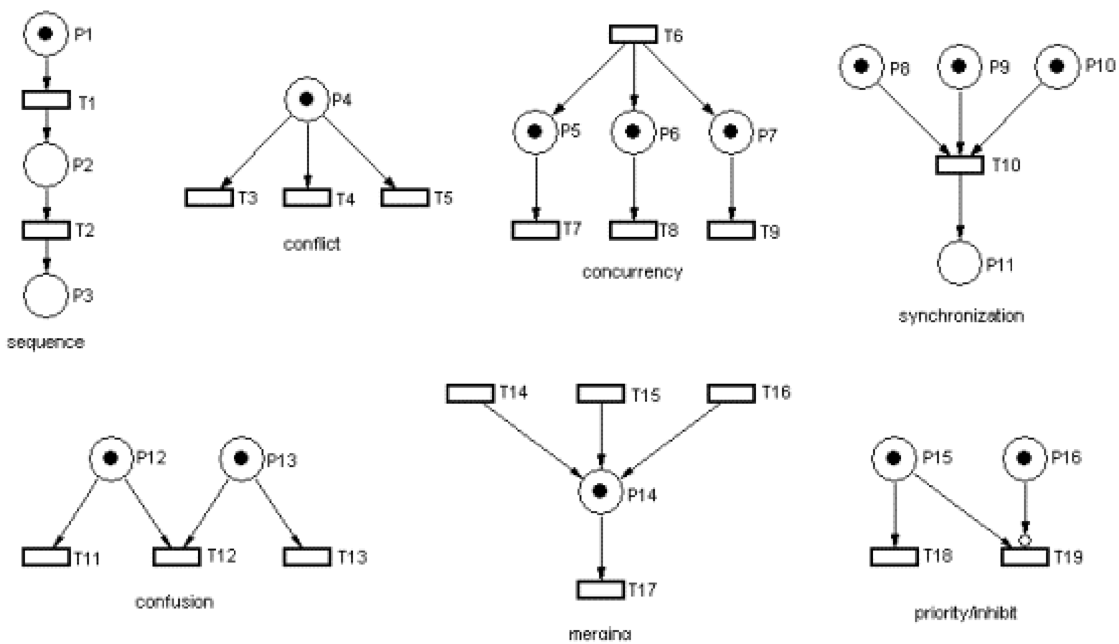


Figure 2.2: Primitive structures that occur in real systems found in PNs [58]

According to [2], "When a probabilistic transition fires, it puts a token to only one of the output places, based on the probability assigned. Output places are connected with probabilistic arcs. These are represented by an arc ending with a filled square." The outputs of PN model were given as inputs to the Bow-Tie model to calculate risk estimates of the top event (hazard event or unwanted state). Once this model is built, it is simulated using Monte Carlo Simulation to predict performance and failure of ED components. As carried out in this research, Figure 2.3 shows the PN model for a passenger lift [2].

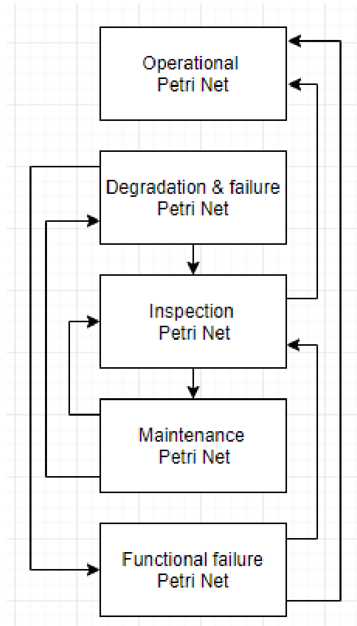


Figure 2.3: Passenger lift PN model [2]

The Bow-tie model is in the shape of a 'bow-tie'. The authors say that the Bow-tie model is a cause and effect model that is used to assess risks quantitatively. However, [59] argues that the model is limited as it can handle only qualitative data. My interpretation of the steps involved in this modelling process is shown in Figure 2.4. The Bow-tie model outline as presented in [59] is shown in Figure 2.5. In the former research [2], the model is based on probabilistic values of basic event occurrence obtained from device failure data [60] [61]. The major practical uses of Bow-tie are presented in Figure 2.6 below [59].

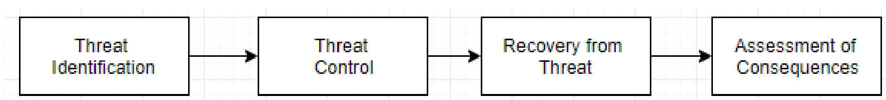


Figure2.4: Steps involved in Bow-tie modelling process

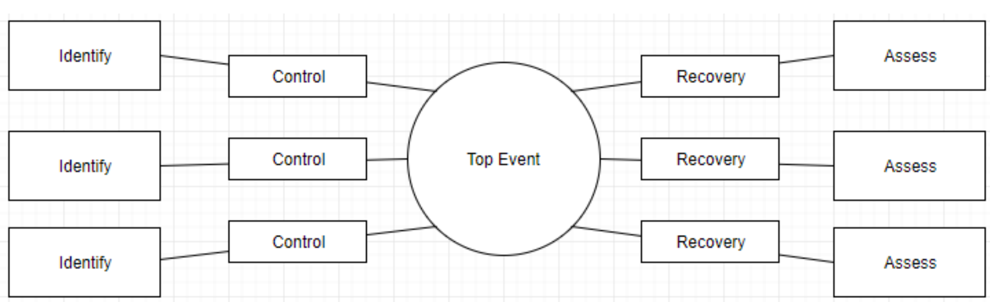


Figure 2.5: Bow-tie model outline [59]

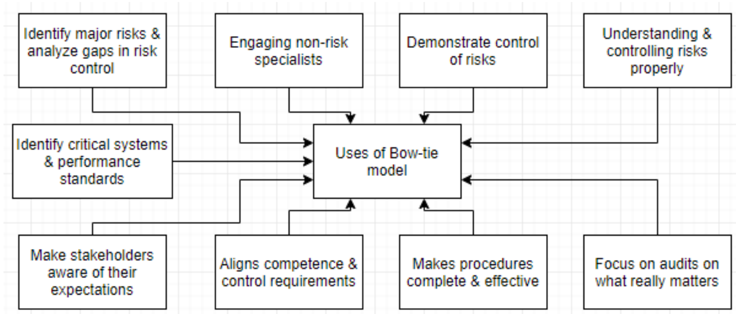


Figure 2.6: Practical uses of Bow-tie model

The research in [2] builds the model for a hazardous event (top event) using FTA approach by representing effects of ED failures using Boolean Logic (AND & OR gates). It consists of fault and event trees, where the top events are represented in the former and initiating events, i.e., all possible causing events in the latter. This research used 'Lift Getting Stuck in between floors' as the top event. The fault tree for [2] is shown in Figure 2.7.

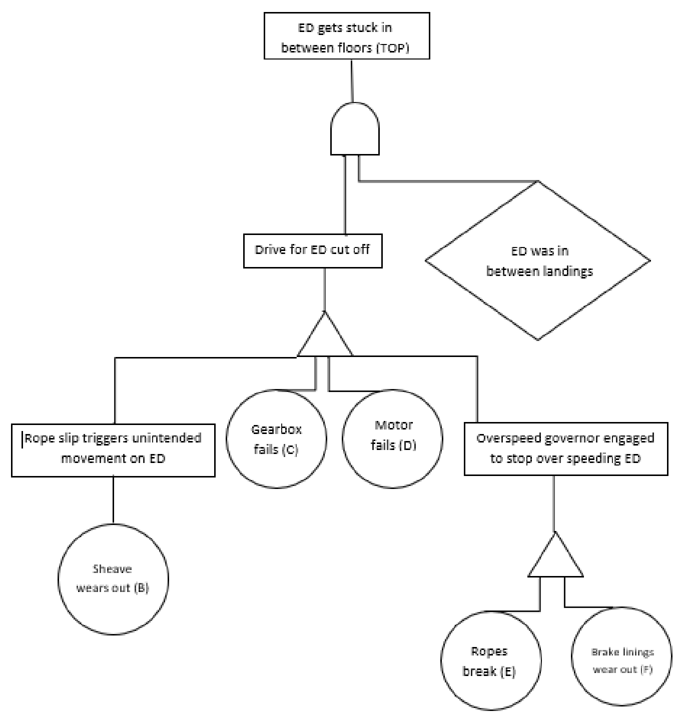


Figure 2.7: Fault tree for "elevator stuck between floors" [2]

The major drawback of using Bow-Tie model according to [2] is that, "it cannot accommodate distinct features of the asset in consideration, in this case the ED. The asset's and individual components' condition, the operational usage, inspection and maintenance policies can impact risk assessment. Hence, there are limitations to the risk analysis."

The rare event approximation is used to find the probability of the top event, which is calculated by [43]:

$$P(TOP) \approx P(AB) + P(AC) + P(AD) + P(AE) + P(AF)$$

Where, *A* – event "ED was in between landings"; *B* – Drive sheave wears out; *C* – Gearbox fails; *D* – Motor fails; *E* – Suspension ropes break; *F* – Brake linings wear out

The probabilities of *P(AB), P(AC), P(AD), P(AE), P(AF)* would be obtained from a PN. The respective event tree for the fault tree shown in Figure 2.7, is shown in Figure 2.8 [2]. This involves determining the path probability by taking the product of probabilities of Initiating Event (E_0) and sub events (E_1 and E_2). An event tree consists of two sub events that classify consequences of an initiating event. For e.g., one sub event could be if there is a lift engineer present on site to handle the hazard. Another sub event could be if there are people trapped in the ED. Combination of these two sub events result in varying end states, which are given in number of hours a passenger has lost [13].

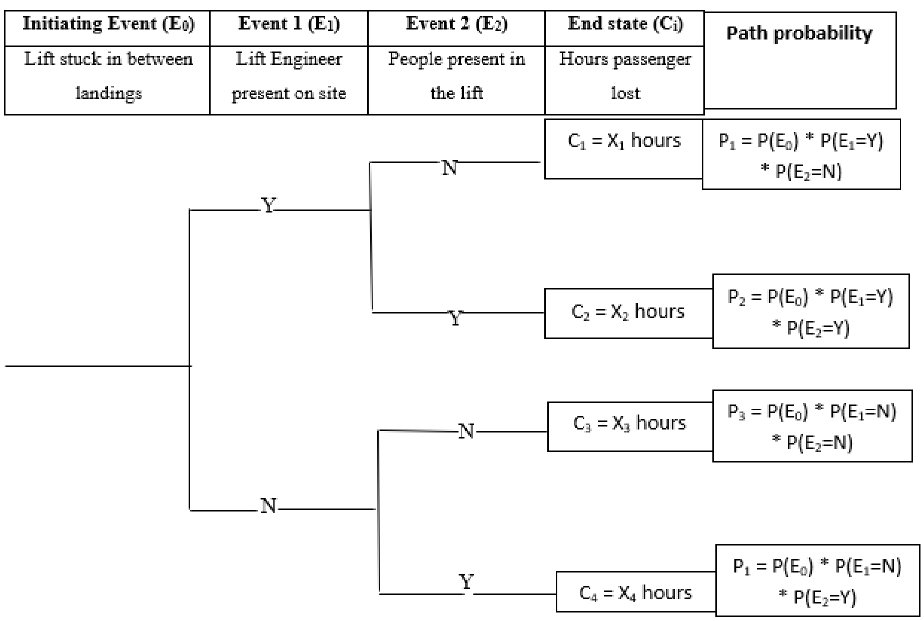


Figure 2.8: Event tree for fault tree in Figure 2.7 [2]

Where, C_i is the end state, i.e., the cost or consequence. Here it is the number of hours a passenger lost; X_i is a random number of hours lost according to the path; P_i is the path probability; E_0 is the initiating event; E_j are the events 1 and 2, where $j = 1,2$; $E_j = Y$ means event E_j is true; $E_j = N$ means event E_j is false

The risk for individual consequence is calculated by taking the product of the cost (consequence) and the path probability. Therefore, the total risk *R* involved for this initiating event is the sum of the product of path probabilities and lost customer hours [3].

$$R = \sum_{i=1}^{4} P_i * C_i$$

Therefore, this shows how the system risk is calculated using a combination of PN, Bow-tie and FTA models.

2.4 <u>FTA for ED Risk & Availability</u>

Unlike section 2.3, where FTA was an integral part of other modeling processes in determining overall system risk, in this section I will talk about how FTA itself has its applications in analysis of system risk and ED availability. Although there is no commonly accepted definition for ED system availability [13], according to [63], "availability of a system is the probability that the system failure does not exist at some specified time in the future. Unavailability is the probability that the system failure exists which is unity minus availability. The general assumption in calculating availability is that no system component failure exists at time $t = 0$. Reliability is the probability that a system has experienced no failures in time t. The unreliability is the probability that a system has experienced one or more failures at time t, which is unity minus reliability."

FTA technique was used in the "TSSA elevator availability study" for determining the risk of elevator non-availability (Figure 2.9). This risk was determined in terms of health hazards to passengers and measured in terms of probability of a fatal accident per year. This is compared with an individual risk acceptability criterion of a probability of 1 out of 1,000,000 fatalities per year. Risk of ED non-availability is estimated using the following formula [13]:

$$Risk = E_{AD} * E_m * E_x * F_e$$

Where, E_{AD} = Frequency of ED Unavailability; E_m = Probability of emergency when ED is unavailable; E_x = Probability of a passenger exposed to emergency; F_e = Probability of an incident while exposed to fully or partially unavailable ED

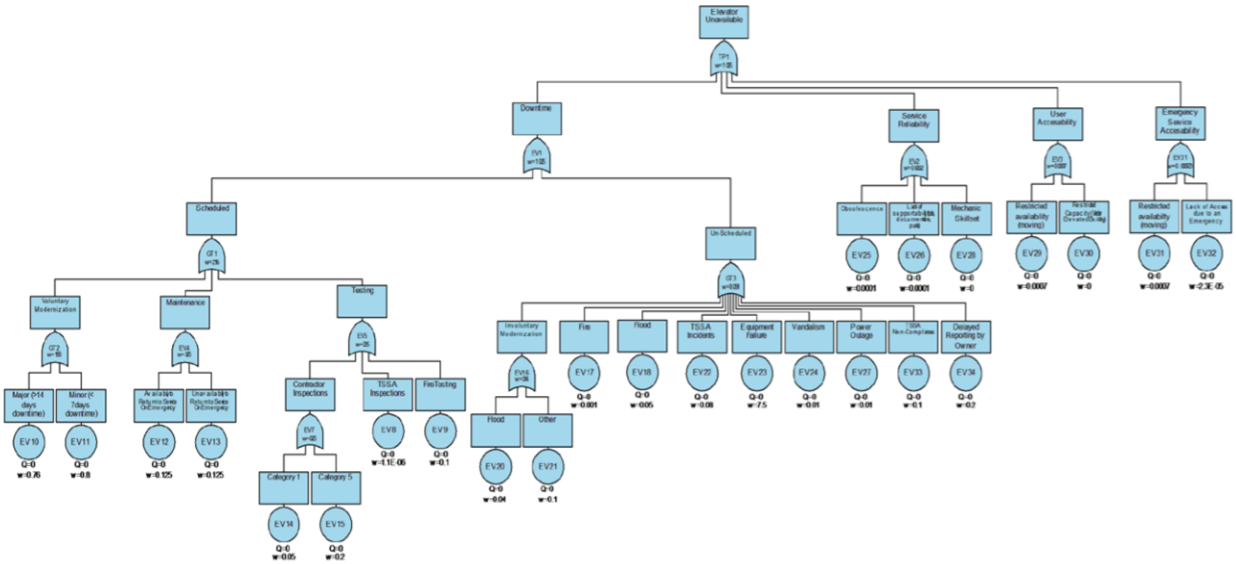


Figure 2.9: FTA done by TSSA to determine frequency of elevator unavailability [13]

2.5 Multi-State Fuzzy Bayesian Network

Another research that involved a combination of modelling methods was by extending BBNs with Fuzzy Theory [10]. According to the research, the exact value of fault probability of components in an ED was obtained by combining Fuzzy Theory and Bayesian Networks. The research was done by building a Bayesian Network model (Figure 2.10) of the ED's horizontal vibration based on the logical relationship between factors.

In this research, an important concept called 'importance degree' is used. It is "a quantitative index of reflecting the influence of each component on the top event in the reaction system. It can do the quantitative analysis of the safety and reliability of a system. It can compare importance of various events in the system. The importance degree of factors affecting the ED's horizontal vibration is retrieved by the importance analysis. It is according to this importance degree that an ED is maintained and checked. This improves the reliability of the ED in normal operation and enhances the maintenance efficiency" [10].

A source quoted in the above research says that the probability importance degree played a key role in implementing the quantitative analysis of the safety and reliability of the ED. It reflects the role of basic event on the top event and can compare the importance of various events in the system [9].

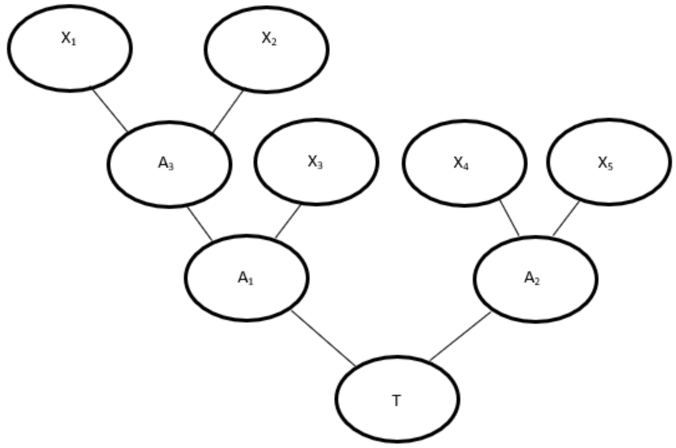


Figure 2.10: Bayesian Network model of horizontal vibration of ED [10]

Where, T represents the leaf node; A_1, A_2, A_3 are used to signify guidance system, car system and quality of guide rail, respectively; X_1, X_2, X_3, X_4, X_5 are the root nodes used to denote surface profile of the ED guide rail, installation quality of ED guide rail, guide wheel shape of the rolling guide shoe, static equilibrium of the ED car, passenger load limit, respectively. In a 'Fuzzy Approach', the fault state of a node is fuzzy, i.e., it follows a 'this' or 'that' state. In the study, the state space used was {0,1,2} where 0 represents normal state; 1 represents semi-fault state and 2 represents completely failed state [10].

According to the research paper, there have been very less work done with Bayesian Networks for ED reliability analysis [10].

2.6 Risk Estimation using ALARP Model

A research was done where the ALARP model was used to label different levels of risk as 'intolerable', 'undesirable', 'tolerable', and 'negligible', and to even quantitatively define the class of risk [11]. In this study, an analysis of the SIL of a braking system of a moving walk was done. SIL is defined by IEC 61511-1 as a "discrete level (one out of four) for specifying safety integrity requirements of the safety instrumented functions to be allocated to the safety instrumented systems" [11]. Highest and most reliable SIL is SIL4 and lowest is SIL1. Maximum possible SIL for escalators and moving walks is SIL3. SIL4 is not allowed "as it is not relevant to the risk reduction requirements associated with machinery" [11].

In the research [11], four consequence levels of accidents happening in moving walks were classified as Catastrophic (Ca), Major (Ma), Severe (Se) and Minor (Mi). As discussed in [11], Table 2.1 below shows the corresponding relation between the unavailability of the system and the consequences of an accident. This is generally used for any kind of people transportation equipment [11].

	Brakes unavailability				
Consequence	<1 hour	<1 day	<2 days	<1 week	<1 week
No injuries	Mi	Se	Se	Se	Se
No major injuries	Se	Se	Se	Ma	Ma
<5 major injuries	Ma	Ma	Ma	Ma	Ca
<10 and >5 major injuries	Ma	Ma	Ma	Ca	Ca
>=1 death and / or many major injuries	Ca	Ca	Ca	Ca	Ca

Table 2.1: Relation between system unavailability and consequences [11]

Another study was done using the ALARP model to classify risk and identify priority safety areas [12]. Unlike [11], [12] classified risks into three regions, namely ‘Unacceptable’, ‘Tolerable’ and ‘Acceptable’. This classification is shown in Figure 2.11. I have used shades of grey to represent the severity of the risks [12].

According to the study, acceptable risk zone, usually denoted in green color, is the area with risk level less than 50% of the risk acceptability criteria. These are the ones that do not require immediate attention. An example is failure of technologies regularly inspected by the organization. Tolerable risk zone, usually denoted in yellow color, is the area with risk greater than or equal to 50% of the risk acceptability criteria. These are risks that will need attention sooner than later. Examples are fire risks in food service locations, fuel risks in business units. The decision of classifying a risk as tolerable is done by the concerned authorities. Unacceptable risk zone, usually denoted in red color, is the area that exceeds the acceptability criteria. These are risks that require immediate attention. Examples include fuel risks in academic locations, human danger on EDs, care and retirement homes, etc. [12].

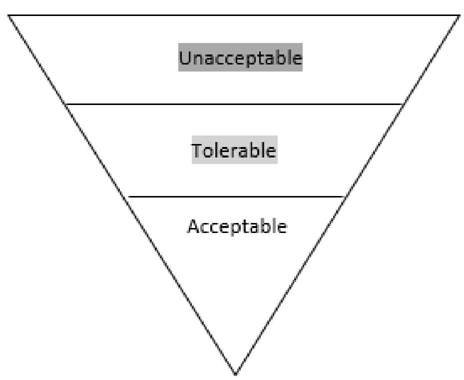


Figure 2.11: ALARP risk classification model [12]

2.7 Evaluation of the above Modelling Methods

Based on the above information I have gathered above about a few modelling methods where ED risk has been analyzed, I am going to now evaluate each of the above modelling methods and decide which is the best suitable modelling method to model the data I have gathered such that it meets my objective. I am going to do this by analyzing the benefits and limitations of each of the modeling methods.

2.7.1 PNs Modelling Approach

There are several advantages and disadvantages of PNs for dynamic systems, according to [54] [55] [56]. I am presenting these in Table 2.2 below.

Advantages	Disadvantages
Easy visualization of a complex system graphically	Increases complexity as it improves utilization and throughput
Hierarchical modelling of a system (top-down)	Unable to test for exactly a specific marking in an unbounded place and to act on the test outcome
Provides complete qualitative analysis of a system	It is unable to model many systems
Timed Petri Nets can evaluate system performance	At the expense of decision power, it increases the modelling power
They have a balance of modeling power and decision power	
Can be used as a model of parallel computation	

Table 2.2: Advantages and disadvantages of PNs

2.7.2 Bow-tie Modelling Approach

According to [59], there are various benefits and drawbacks of Bow-Tie method, as shown in Table 2.3 below.

Advantages	Disadvantages
Easy communication	Entirely qualitative
Ownership – involves people; practical approach	Depends on experience of personnel
International applications – overcomes languages	Ensure controls in Bowtie are truly independent
Can handle any type of risks	Depends on active workforce involvement
Risk reduction – identifies where resources should be focused for risk reduction / prevention / mitigation	

Table 2.3: Benefits and drawbacks of Bow-tie method

2.7.3 FTA Approach

According to an online source [62], there are several benefits of using FTA approach, and according to a research paper [63], there are also limitations for FTA. These are provided in Table 2.4 below.

Benefits	Limitations
Identify failures deductively – helps a team study causes of every event in a logical sequence that leads to failure	It uses binary assumption, i.e., an event is failed, or it is working. Degradation is not considered.
Assists in system analysis & management graphically, especially for complex systems, it helps to focus on critical components	Repair of failed primary events does not guarantee repair of top event.
Improving one element causing failure to many paths can minimize the possibility of multiple failures	Inapplicable or insufficient data is a problem for system reliability analyst
Focuses on one fault at a time – focus on overall failure or one particular element	Good amount of data is required to calculate expected number of system failures, availability & reliability
Account for human, hardware and software factors	
Allows examining various ways a fault may occur and expose paths to failure not easily visible	

Table 2.4: Benefits and limitations of FTA

2.7.4 Fuzzy Approach

According to a study on "Fuzzy Approach to Risk Analysis and its Advantages against the qualitative approach" [64], Table 2.5 shows how this approach is useful and with some of its drawbacks.

Advantages	Disadvantages
Changes of input data changes output, so regular repeating of analysis is meaningful	Requires real experiences of experts and competent personnel to identify & collect data
Useful for assessing highly dynamic systems	Subjective evaluation is limited compared to other methods
Tolerant to imprecise data	Some risks can be evaluated only after long & time-consuming tracking & analysis of statistical data
Regular risk analysis can create an effective control system	Comprehensive understanding of system processes is required to conduct analysis
Flexible framework can be created on top of expert knowledge	Correct & consistent identification of sources of risk is required

Table 2.5: Uses and drawbacks of Fuzzy Approach

2.7.5 BBN Approach

According to [5], there are various benefits and shortcomings of using BBNs as shown below in Figure 2.12 and 2.13.

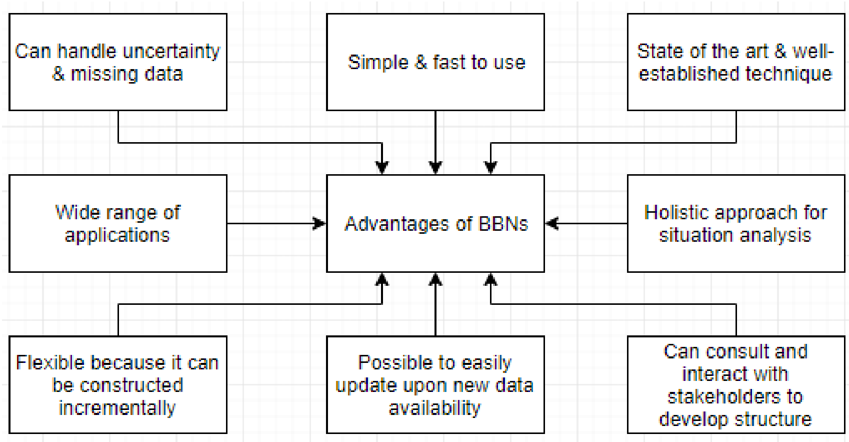


Figure 2.12: Advantages of BBNs

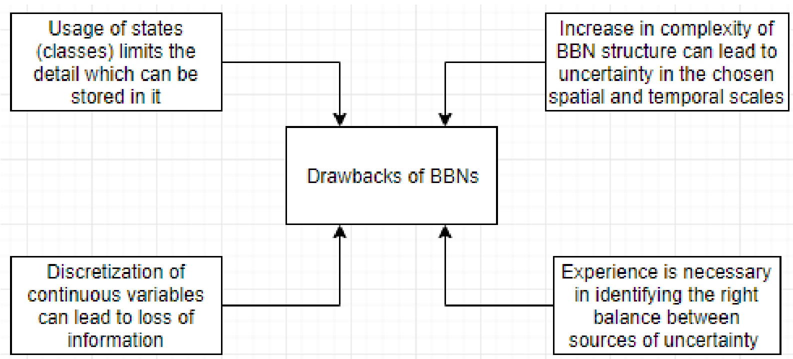


Figure 2.13: Disadvantages of BBNs

2.7.6 ALARP Approach

According to an online article [65] on the ALARP principle, the advantages and disadvantages of using this technique are given in Table 2.6 below.

Advantages	Disadvantages
It is flexible as it allows to set goals rather than being perspective	Deciding whether a risk is ALARP can be challenging because it is based on judgement
Easy to refer to existing practice established in discussion with stakeholders	Not applicable everywhere because different countries may follow a different form of risk control standard

Table 2.6: Advantages and Disadvantages of ALARP

2.8 Insights Gained

From the description of the various modelling methods above, I could understand that most, if not all the methods have a single major concept behind modeling it. That is 'risk'. In simple terms and as commonly known, 'risk' is the probability of something going wrong and the consequences if it does. 'Probability', i.e., chance is another important concept here. When we are modeling a risk, it is only a probabilistic representation of a hazardous event. The event modeled may or may not happen, and consequences may or may not occur.

So, what I am trying to say here is, I understood that most of the models above are trying to represent and analyze system risk in some way to study the significance of a risk. The way most of the analyses have been conducted in the above researches is by using some existing evidence of system risk or through the data provided to the authors by their client or through some source. 'System' in all the above cases and in my case is the ED. Although, each method has a different modeling notation and has been applied in different areas of ED risk modelling, at the end it is a 'causal analysis'. So, if an event (trigger) causes something to happen (risk event) then what will be the 'consequence'? There can also be 'control events' and 'mitigant events', which helps avoid risk event and negative consequences, respectively [7]. This is what is being represented in one way or the other in most, if not all the above risk models. In some instances, there was a combination of two or more of the individual methods applied to carry out risk analysis which I found quite interesting.

2.9 Summary

This chapter was in a sense a follow on of Chapter 1, as my aim was to select a risk modeling method suitable for my data in Chapter 1. To reach a decision on this, I did a critical review of various modelling methods such as PNs, Bow-Tie, FTA, Fuzzy Approach, ALARP principle and BBNs by evaluating their benefits and drawbacks in elevator system risk analysis. I understood the probabilistic concept used behind implementing these methods and how ED system risk analysis was performed. For me it was the concept of 'causal analysis' that was most interesting. This would be representative of a trigger event → risk event → consequence as briefly mentioned earlier. Also, upon evaluating the pros and cons of the above methods and fitting it with the qualitative and quantitative data I have gathered, the modeling method that I think is most closely representative of my problem context, interest and findings thus far, is BBNs.

CHAPTER 3

SPECIFIC LITERATURE ON BBN METHODOLOGY & INTRODUCTION TO MODELLING TOOL

3.1 Introduction

In this chapter, I will be discussing about BBNs and IDs; their features; advantages and disadvantages of BBNs; process of developing and requirements of a BBN; briefing on Bayes Theorem and basic probability concepts; BBN structure; a brief description on the various BBN software / tool available; reason for choosing and implementing my model using Netica; learning to use Netica through a simple problem of my own, thereby explaining the key features of the tool; ending with a summary of the chapter.

3.2 Why I chose BBN Modeling Method

After reviewing various system risk analysis methods and considering the mixture of quantitative and qualitative data that I have, along with the quality and quantity of the data I have gathered, I decided to model the ED system risk using BBNs and its extension, IDs. The reason why I chose this method is because of the advantages I mentioned in the section about BBNs (section 2.7.5). It has the flexibility of handling missing and uncertain data. I do not have exact probabilities or well-structured data (reminding that the data I collected was purely from various raw secondary sources which I transformed into tables and figures out of my own thought process). Moreover, according to [7], even when data-driven approaches to risk assessment are not possible, BBNs are useful in addressing these types of problems. It is recognized as a powerful technology for handling risk assessment, uncertainty and decision-making [7].

Hence, I thought it is the apt method to represent an event, its risk and its consequences as a 'causal network' so that the system risk events are clear. Although I could not find accurate probabilistic values for the events and / or the consequences, I would be providing only dummy probability values, i.e., 'beliefs', based on the data I have gathered. This is how Bayes' Theorem comes into place. It enables us to update a prior probability of an unknown event when there is evidence for the same [7].

Using 'causal model' such as BBNs, it is possible to understand how risks emerge, are connected, and how they can be controlled and mitigated. With my data, I can frame decision variables and assign probabilities based on the knowledge I have from it. I can also breakdown my objective into meaningful events and relationships. Since I am dealing with only a chance of events happening, I need to model this uncertainty at a useful level that meets my objective [7].

3.3 BBNs in detail

The information in sections 3.3 to 3.7 have been adopted from an online factsheet about BBNs [5] unless otherwise referenced. It says that they are a useful knowledge representation mechanism to interpret any system, provided the existing knowledge of stakeholders about a certain process. BBNs have various pseudonyms, namely Bayesian Networks, Bayes Networks, Causal Probabilistic Networks, or simply Belief Networks. According to [7], Bayesian Network as an "explicit description of the direct dependencies between a set of variables." Let us look at BBNs more in detail.

3.3.1 Bayes Theorem and Basic Probability Concepts

In a BBN, all inputs and outputs have an uncertainty associated with it. This is propagated throughout the network by the means of Bayesian conditional probabilities. The Bayesian formula, i.e., Bayes Theorem for conditional probability is given by [7]:

$$P(A/B) = \frac{P(B/A)P(A)}{P(B)}$$

Where, P(A) is priori probability; P(A / B) is posterior probability and P(B / A) is likelihood ratio

From the basics of probability, we already know that, if A and B are independent events, the probability of both A and B happening together can be shown as below:

$P(A\cap B) = P(A) \times P(B)$, where $P(A\cap B)$ is the joint event, also written as $P(A,B)$ **(1)**

We also know that, if A and B are not necessarily independent, probability of both A and B happening together can be shown as below:

$P(A\cap B) = P(A) \times P(B \mid A)$, where $P(B \mid A)$ means B given A **(2)**

Therefore, from (2), $P(B \mid A) = P(A\cap B) / P(A)$, provided $P(A) \neq 0$ **(3)**

According to the rule of conditional probability, if A and B are any event, with $P(A) \neq 0$, (3) can be written as:

$P(B \mid A) = P(A\cap B) / P(A) = P(A,B) / P(A)$ **(4)**

3.3.2 Structure of a BBN

BBNs consists of nodes (oval shape entity) and links (arrows) to show the flow of information [5]. Here nodes denote uncertain variables and links showing the influence (relationship) between the nodes, represented by the direction of the arrow. It validates this knowledge, thus making it a transparent method for depiction of the process. It is used for models that contain only random nodes. This is only to present the theory, as while developing a BBN model using a tool, there are different types of nodes, such as nature node, decision node and utility node with links between them [46]. These are discussed in detail in section 3.5. An important point to note while creating a BBN or an ID is that, the model should not be cyclic at any stage or instance. Also, a bad practice is to set one of the nodes representing an entire process [7].

There are three types of BBN connections, namely Diverging, Serial and Converging. Diverging connections show a common cause. Serial connections show evidence of a node transmitted through another, leading to an action. Converging connections have a common effect [7].

Figure 3.1 shows my modified version of a simple BBN example from [7] about ‘Flood’. The purpose of this is to demonstrate it as a probability model, showing downward flow of information (causal effect) through links (arrows). The network starts with two parent nodes ‘Dams_Open’ and ‘Hurricane_Storm’ leading to its respective child node ‘River_Level_Rise’ and ‘Heavy_Rainfall’, together causing the ‘Flood’. Then its after affects are shown, i.e., ‘People_Drown’ and ‘Property_Destruction’. The sequence continues, ending with “Quality_of Rescue_Measures’.

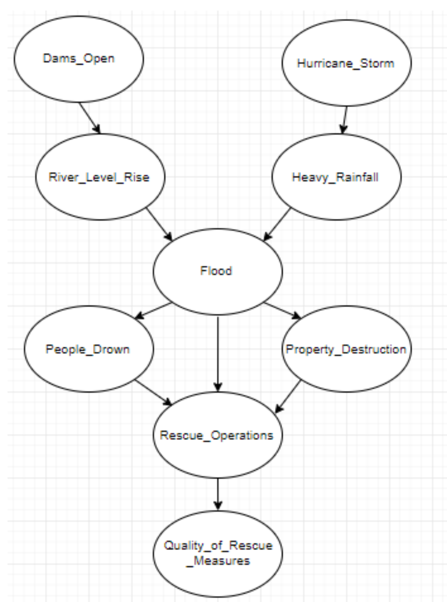


Figure 3.1: Example of BBN structure [46]

3.3.3 Features of BBNs

There are several features of BBNs described in [5] as shown below in Table 3.1 that make it usable for system risk analysis.

Feature	Description
Knowledge representation through compact model	BBNs can be used for modelling simple tasks or it can be used to outline a simulation of a more complex model, where the input and output variables have conditional probabilities
Link various knowledge domains	BBNs can link different kinds of information and models, where there maybe multiple layers of nested networks (object-oriented BBNs) or dynamic BBNs, which model temporal dependencies. So, it is possible to extend and adapt BBNs to complex scenarios
Continuous knowledge updating	BBNs are not static, i.e., they can be updated with new information as it comes in. It weighs the new incoming data against the existing and then updates the strength of the relationship
Shared causal model construction	BBN can adapt to stakeholders' ideas of the causality structure and the knowledge of each outcome. They can be used live for studying scenarios as model run time is instant upon compilation. So, BBNs help in obtaining a shared understanding of the scenario
Value of information	BBNs have value of information of every variable with respect to a specific outcome. If there is information on the cost of including additional data, BBNs can help decision-makers determine if the cost of that data will add value and improve overall returns
Decision support tool	Since BBNs can handle uncertainty, it can be used as a decision support tool. It can calculate net returns of decision alternatives, which may be associated with costs or end-results. BBNs can have multiple outcomes, which is a multi-criteria analysis scenario, where there will be values associated with each attribute and weights associated with each outcome
Relevance to scale	The scales at which a BBN is constructed are clearly defined at the beginning of a study. These are chosen by the knowledge engineer. If these scales are modified, then the BBN structure will also have to change. Due to this, the inputs and outputs are also associated to the scales. So, it is challenging to upscale or downscale data from various sources to suit the allocated scales

Table 3.1: Features of BBNs

3.3.4 Development of a BBN

There are three basic steps to set up a BBN [5] as shown below in Figure 3.2.

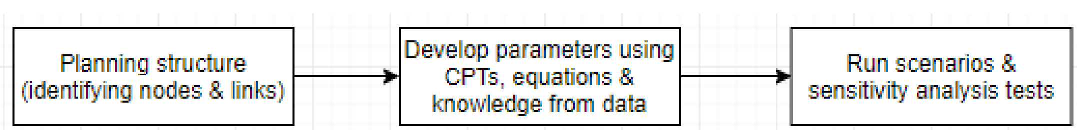


Figure 3.2: Basic steps to set up a BBN

Figure 3.3 shows a flow diagram of my own interpretation of the process of developing a BBN.

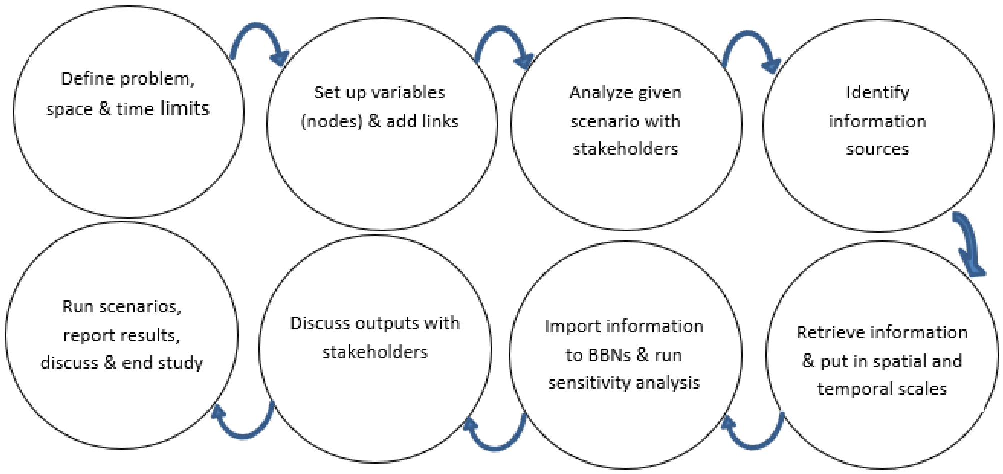


Figure 3.3: BBN development process

3.3.5 Requirements to build BBN

To build a BBN, there are a few requirements [5]. I have provided my own interpretation of this in Figure 3.4.

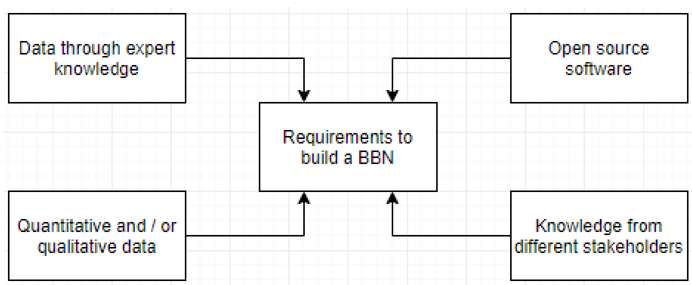


Figure 3.4: Requirements to build BBN

3.4 Choosing the BN Tool

An important decision to take here would be to decide which tool (software) I could use to develop and show the ID. Reminding that this is how I want to represent my final model of the problem in context by the end of the study.

My method of showing the 'causal relationship' of the risk events pertaining to the problem specification is to create an ID model for my problem in context using a professional software. Before deciding on which BN software to use, I read online [66] about the different ones that are available for use, and some of their features.

According to the article, some of the popular ones are AgenaRisk, Bayesia, BayesServer, Dezide and Netica. AgenaRisk is largely used in aerospace, banking, defense, telecoms and transportation industries for modelling, analyzing and predicting risk. Bayesia creates BNs with graphical capabilities. It has applications in simulating market analysis of offers for a population. BayesServer has a GUI and a set of tools for diverse BN tasks. For e.g., dynamic BNs for time series, relevance optimization, etc. So, it has its major application in classification, regression, time series prediction, and data mining. Dezide is a knowledge base system using BNs and applications in the contact center, customer self-service, etc. A few products built using this software are Contact Centre Portal, Self-Service portal, Virtual Assistant and other automated advisory systems. Netica™ from 'Norsys' is claimed to be the most widely used BN software. The GUI supports BBNs and IDs, giving it a more illustrative perspective to Bayesian analysis [66].

So, although all the above software can in one way or the other develop an ID, as the technique and logic behind it remains the same irrespective of the tool, I weighed the above brief descriptions to my problem context. I decided to download a limited version of an open source software called Netica™, from a Canadian software firm named 'Norsys Software Corp'. When I read more about it on its official website, I thought it would suit my overall purpose of creating both BBNs and IDs. According to Norsys site, Netica is the world's most widely used BBN development software for various organizations and agencies. It was designed to be simple, reliable, high-performing and especially for managing uncertainty. It has applications in industries such as ecology, business, engineering and medicine. Both Belief Networks and IDs can be created using this [46].

3.5 Description of IDs

According to Norsys Software Corp, 2018, IDs are also known as 'decision nets'. These represent a decision, or a planning problem faced by decision makers. They are useful in solving decision problems. The goal here is to find a set of decision functions which maximize a utility objective (in my case, maximize ED availability and safety). An important question to ask here is, how can we develop an ID from BBNs? When decision variables (entities that are controlled) and utility variables (entities that are to be optimized) are added to the relationships of a BBN, it forms a decision network, otherwise known as an ID. This is used to find the optimal decisions that maximizes values of variables [46]. In a sense, it assesses the impact on the top event when variable value changes that assists me with making a decision.

Another source [53], says IDs are a natural extension of BBNs, that allow one to represent the uncertainties of random variables, explain decision variables and evaluating any consequences of selecting a decision variable. According to [5], an ID is a generalized BBN if it has decision nodes (represented as squares) and consequence nodes (represented as hexagons) as shown in Figure 3.5. The former is used to identify the optimal decision. The latter shows the value of outputs of the top event, whose impact will be assessed when a certain variable changes that assists with a decision. It can model, for e.g., costs.

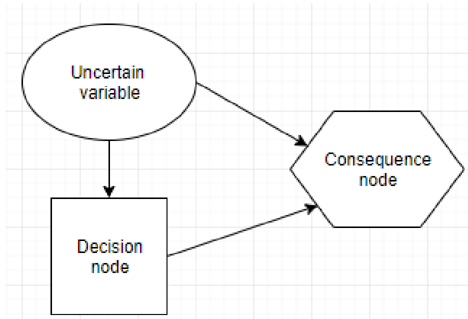


Figure 3.5: Structure of an ID

According to [8], "strong qualitative consequences could be inferred about a problem from the ID without referring to the probability or other utility specifications. A variable may be informative of another". The source also says that, "Influence Diagrams is useful in stating and solving decision and inferential problems. Problems that were solved using conventional decision trees could be solved using IDs. It can be used to frame a decision on the confused knowledge about uncertain quantities and to explore the values that influences the decision. Almost every human action or knowledge can be represented using IDs" [8]. The source says that IDs could help provide information about which variables would be necessary to make certain decisions, stressing that, without including decisions in the analysis, models would not be helpful [8].

3.6 Learning Process using Netica

Before I could create the ID for the problem context using Netica, I had to become familiar with it and learn the features of the tool. So, below I am showing some crucial aspects of the tool which is important for me to build an ID. I will be using a sample problem of my own to demonstrate this.

3.6.1 Tool Interface – Figure 3.6 shows the interface of the Netica software. I opened a new 'Network' by clicking on 'File' → 'New' → 'Network'. It has a tool bar with all the necessary features to build an ID.

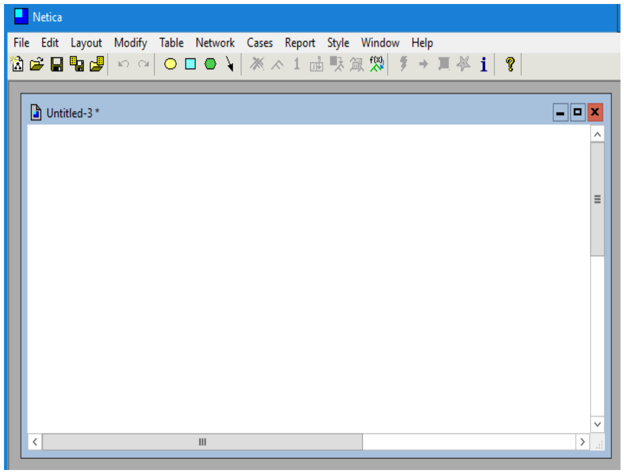


Figure 3.6: GUI of Netica

3.6.2 Key Icons to Represent Nodes

There are three basic nodes used namely, nature node, which are my uncertain variables; decision node, which is what I want to decide upon; and utility node, which is what the consequence of making such a decision would be considering the variables input. I have a link icon to connect my nodes. These are shown in Figure 3.7.

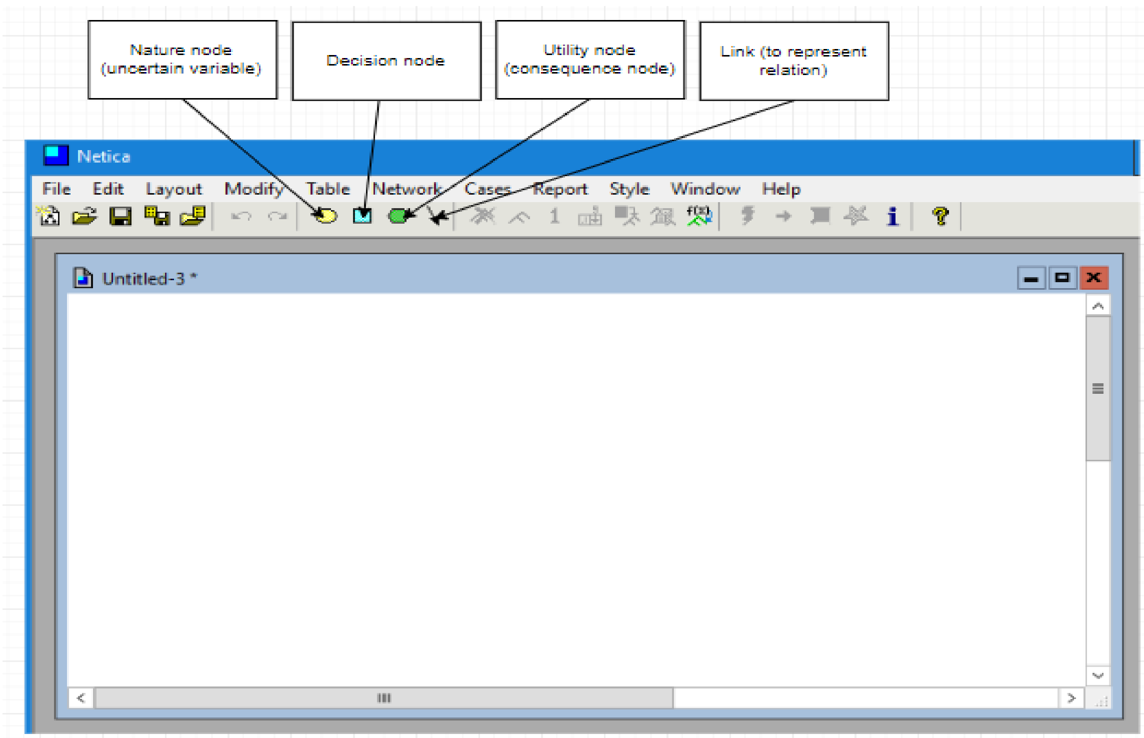


Figure 3.7: Node representation in Netica

3.6.3 Creating a Simple ID Model

What I am going to do now is, demonstrate how to create a simple ID to model a problem I faced when deciding which country to do my PG studies. Firstly, I will illustrate how the ID will look like in the planning stage (left side of Figure 3.8 below) using the notations mentioned earlier, then upon development and transformation using Netica, it will look how I have shown on the right side of the figure. The whole purpose of doing this exercise is to feel comfortable with using the tool's basic features to model a simple and a more well-known problem, before implementing the actual problem in context.

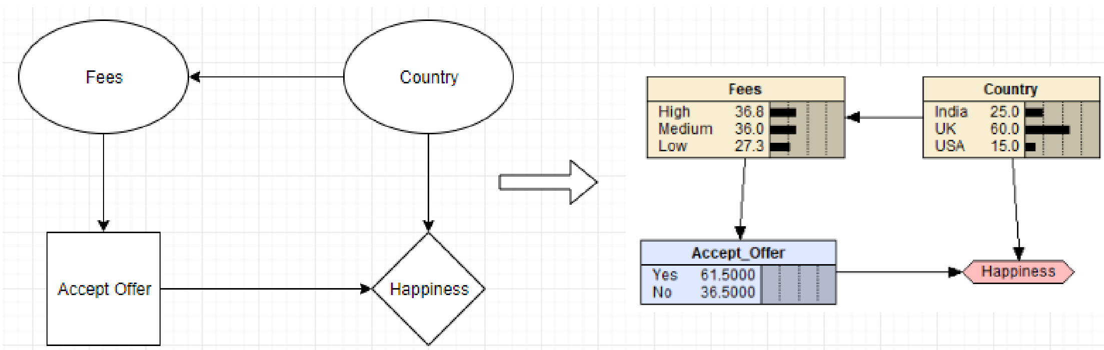


Figure 3.8: Transformation of ID in planning stage to finished stage using Netica

How I created the model in Figure 3.8 above is shown as a screenshot in Figure 3.9. I clicked on the required type of node from the toolbar and dropped it onto the white space. For each nature node (Country and Fees), I named it by double clicking on the node. I can do it this way or by right-clicking on it and selecting properties. The former method is easier. Then I filled in the 'State' box by adding 'New' items, with my country preferences. Two points to note are; one, space is not allowed between two words when labeling a node or a state (use _ to separate words); and two, not more than 30 characters can be typed as a label.

Note here that, I have linked 'Country' node and 'Fees' node because logically, if I study in a country, I must pay fees. So, this simply means 'Country' node leads to 'Fees' node. I do not have to link 'Country' node to 'Accept_Offer' decision node because 'Fees' is the child node that inherits the properties of 'Country', the parent node. However, for the consequence node 'Happiness', there must always be a parent node and a decision node which evaluates the level of happiness of accepting and not accepting an offer from each of the countries. This level of happiness is my top event that I will try to see the impact of, when I change my variable that assist me with my decision.

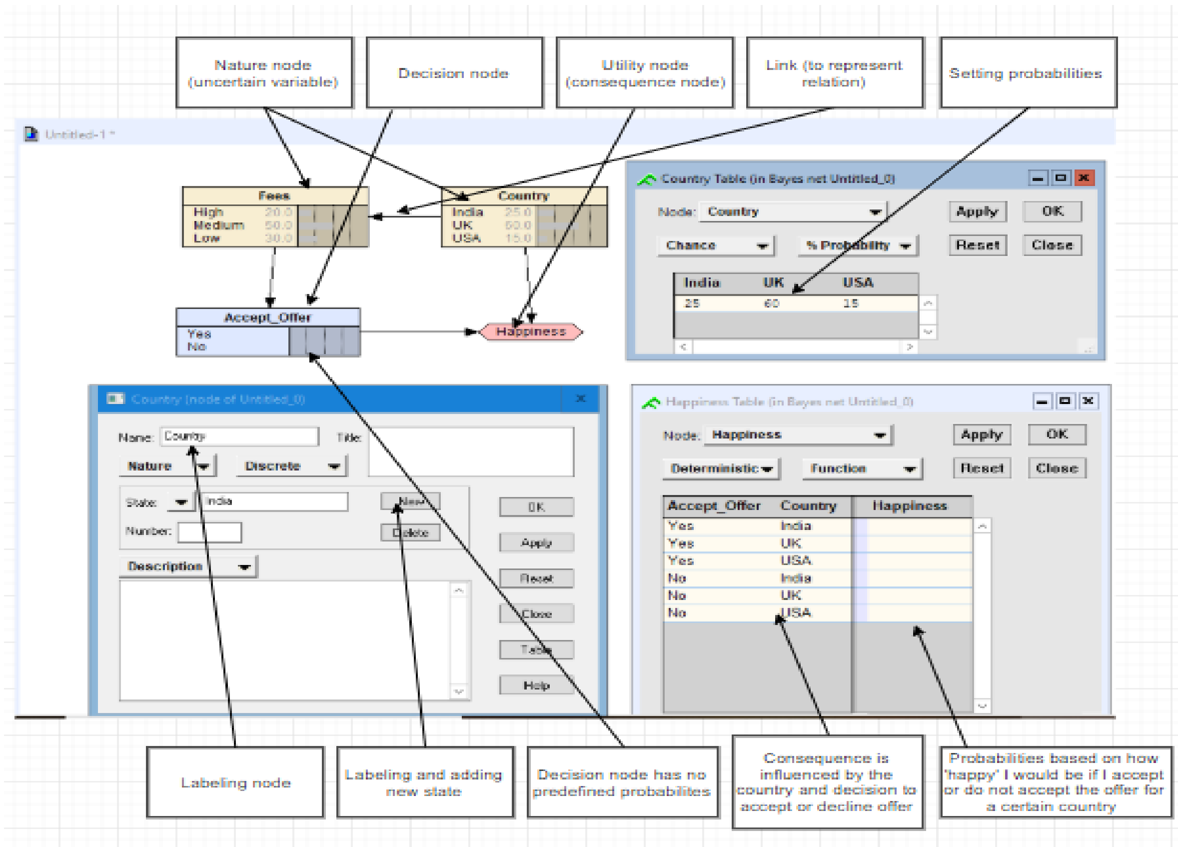


Figure 3.9: Aspects of node labeling and probability filling

After that, I filled in the probabilities based on which country I prefer to study in the most. I can do this by clicking on ‘Table’ or by right-clicking on the node and selecting ‘Table’. I would then do the same for the states in the ‘Fees’ node as well, by filling in the probabilities as per my preference. By default, it would give equal split of probabilities to add up to 100%, but I would have to change the individual probabilities based on my preference.

The decision node, in this case, whether I decide to accept the offer, must be labeled and filled, along with the states as ‘Yes’ or ‘No’. The key point to note about decision nodes is that, this does not require probabilities to be filled because this is what we want our output to show as a probability, based on the nature nodes and consequence node. This means ‘Netica’ will solve the decision net and output the values for the decision nodes. The consequence, i.e., my ‘level of happiness’ is a probability which is influenced by the country and whether I decide to accept the offer. I filled in all the probabilities in a table, called NPTs or CPTs [7], based on my knowledge of how the fee range in each country is for their courses. It is not based on any dataset. They are artificial values.

Now that I have my model, I must now compile and run it, by clicking this icon,  in the toolbar. Then I will get values in the decision node. Based on that, I can decide whether to accept the offer.

3.6.4 Significance of Output

The hidden Statistics behind calculating these probabilities in all the nodes is Bayes' Theorem. The more number of nodes there are, the more complex and time consuming the calculations will be. Hence, I will not be demonstrating the calculations for these probabilities.

However, what do the probability values in the decision node mean? It indicates the 'expected utility' of making that choice. So, when no information is known for sure, deciding to accept the offer with the available information has better value of 61.5, rather than declining the offer which has only 36.5. Now, say suppose I will surely accept an offer only if the fee is affordable for me, so that means I will avoid high fees for sure, but at the same time I do not want to go for a cheap course, because the quality of the course would not be great. So, I will choose only a medium course fee and the country doesn't matter. So, what is the probability of me accepting the offer? How I do this is, click on 'Medium' in the 'Fees' node. It will automatically change to 100 and the remaining 'High' and 'Low' would become 0. This would show the change in values in the 'Country' node and 'Accept_Offer' decision node as shown below in Figure 3.10. From this, I can accept the offer if it is from a UK university as the fees is medium level and the offer acceptance value is ~64.6.

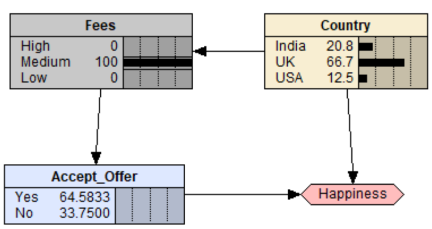


Figure 3.10: Change in node state values upon selecting known information

Similarly, I can select any state in either 'Fees' or 'Country' node as I get more concrete information and decide whether to accept the offer based on whichever state value is higher. To return all the values back to the way it was initially, I just had to click on the state again.

3.7 Summary

In this chapter, I did a detailed review about BBNs and IDs. I understood their logical and theoretical concepts. I also investigated the various BN modelling tools and chose 'Netica' to model my problem. I learnt to use the basic features of the tool through carrying out a simple problem of my own.

CHAPTER 4

ID MODEL DEVELOPMENT FOR PROBLEM SPECIFICATION

4.1 Introduction

Now I am coming to the most important part of my project. In this chapter, I will be developing an ID to model the impact of regulatory control for elevator devices on the consequences elevator risk have for users in Toronto, NYC and Mumbai. **The purpose of my model is to advice the user of the model on a course of action to take upon processing variable inputs, considering its consequences.** My aim is to develop a single hybrid ID model that represents the whole problem context, rather than creating a region-specific model. I mean, it will be a common model that can be used by any of the three ED authorities. This is my aim. I decided to do it this way because if I create multiple ID models for each region separately, it will be challenging to visualize the entire problem in a single picture. So, my goal is to build one ID that captures maximum amount of information.

4.2 Process of Selecting Consequences, Variables and Decision Nodes

To build my model, I had to select those events (variables) and key decisions that were most representative and relevant to my problem specification and which would fulfil the purpose of my model. I could get this information only from Chapter 1 because that is where I had all the data that would tell me, “Yes, this is a cause of major concern leading to my top events (consequence nodes) ED hazards and availability issues”. It was crucial for me to understand and figure out the crux of the problem and think about why these issues are happening or what events could be leading to these, and to find a course of action (decisions) to take.

4.2.1 Choice of Consequence Nodes and Definition

I had two consequence nodes in my model (Figure 4.1). I am defining them below in Table 4.1.

Consequence Node	Definition
ED Hazard Occurs	Defined as the probability of the event of human casualties and / or damage caused to the ED or its associated parts
ED Unavailable	Defined as the probability of the event of ED not functional at any point of time

Table 4.1: Consequence nodes and their definition

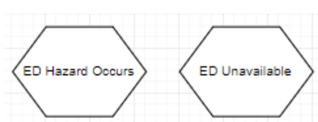


Figure 4.1: Consequence nodes

4.2.2 Choice of Variables and Definition

From my data, I found that all the regions had a few similar issues (more or less) that were causing elevator hazards and availability issues, which I thought was quite interesting. For e.g., safety regulation violation taking place; lack of serviceman availability for conducting repairs; scheduled maintenance checks not taking place, complaint information not passed in a timely manner to servicemen, etc. are some common issues I identified were taking place in the regions.

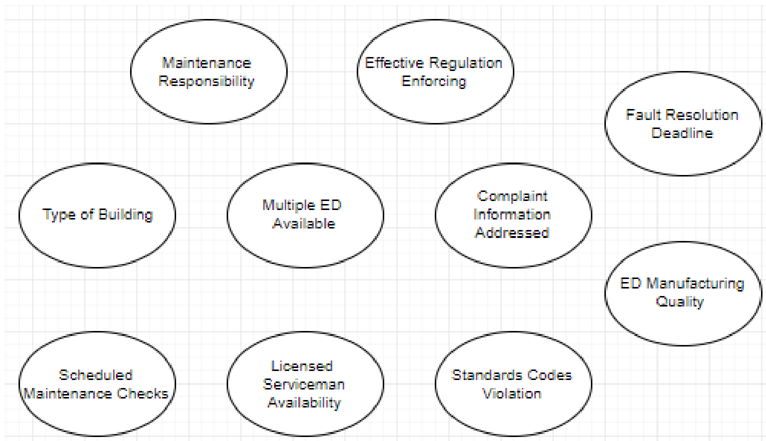


Figure 4.1: Choice of variables

Variable	Definition
Type of Building	Defined as the purpose of a building
Multiple ED Available	Defined as whether there are more than one ED available in a building
Maintenance Responsibility	Defined as the person (group) responsible for ensuring ED maintenance happens
Scheduled Maintenance Checks	Defined as whether maintenance checks of EDs happen on time as scheduled
Licensed Serviceman Availability	Defined as whether an authorized serviceman for replacing or modernizing ED is available
Standards Codes Violation	Defined as the degree of violation of building and ED regulations
ED Manufacturing Quality	Defined as the degree of quality of the available ED
Fault Resolution Deadline	Defined as the timeline (days) provided by the authorized serviceman to replace or modernize ED
Effective Regulation Enforcing	Defined as whether the ED authority is effectively enforcing the regional building and ED standards and codes
Complaint Information Addressed	Defined as how quickly the building owner or representative addresses user complaint on ED repair or unavailability

Table 4.2: Variables and definitions

4.2.3 Variable States and Definition

Now I will present each of the above variable's states and their definition in the following tables. It is important to note that the variable states are probabilistic in nature. I mean they are all defined in terms of a probability of occurrence. So, there is a chance associated with each state happening.

State	Definition
Hospital and Care Home	Defined as any building type with medical practitioners providing care, treatment or supervision to aged and vulnerable people
Residential	Defined as any building type with households living in it; includes houses, apartments and condominiums
Commercial	Defined as any non-residential building type where people come to work, for public gathering or for leisure; includes office buildings, shopping malls, hotels, restaurants, etc.

Table 4.3: Type of Building variable states and definition

State	Definition
Yes	Defined as more than one ED is functional in a type of building
No	Defined as no more than one ED is functional in a type of building

Table 4.4: Multiple ED Available variable states and definition

State	Definition
Building Owner	Defined as the person or representative or group who owns a building
Elevator Contractor	Defined as the person who is licensed and approved by the government to perform maintenance and repair of Elevators in a building
None responsible	Defined as no person or representative or group claiming responsibility for performing maintenance and repair of Elevators in a building

Table 4.5: Maintenance Responsibility variable states and definition

State	Definition
Yes	Defined as maintenance checks of EDs in a building happening on time as scheduled
No	Defined as maintenance checks of EDs in a building not happening on time as scheduled

Table 4.6: Scheduled Maintenance Checks variable states and definition

State	Definition
Yes	Defined as government approved serviceman authorized to perform maintenance, repair, modernization or replacement of EDs as immediately available to address ED fault or complaint from building owner, representative or group
No	Defined as government approved serviceman authorized to perform maintenance, repair, modernization or replacement of EDs as not immediately available to address ED fault or complaint from building owner, representative or group

Table 4.7: Licensed Serviceman Availability variable states and definition

State	Definition
High	Defined as building and / or ED standards / laws / regulations / codes being violated by any ED stakeholders or users, to an extent that it results in human casualties and damaged ED or its associated parts, such that it is not functional
Medium	Defined as building and / or ED standards / laws / regulations / codes being violated by any ED stakeholders or users, to an extent that it has no human casualties, but results in damaged ED or its associated parts, such that it is not functional
Low	Defined as building and / or ED standards / laws / regulations / codes being violated by any ED stakeholders or users, to an extent that it has no human casualties, or damage to the ED or its associated parts

Table 4.8: Standards Codes Violation variable states and definition

State	Definition
Good	Defined as the ED installed from the manufacturer has not resulted in any human casualties or damage to ED or its parts
Average	Defined as the ED installed from the manufacturer has not resulted in any human casualties, but has resulted in malfunctioning of the ED or its parts
Poor	Defined as the ED installed from the manufacturer has resulted in human casualties and in malfunctioning of the ED or its parts

Table 4.9: ED Manufacturing Quality variable states and definition

State	Definition
Within 15 days	Defined as the timeline provided by the licensed serviceman to perform maintenance or repair a malfunctioning ED to the building owner or representative or group
Between 15 to 30 days	Defined as the timeline provided by the licensed serviceman to perform mai repair or advise on a course of action to the building owner or representative or group, if it is not under his capability to perform the maintenance or repair
More than 30 days	Defined as the timeline provided by the licensed serviceman to perform maintenance or repair or revert to the building owner or representative or group on a future date if he is capable of performing maintenance or repair, but needs a specified amount of time to revert with the necessary equipment to perform the maintenance or repair

Table 4.10: Fault Resolution Deadline variable states and definition

State	Definition
Yes	Defined as the ED regulatory authority is effective in enforcing all building and ED regulations / laws / standards / codes and takes immediate action and steps to resolve ED hazards and unavailability issues
No	Defined as the ED regulatory authority is not effective in enforcing all building and ED regulations / laws / standards / codes and does not take immediate action and steps to resolve ED hazards and unavailability issues

Table 4.11: Effective Regulation Enforcing variable states and definition

State	Definition
Immediately	Defined as the ED fault or malfunction complaint received from user addressed by the building owner, representative or group immediately upon knowledge
With Delay	Defined as the ED fault or malfunction complaint received from user addressed by the building owner, representative or group with delay upon knowledge

Table 4.12: Complaint Information Addressed variable states and definition

4.2.4 <u>Choice of Decision Nodes and Definition</u>

So, I had three decision nodes in my model, as shown in Figure 4.3. I am providing their definition in Table 4.13

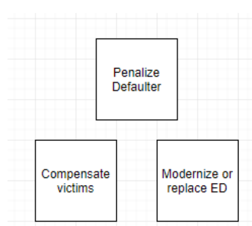


Figure 4.3: Decision nodes

Decision Node	Definition
Penalize Defaulter	Defined as the decision to take disciplinary action by the user of the model against the stakeholder or ED user in the event of violating building or ED regulations / laws / standards / codes, leading to ED hazard or unavailability. The form of penalty would be determined by the model user according to the level of offense committed by the wrong-doer
Compensate victims	Defined as the decision to take necessary steps by the user of the model to repay users in the event of human casualty if an ED hazard occurs. The form of reimbursement would be determined by the model user, according to the level of ED hazard and unavailability occurred
Modernize or replace ED	Defined as the decision to take by the user of the model whether to modernize or replace the ED in the case where it has been advised by the licensed serviceman to do so while performing maintenance checks. Such a decision would be taken only in cases where a regular repair or maintenance checks would not be suitable, owing to the present poor condition of the ED.

Table 4.13: Decision nodes and definition

The states for the decision nodes are all 'Yes' and 'No', indicating the action that needs to be taken based on the higher utility value for the state.

To summarize, I selected the above events as my variables, decision and consequence nodes to build a single hybrid ID model. Having shared their definitions, according to me, ED hazard (risk) and unavailability are equally important top events. This is because users in the selected regions are faced with concerns in their daily usage of EDs that surround these two problems. According to my research, they are not happy with the way the regulations in the regions are addressing these issues. I found that most of their complaints was owing to the fact that there was no ED available, but even for the ones that are available, the users were more often 'scared', rather than feeling 'safe' travelling by EDs, owing to various reasons that are causes for these, as described through my selection of variables. Many users showed their displeasure because the authorities have not addressed many of their concerns. It is to accurately address these two major concerns, I came up with the three decision nodes the way I did.

I came up with 10 such variables that I found are major causes or events that contribute significantly to ED hazards and availability issues. Similarly, the key decision nodes I sensed are most important for the ED authorities to act upon collectively. In my research, I found that currently, many of the events I have highlighted are causing major inconvenience to users, in many of the cases, despite addressing them to the authorities. This is why it has turned out be a big issue in the communities today. Hence, for either of the consequences arising, I feel, not just the defaulters and victims should be penalized and compensated, accordingly, but the ED should also be modernized or replaced as required, as the variables' state changes.

4.3 <u>Development of ID Model</u>

Figure 4.4 is the ID model plan I developed based on my understanding of the problem and what I want to show from it. I used the conventional notations (squares, ovals, hexagons, arcs). So, in the ID model, a decision is taken on the consequence of the event specified in a variable. Arcs (directional links) are used to capture relationships and flow of information in an upward direction leading to the top events. This is the outline of model. It can follow a top-down, bottom-up or a hybrid of both types. The background logic of the ID is in terms of NPTs (CPTs) based on Bayes Theorem. For e.g., what is the consequence of 'Modernize or replace ED' given 'Fault Resolution Deadline' (in %). The conditional probability of this is represented in the CPT for 'Elevator Unavailable'. I have populated the CPTs based on artificial values. This is necessarily not evidenced in my data. These are only 'beliefs'. One of the advantages of BBNs, as stated earlier, is it can always be updated upon availability of stronger evidence, and then the model can be recompiled and rerun.

According to [7], evidence is an observation of an event. This is entered as the state value. There are two types of evidences, namely 'hard evidence' and 'soft evidence'. The former is when we know for sure (100%) about an event. The latter is when there is no certainty of an event (<100%), so we enter only beliefs in the state. Soft evidence is the approach I followed for my model because it uses only artificial beliefs.

Figure 4.4: ID model plan before creating it in Netica

It is worthwhile to also note that when linking variables, it is not required to provide direct link to those variables that are being linked transitively. I mean, for e.g., if variable A links variable B and variable B links variable C, it is implied that variable A links variable C, so relinking is not required.

I then developed it using Netica (Figure 4.5). This is the pre-Netica version of my model where I had filled in all the NPTs for all the variables (more details on this in the following pages).

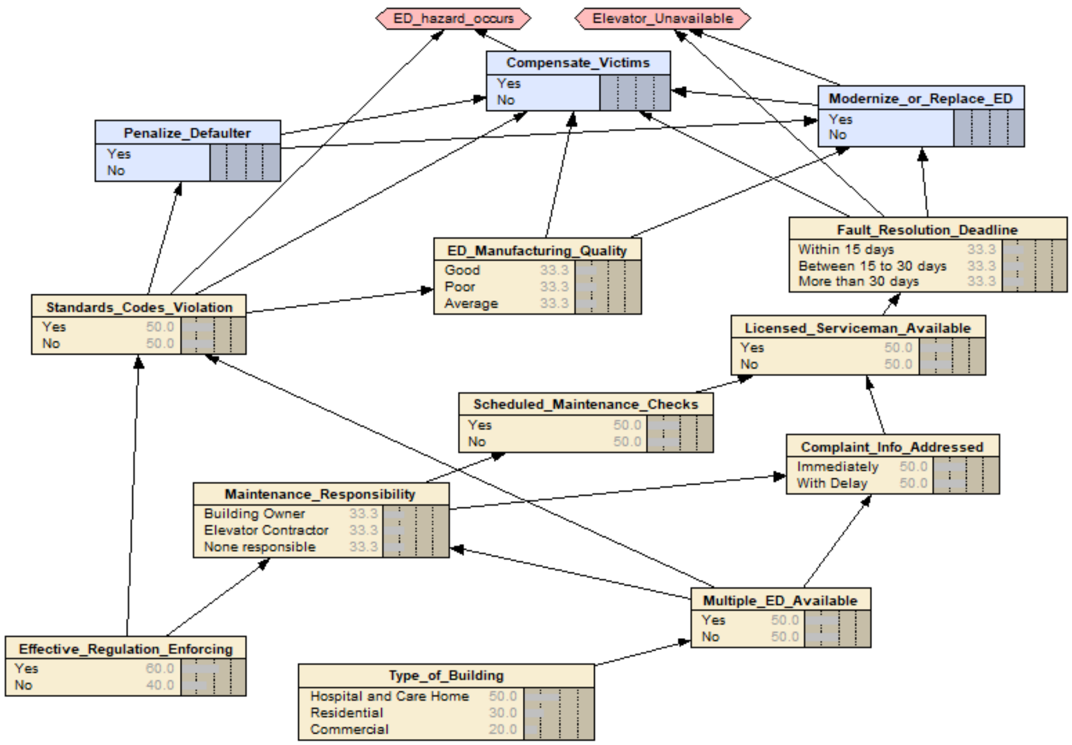


Figure 4.5: ID model for the specified problem context using Netica

An interesting aspect I noticed about 'Netica' when I compiled and ran the model is that it optimized the ID I created, and it output the ID as shown in Figure 4.6. This is a very important feature of Netica. According to Netica's online manual, "when a decision net is compiled, Netica may add or remove some links directed to or from decision nodes. If a link disappears from the original version post compilation, it means that for all possible utilities or CPTs, that link wouldn't be relevant to the decision. So, this is an automated feature of Netica during net compilation process, rather than manual.

Similarly, if a new link appears to a decision node in the compiled version, then it is a 'no-forgetting link' that is relevant to the decision". No-forgetting link, according to Netica online help, is when a "decision-maker remembers the decision they made earlier and also remembers the knowledge they had at that time. So, in the decision net there would be informational links from earlier decision nodes to later ones".

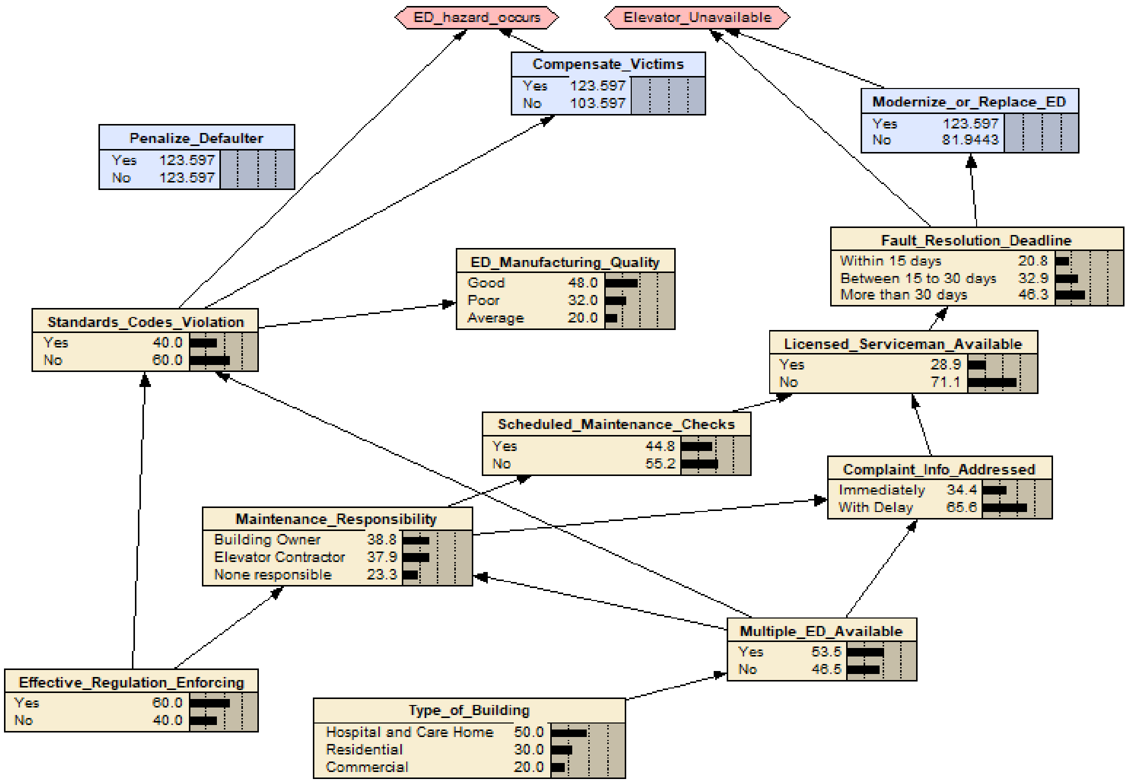


Figure 4.6: Optimized ID model using Netica

In my model, "No-forgetting link" was not applied as there were no new links added in the compiled version. It is important to note that only those links to and from decision nodes were removed and not those connecting variables. There were seven such links removed from my model after compilation from the original version. I found this to be interesting because Netica analyzed the links between the variables, decisions and consequence nodes probably in an optimal way, in which maybe I may not have thought. This is because I wanted to create links between the components of the model that would be sensible to me and the problem I want to answer. I believe Netica has provided an alternative to my thinking process here.

Another point worth mentioning is the fact that the variable 'ED Manufacturing Quality' seems to end abruptly, without having links to any other node or variables. However, recall from Figure 4.4 and 4.5 that I had provided a link from this link to decision node 'Modernize or Replace ED'. Upon Netica compilation of the original model, this arc has been removed, using the tool's logic. Note a similar, and a stranger instance for 'Penalize Defaulter' decision node. It seems that it has no incoming or outgoing links. However, in Netica's background logic, there are calculations happening which is causing the state values in the decision node to change as its associated variables changes. Why I think this is happening is because it 'remembers' the links it was attached to in the original model, but removed them during the compilation, at the same time not forgetting the fact of changing its own state values when associated variables' in its memory changes.

4.4 Detailed Reasoning behind ID Model

Let me explain my model in detail below. This will help me, and the readers better understand the logic behind my model and why and how I did, what I did. I will go through each node in my model one by one and discuss how and why I defined their states the way I did; and also talk about how and why I linked them to the relevant nodes using directional arcs (arrows). I will first discuss about the variables, then the decision nodes and then the consequence nodes.

4.4.1 Variables (Nature Nodes)

Type of Building

Thinking logically, in order for ED hazards or availability issues to take place, there simply first needs to be a building where EDs are installed. So, starting with the variable "Type of Building", there are three states in it, namely 'Hospital & Care Home', 'Residential' and 'Commercial' (labels of states of variables are supposed to be only keywords of not more than the set limit of 30 characters). Please refer to Table 4.3 for definitions of the states of this variable.

In my research, I found that ED authorities in the regions prioritize ED hazards and ED unavailability according to the vulnerability of the building type, i.e., it prioritizes services for hospitals and care homes first, and then only it serves residential and commercial buildings. So, considering this fact, I have populated the beliefs as shown in Figure 4.7. Here, I have given an artificial value of 50% and 30% for Residential buildings and 20% for commercial buildings, simply based on intuition. This is debatable because some people argue that more number of people live in residential buildings or more financial transactions happen in commercial buildings, so different cohorts have different requirements for needing urgent services for the type of building they are functioning out of. This is one of the major issues ED authorities are facing, being unable to decide which building to prioritize in case of hazards or unavailability. I am of the opinion that all three types of buildings should be given equal priority, but at the same time, the authority should also evaluate other associated variables that also play an equal part in making an overall decision.

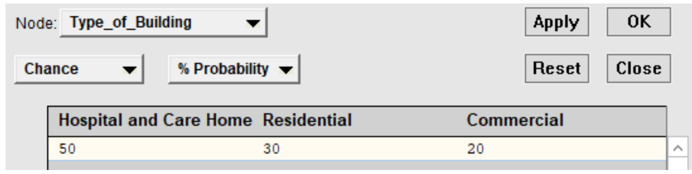


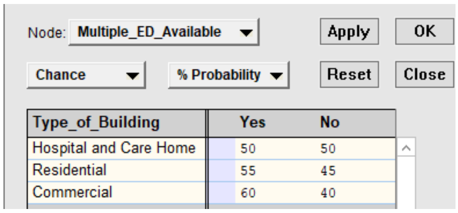
Figure 4.7: Beliefs for Type of Building variable

<u>Multiple ED Available</u>

Moving onto the direct cause of "Type of Building" variable, i.e., "Multiple ED Available". Firstly, a building of certain height (as specified in Table 1.12) should ideally have multiple EDs in a building so that commuters can use another ED if one breaks down. However, this is another main topic of concern for the residents in the regions (NYC, Toronto, Mumbai) because currently when an ED hazard or unavailability issue occurs, in many cases there are no replacement EDs. This is highlighted in several news articles, where residents in apartments and care homes complain of being left stranded in their houses for days because there is no standby ED. So, considering this current situation, I have given two states for this namely, 'Yes' or 'No', i.e., whether a building has multiple ED or not.

The NPT for "Multiple ED Available" variable is different from the above NPT for "Type of Building" variable. This is because the former node is the child node and the latter is the root (parent) node. This can be interpreted as the marginal probability, i.e., the direct cause (child node) conditional on the root cause (parent node). This is where the conditional probability concept of Bayes Theorem comes into picture. This is what happens in the background in Netica. It does the calculation automatically as the beliefs change. As the discussion of the Mathematical concepts behind Bayes Theorem and calculation of the conditional probabilities is out of scope of this project, I will not be getting into the derivation.

However, in simple terms this conditional probability can be understood as, for e.g., out of 100% chance of "Type of Building" being 'Residential', cases where multiple ED is available constitutes 55% and cases where multiple ED is not available constitutes 45%. Table 4.8 shows the beliefs I populated into the NPT. The other two states can be interpreted in a similar manner. These beliefs are artificial and have been entered purely based on my perception of the current situation. The point to remember here is that the row-wise probabilities in the NPTs must sum up to 100%. Another point to note here is shown in Figure 4.9. As I updated the beliefs in this variable for each combination of states from "Type of Building" and "Multiple ED Available", the overall probability of each of the state for this variable changes because of the condition applied on it. This is calculated automatically by Netica using Bayes Theorem. So, for instance, the overall probability of multiple ED being available given any type of building is 53.5% and not being available is 46.5%. These two probabilities must sum up to 100%.



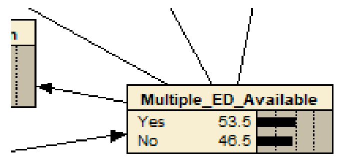


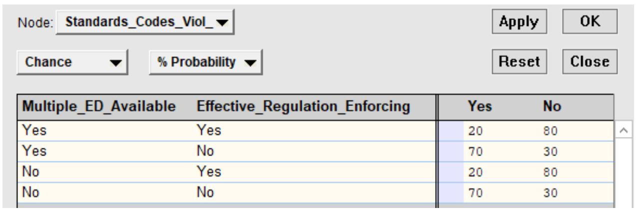
Figure 4.8: Beliefs for Multiple ED Available   Figure 4.9: Overall probability of Multiple ED Available

Standards Codes Violation

"Multiple ED Available" is the parent node to "Standards Codes Violation" child node. This is because violation of standards and codes are also a rising concern for ED authorities and users, where there have been a few incidents in Mumbai where local builders were not following the building standards set out by the government. For e.g., builders were not allocating space to build ED shafts in high-rises, resulting in delay in sanctioning of the further work by the building inspectors. So, I have included this as a variable with two states 'Yes' and 'No', indicating whether the building or ED is violating standards or not. An alternative way of looking at this is in terms of levels of violation, such as "High", "Medium", "Low". I chose to go with the former because now I was more interested in a "this" or "that" situation, rather than categorizing the violation in different levels. I might attempt this in the latter manner next time and observe the difference.

The beliefs in this variable is more complex because there are two parent nodes for this child, namely "Multiple ED Available" and "Effective Regulation Enforcing". What I mean by this is, these two variables can cause or lead to "Standards Codes Violation". For e.g., "Multiple ED Available" causes "Standards Codes Violation", because there are chances the EDs in a building are not constructed according to standards, thereby violating the codes. In this case, it will not get permission to be installed in the building by the ED inspectors. Similarly, if there is no effective regulation enforced, it will lead to violation of standards and codes.

So, as it can be seen here, both variables play an important role in determining the overall effect of this variable. Since this variable is conditional on two other variables, the NPT table is more complicated as it takes all the possible combinations of the states of the two variables. In simple terms, this conditional probability can be understood as, for e.g., out of 100% chance of "Multiple ED Available" is 'No' and "Effective Regulation Enforcing" is 'No', cases where "Standards Codes Violation" occurs (Yes) is 70% and does not occur (No) is 30%. Figure 4.10 shows this in detail. Currently not many such incidents have been reported in the cities, but it is surely a concern that can in the long run impact the stakeholders like building owners and building constructors. I have filled the beliefs as per my perception of the current scenario. The overall probability for this from Figure 4.11 is 40.0% for 'Yes' state and 60.0% for 'No' state.



Multiple_ED_Available	Effective_Regulation_Enforcing	Yes	No
Yes	Yes	20	80
Yes	No	70	30
No	Yes	20	80
No	No	70	30

Figure 4.10: NPT for Standards Codes Violation

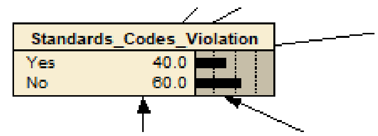


Figure 4.11: Overall probability for Standards Codes Violation

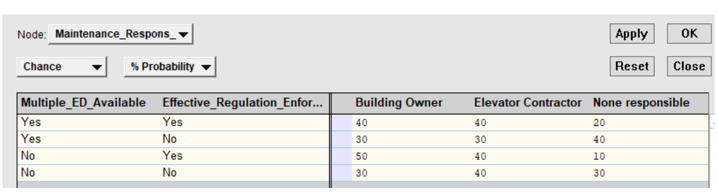
Adding to my above discussion about "Standards Codes violation", for e.g., before EDs are built, the authority responsible for buildings, such as NYC DOB will inspect the building and evaluate its height and advice on the number of elevators that must be available. If this is not obeyed by the building owner or the responsible person for the building, it would lead to the violation of standards. It can be the other way around too. The building owner and constructors may have planned to construct multiple EDs, but the building inspector can counter that and say that according to the building height specification, the permission only for 'n' number of elevators can be granted. If the builders don't re-plan, then it would be a violation and permission would not be granted till a new plan is presented. A presentation in NYC DOB talked about a similar event. This is likely to happen, although not very commonly. It is a problem that must be taken seriously though. NYC DOB and TSSA conduct awareness sessions with stakeholders on updates to building codes, but there is no information on whether Government of Maharashtra does something like this for Mumbai.

Moreover, EDs have its own set of standards set by the respective authorities, which are not followed at times by the ED manufacturers. This too can lead to hazards. For e.g., a senior official from one of the leading elevator manufacturing companies wrote in a magazine that, most of the states in India have its own ED safety regulation protocol that it is almost impossible to follow each one. This although makes sense coming from a senior official, it must however, be alerted by them to the respective authorities about this. Very few or no such risks have occurred in the regions till date, but it is definitely an event that must be looked out for by the authorities, as it can lead to severe hazards and unavailability issues.

Maintenance Responsibility

Moving onto one of the child nodes from “Multiple ED Available”. EDs in a building require someone responsible who will coordinate timely maintenance checks to ensure smooth operation of the ED. Hence, I have a variable link to “Maintenance Responsibility”. This is in my point of view inevitable and must be done. However, there have been numerous cases in the cities where there is no one claiming responsibility to ensure ED maintenance is done. So, this is either not at all happening, or it is happening with a lot of delay. This is a major concern for users causing unavailability issues and associated hazards. For e.g., in Mumbai and Ontario, if a maintenance has been scheduled after six months, it is happening after eight months or one year. In another case in NYC, the local maintenance personnel who have the license to perform maintenance were not doing it fully and thoroughly. This was found out by the Elevator Unit of NYC DOB during their random inspection of ED maintenance. This was because there were no one responsible managing this.

So, considering the gravity of the situation, I have included this as a variable and allocated three states, ‘Building Owner’, ‘Elevator Contractor’, ‘None Responsible’ (refer Table 4.5 for definitions). Like the previous scenario, this is dependent on two other variables, namely “Multiple ED Available” and “Effective Regulation Enforcing”. The NPT for this is shown in Figure 4.12. The logic is similar to the one discussed earlier in 4.10. In simple terms, this conditional probability can be understood as, for e.g., out of 100% chance of “Multiple ED Available” is ‘Yes’ and “Effective Regulation Enforcing” is ‘Yes’, cases where “Maintenance Responsibility” is ‘Building Owner’ is 40%, ‘Elevator Contractor’ is ‘40%’ and ‘None responsible’ is 20%. This means, the two former cohorts of people are mostly responsible for ED maintenance where there are “Multiple ED Available” and “Effective Regulation Enforcement”, with only 20% where there is no one holding responsibility. The overall probability for this from Figure 4.13 is 38.8% for ‘Building Owner’ state, 37.9% for ‘Elevator Contractor’ state and 23.3% for ‘None responsible’.



Multiple_ED_Available	Effective_Regulation_Enfor...	Building Owner	Elevator Contractor	None responsible
Yes	Yes	40	40	20
Yes	No	30	30	40
No	Yes	50	40	10
No	No	30	40	30

Figure 4.12: NPT for Maintenance Responsibility

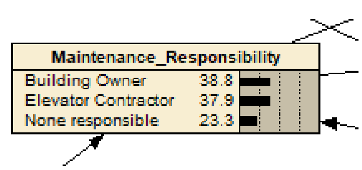
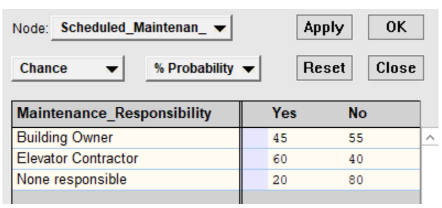


Figure 4.13: Overall probability for Maintenance Responsibility

Scheduled Maintenance Checks

Another event related to "Maintenance Responsibility" is the "Scheduled Maintenance Checks" variable. From Figure 4.4, it is can be seen that it is the child node of "Maintenance Responsibility". This is an important variable for the reasons included previously. Regular maintenance of EDs are rarely happening in all the cities because of lack of responsibility of the authority in ensuring this, which is turning out to be a major concern for users, leading to hazard and unavailability issues. So, I have included this as a variable and allocated two states, 'Yes' and 'No', indicating whether maintenance check has been done or not. The NPT for this is provided in Figure 4.14 below. In simple terms, this conditional probability can be understood as, for e.g., out of 100% chance of "Maintenance Responsibility" is 'Building Owner', cases where "Scheduled Maintenance happens ('Yes') is 45% and does not happen ('No') is 55%.

The overall probability of the variable states given the condition of the states in "Maintenance Responsibility", is shown in Figure 4.15. This implies that given any condition of the states in "Maintenance Responsibility", the overall probability of "Scheduled Maintenance Checks" happening ('Yes') is 44.8% and not happening ('No') is 55.2%.



Maintenance_Responsibility	Yes	No
Building Owner	45	55
Elevator Contractor	60	40
None responsible	20	80

Figure 4.14: NPT for Scheduled Maintenance Checks

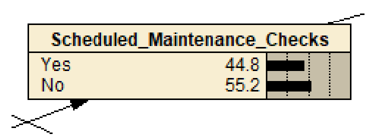
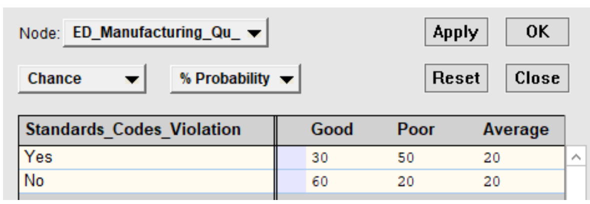


Figure 4.15: Overall probability of Scheduled Maintenance Checks

ED Manufacturing Quality

Moving onto a child node from "Standards Codes Violation", i.e., "ED Manufacturing Quality". This is quite an interesting topic because in the regions, there are both local as well as international players. In Ontario, some users were of the opinion that ED makers from the local market were more reliable for them than the EDs from the international ones. In Mumbai, however, the local market elevators have not been successful, and some hazards have been reported in news articles owing to unreliable parts used to design and build EDs. So, considering this fact, I have given three states for this variable, i.e., 'Good', 'Poor' and 'Average' (refer Table 4.9 for definitions). So, this is a major concern for building owners and users. There have been instances where the lift manufacturers license has been canceled by the ED authorities for installing unreliable EDs.

Adding to the above, a point to note here is, the "ED Manufacturing Quality" is determined by the conditional probability of it violating standards. This can help identify certain patterns whether there are EDs built using the same manufacturer or different manufacturer that is regularly violating standards, so the defaulter can be identified easily by checking if only certain brands of EDs are having quality issues. Figure 4.16 shows the NPT for this. In simple terms, this conditional probability can be understood as, for e.g., out of 100% chance of "Standards and Codes Violation" is 'No', cases where "ED Manufacturing Quality" is 'Good' is 60%; cases where it is 'Poor' is 20% and cases where it is 'Average' is 20%. The overall probability is given in Figure 4.17 for this child node. This can be read as, given either state of "Standards and Codes Violation", the overall probability that the "ED Manufacturing Quality" is 'Good' is, 48.0% of the time; 'Poor' is 32.0% of the time; and 'Average' is 20.0% of the time.



Standards_Codes_Violation	Good	Poor	Average
Yes	30	50	20
No	60	20	20

Figure 4.16: NPT for ED Manufacturing quality

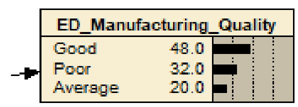


Figure 4.17: Overall probability for ED Manufacturing Quality

Basically, what I am trying to say so far is that each variable discussed till now leads to another variable. In simple terms, one event leads to another event. This is the story I was referring to earlier. Not all the variables will be connected to every other variable though, but my intention is to think about and build a practical and logical connection between most of the variables and decision nodes, leading to an evaluation of the consequence, so that the authority can be advised on the right decision to take through my model. Note that the flow of information is directed in an upward manner leading to the top event.

Effective Regulation Enforcing

"Effective Regulation Enforcing" is an important variable as it determines how effective the ED authority is in enforcing standards and regulations pertaining to buildings and EDs. As I briefly stated earlier, there is evidence of only TSSA and NYC DOB conducting regular information sessions to its stakeholders about updates in standards and regulations. There was no evidence of this happening in Mumbai. I have two child nodes, i.e., "Standards Codes Violation" and "Maintenance Responsibility". This means if "Effective Regulation Enforcing" does not happen, it can lead to violation of standards. Similarly, “Effective Regulation Enforcing” would ideally ensure that there is a responsible person for every ED in the area, ensuring and taking necessary steps for regular maintenance of EDs to happen. Hence, I have provided the arc between the parent node “Effective Regulation Enforcing” and direct cause node “Maintenance Responsibility”.

I have two states for this, ‘Yes’ and ‘No’. Note that this variable has no parent nodes. The NPT for this is shown in Figure 4.18, and Figure 4.19 shows that the overall probability of “Effective Regulation Enforcing” taking place (‘Yes’) is 60.0% and not taking place (‘No’) is 40.0%.

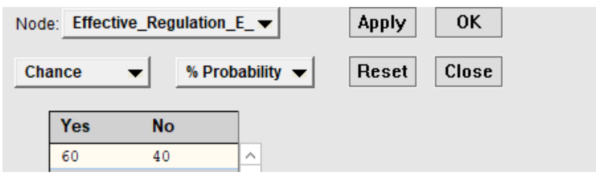


Figure 4.18 NPT for Effective Regulation Enforcing

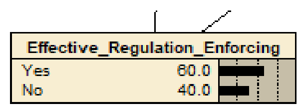
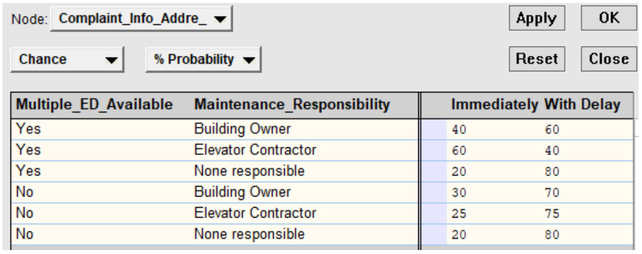


Figure 4.19: Overall probability of Effective Regulation Enforcing

<u>Complaint Info Addressed</u>

The building owners or representatives not addressing the information about the faulty ED complaints from users in a timely manner is one of the major concerns faced by users. According to several news articles, residents complain that the building owners are not taking immediate action of passing on complaints to the serviceman or the concerned authorities for fixing the fault. They are passing on the information with a delay, owing to expenses that the owners are not willing to bear. This is causing long unavailability issues where residents are stranded for days without being able to get out of their homes. Same issues are happening in care homes as well, where patients are stuck without being able to go out.

I have two states for this, i.e., if the complaint is addressed immediately or with a delay. The NPT for this (Figure 4.20) is similar to the one in Figure 4.10 in terms of the logic of NPT and to understand the information. For e.g., out of 100% chance of “Multiple ED Available” is ‘Yes’, and the “Maintenance Responsibility” is ‘Elevator Contractor’, cases where “Complaint Info Addressed” ‘Immediately’ is 60%; cases where it is ‘With Delay’ is 40%. Figure 4.21 shows the overall probability of this variable. These values mean that given any combination of states in the two parent nodes, the overall probability that the complaint will be addressed ‘Immediately’ is 34.4% and it will be addressed ‘With delay’ is 65.6%.



Node: Complaint_Info_Addre_ | Chance | % Probability | Apply | OK | Reset | Close

Multiple_ED_Available	Maintenance_Responsibility	Immediately	With Delay
Yes	Building Owner	40	60
Yes	Elevator Contractor	60	40
Yes	None responsible	20	80
No	Building Owner	30	70
No	Elevator Contractor	25	75
No	None responsible	20	80

Figure 4.20: NPT for Complaint Info Addressed

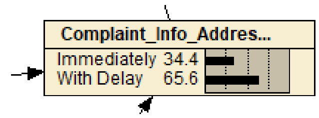
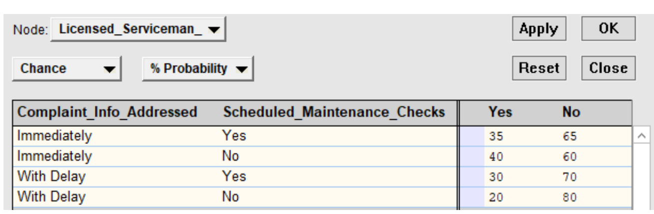


Figure 4.21: Overall probability of Complaint Info Addressed

Licensed Serviceman Availability

"Licensed Serviceman Availability" is also a common growing concern in all the regions. Licensed serviceman is very limited and building owners and users are facing problems with EDs when it is being serviced by personnel who do not have a license. The fact is that, compared to almost a decade ago, today the number of elevators have almost doubled, but the number of licensed personnel available is still the same. One of the articles quoted that the number of EDs a personnel is in charge of servicing has almost doubled than what it was ten years ago.

I have two states for this, namely 'Yes' and 'No'. The NPT for this is dependent on the states of "Scheduled Maintenance Checks" and "Complaint Info Addressed" as shown in Figure 4.22. In simple terms, this conditional probability can be understood as, for e.g., out of 100% chance of "Complaint Info Addressed" is 'With Delay' and "Scheduled Maintenance Checks" takes place ('Yes'), cases where "Licensed Serviceman Availability" is 'Yes' constitutes 30% and cases where it is not available ('No') constitutes 70%. What I mean by this is, what is the probability of "Licensed Serviceman Availability" given the timeliness of the "Complaint Info Addressed" and the "Scheduled Maintenance Checks" happening. According to Figure 4.23, the overall probability of serviceman being available ('Yes') given the different combinations of the two parent nodes is 28.9% and not available ('No') is 71.1%. The values of the beliefs have been populated based on my understanding of the current situation.



Node: Licensed_Serviceman_ | Chance | % Probability | Apply | OK | Reset | Close

Complaint_Info_Addressed	Scheduled_Maintenance_Checks	Yes	No
Immediately	Yes	35	65
Immediately	No	40	60
With Delay	Yes	30	70
With Delay	No	20	80

Figure 4.22: NPT for Licensed Serviceman Availability

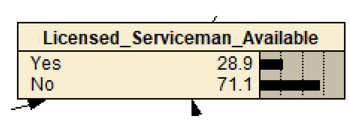
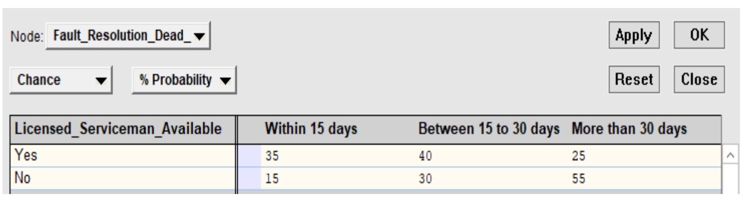


Figure 4.23: Overall probability for Licensed Serviceman Availability

Fault Resolution Deadline

The last variable I have is “Fault Resolution Deadline”. This was mentioned in Table 1.12. Each region has its own timeline for repairing faults. It could be based on the type of fault or the time taken by the serviceman to check the fault and provide a timeline for repair. Why is this important in my model? The deadline will be determined by the availability of the licensed serviceman. It will have three states as shown in Figure 4.24, namely ‘Within 15 days’; ‘Between 15 to 30 days’ and ‘More than 30 days’. In simple terms, this conditional probability can be understood as, for e.g., out of 100% chance of “Licensed Serviceman Availability” is ‘Yes’, cases where “Fault Resolution Deadline” is ‘Within 15 days’ constitutes 35%; cases where it is ‘Between 15 to 30 days’, constitutes 40% and cases where it is ‘More than 30 days’ constitutes 25%. The overall probability of the three states given the combination of states in “Licensed Serviceman Availability” is shown in Figure 4.25. This means, resolving the fault within 15 days is 20.8; between 15 and 30 days is 32.9 and more than 30 days is 46.3.



Licensed_Serviceman_Available	Within 15 days	Between 15 to 30 days	More than 30 days
Yes	35	40	25
No	15	30	55

Figure 4.24: NPT for Fault Resolution Deadline

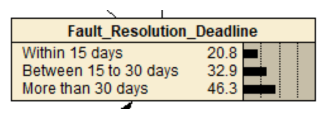


Figure 4.25: Overall probability for Fault Resolution Deadline

4.4.2 Decision Nodes

Now coming to the decision nodes. I have three in my model. Why did I choose these? I wanted to look at any situation (scenario) from three perspectives. Who does it impact? Who caused the impact? How do I fix it? This is what my decision nodes represent as shown in Figure 4.26. Decision node NPTs do not need to be populated. It is what Netica outputs based on the inputs.

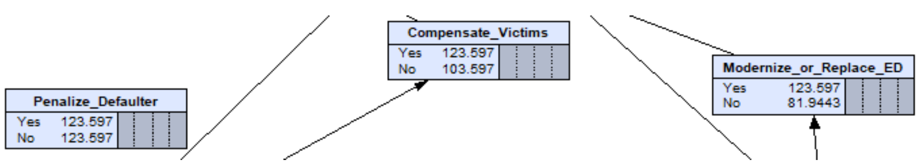


Figure 4.26: Decision Nodes

Penalize Defaulter

In my model diagram (Figure 4.4), I have one incoming link to “Penalize Defaulter” decision node from “Standards Codes violation”. Why did I link this to this decision? From the research I did, I found that when ED hazards have occurred, the major reason has been based on violation of standards and regulations for buildings and EDs set by the authority. So, I think this variable plays a major part in deciding whether to penalize the defaulter for the offense. So, I have two states here, 'Yes' and 'No', indicating whether to penalize the defaulter or not, respectively. The type of penalty to charge on the defaulter should be decided by the regional ED authority. In my opinion, this penalty should take place, so that such incidents can be minimized in the future, and the wrong-doers are more careful and reluctant to break any safety regulations.

Compensate Victims

Next decision node is "Compensate Victims". Here, compensate does not mean necessarily in terms of money, it can mean any action taken by the ED authority to help users in a difficult situation. I have two states here, 'Yes' and 'No', indicating whether or not to compensate the victims. I have five incoming arcs (two from decisions and three from variables) into this. Why is this so? The decision taken with "Penalize Defaulter" will impact the decision of this node. For e.g., if penalty of the defaulter takes place, then I would need to compensate the victims. This is again depending on whether there are "Standards Codes Violation" because if there are, it is going to impact users. "ED Manufacturing Quality" will also impact "Compensate Victims", because say if it is of 'Poor' quality, then hazards and availability issues are prone to happen. So, victims will need to be compensated. "Fault Resolution Deadline" is an important link to this decision node. Till the ED is repaired or replaced, what will the users do? How will they use the facilities in the building? ED authority needs to think about what they will do to help the users? Similarly, the decision from "Modernize or Replace ED" impacts whether or not to compensate victims, because say suppose the ED has to be replaced or even repaired and it is likely to take 30 days, how will the users use the facilities in the building till the repair gets over? The ED authority need to find a way to curb this experience for the users.

Modernize or Replace ED

The third and last decision node is "Modernize or Replace ED". I have two states, 'Yes' indicating ED must be replaced and 'No' indicating otherwise. I have three incoming arcs into this. One is the decision from the "Penalize Defaulter" node. This is because if the defaulter is penalized, then there is something wrong with the ED that has caused availability issues. So, it must be replaced or repaired, meaning the former decision causes the latter decision. If the "ED Manufacturing Quality" is 'Poor', then it must be replaced or modernized. That is why I have given an arc between these. Lastly, the "Fault Resolution Deadline" definitely links to this decision. If the deadline quoted by a serviceman to repair the ED is more than 30 days and if this timeline can be brought down by replacing it, rather than repairing it, then the authority should go for that. Especially, if after repair, the problem persists in the future, then there are chances of multiple availability issues.

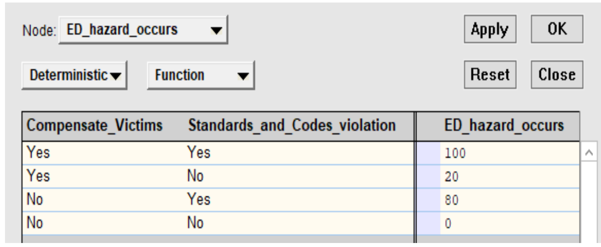
4.4.3 Consequence Nodes (Utility Nodes)

I have two consequence nodes (top events), "ED hazard occurs" and "Elevator Unavailable". These are the two major problems I am addressing in my project and in my model.

ED hazard occurs

From my original model in Figure 4.4, in "ED hazard occurs", I have two inputs. One is the output of "Compensate Victims" decision node and the other is the output of the "Standards Codes Violation" variable. This is because, if I have compensated the victims, it means ED hazard has occurred, owing to violation of standards and codes. Also, note that the output of the other two decision nodes have arcs to "Compensate Victims", so the consequence node logically is taking into account decisions from three nodes to analyze their impact on the variable.

The NPT for this is shown in Figure 4.27. It indicates the scenario of each combination of events from the states of the decision node and variable, as in previous cases. However, for consequence node, the values on the right hand side are differently entered this time. It indicates the favorability of the combination of events. For e.g., best case (0); worst case (100) and middle cases (varying values), in percentage. I filled these values based on my intuition of the current situation in the regions overall. For e.g., if I "Compensate Victims" ('Yes') and there is "Standards Codes Violation" ('Yes'), the consequence of "ED hazard Occurs" is 100, which is the worst case scenario. Whereas, if I do not compensate any user and there has been no violation of any standard or regulation, the consequence of ED hazard occurring is 0, which is the best case scenario. In the third case, if I do not compensate users for their loss and there occurs a standard and code violation, it is mostly a situation I do not want to be faced with, so I have given 80 for that. Lastly, if I compensated users to a certain extent probably owing to any inconvenience it may have cause a user owing to a violation of standards, but it has not been at a severe level of violation of standards or regulation, then that is a situation that is favorable to me, so I have given 20 for that.



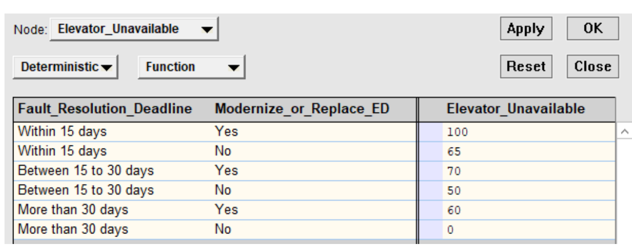
Compensate_Victims	Standards_and_Codes_violation	ED_hazard_occurs
Yes	Yes	100
Yes	No	20
No	Yes	80
No	No	0

Figure 4.27: ED hazard occurs consequence node

Elevator Unavailable

Now, moving onto the final node in my model, "Elevator Unavailable" consequence node has two incoming nodes as shown in Figure 4.4. One from the output of "Modernizing or Replace ED" decision and the other output from "Fault Resolution Deadline" variable. Why did I choose these two nodes? According to me, the consequence of "ED Unavailability" occurs based on the decision that arises out of whether to "Modernize or Replace ED" or not and based on the "Fault Resolution Deadline" provided by the licensed serviceman. These are the two nodes that can most closely determine the consequence of unavailability as opposed to any other nodes, in my point of view.

As shown in Figure 4.28, there are six combinations of scenarios from the states of these two nodes. I have filled the favorability differently this time unlike the other consequence node. For e.g., if I have "Fault Resolution Deadline" 'Within 15 days' and 'Yes' I must "Modernize or Replace ED", then the favorability is 100%, meaning that is the best case scenario for me. I would go ahead with replacing the ED for that short deadline. Whereas, if it will take "More than 30 days" and I decide not to replace the ED, then that is the worst case scenario for me, so I have given 0% for that. Similarly, if the deadline is within 15 days and I do not replace the ED, that is silly of me. I would pretty much not want to end up in a situation like that, unless I have a really good reason to do so. So, I have given 65% for that. Again, these are all artificial values based on my perception of how I would react to the situation if I was put under these scenarios. These can be easily modified by different users of the model. Parallelly, probabilities and utilities of related nodes will also change.



Fault_Resolution_Deadline	Modernize_or_Replace_ED	Elevator_Unavailable
Within 15 days	Yes	100
Within 15 days	No	65
Between 15 to 30 days	Yes	70
Between 15 to 30 days	No	50
More than 30 days	Yes	60
More than 30 days	No	0

Figure 4.28: Elevator Unavailable consequence node

CHAPTER 5

RESULTS

5.1 Introduction

In this chapter, I will talk about the findings from my model and its implications by demonstrating a few example scenarios using my ID model; and show different reports of the model that can be generated.

5.2 Findings and Implications

In Figure 5.1, it can be seen that the "Compensate Victims" decision node has an expected utility of 123.597 as "Yes" and 103.597 as "No", with all the originally assigned beliefs in all the nature nodes. It is important to note that both these are independent expected utility values and should not be taken as percentage values nor should they be summed together. What do these utility values mean? In this case, it means, before any more information on the variables are known, in the current situation, the best decisions to take are, "Yes" compensate the victims as it has a higher utility value; it doesn't matter if the defaulter is penalized for any violation or not, since both utility values are same; and "Yes", replace or modernize the ED as the utility for 'Yes' is higher than 'No'.

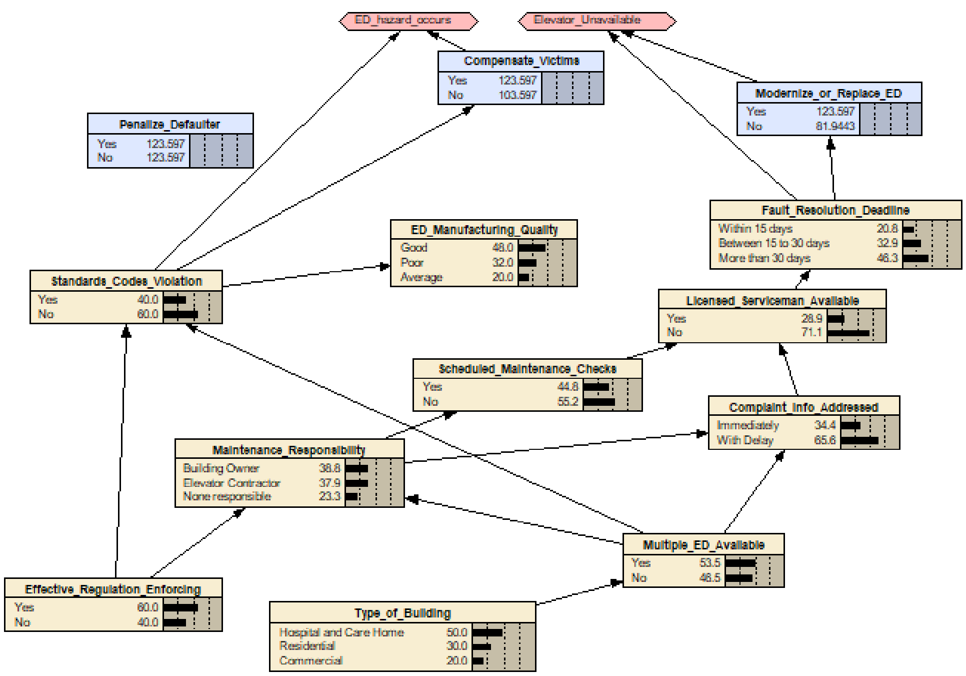


Figure 5.1: "Compensate Victims" decision node in its original state

5.2.1 Scenarios using ID Model

Let me demonstrate a few scenarios where I will show examples of how changes to variables effect associated probabilities of variables and the decision nodes.

Scenario 1

When I change the belief for “Yes” in the nature node “Standards Codes violation” (Figure 5.2) to a 100%, this means I am getting stronger evidence of the event that ‘Yes’, 100% there was a violation in the building standards, rather than the former weaker evidence. So, “Compensate Victims” decision node now shows an expected utility of 171.572 for “Yes” and 151.572 for “No”. “Modernize or Replace ED” decision node now shows 171.572 for “Yes” and 129.895 for “No”. It is also worth noting that, not just the decision node values have changed, but also all the other variables “Standards and Code violation” is associated to has also changed. This figure maybe compared with Figure 5.1 to verify. What does this mean?

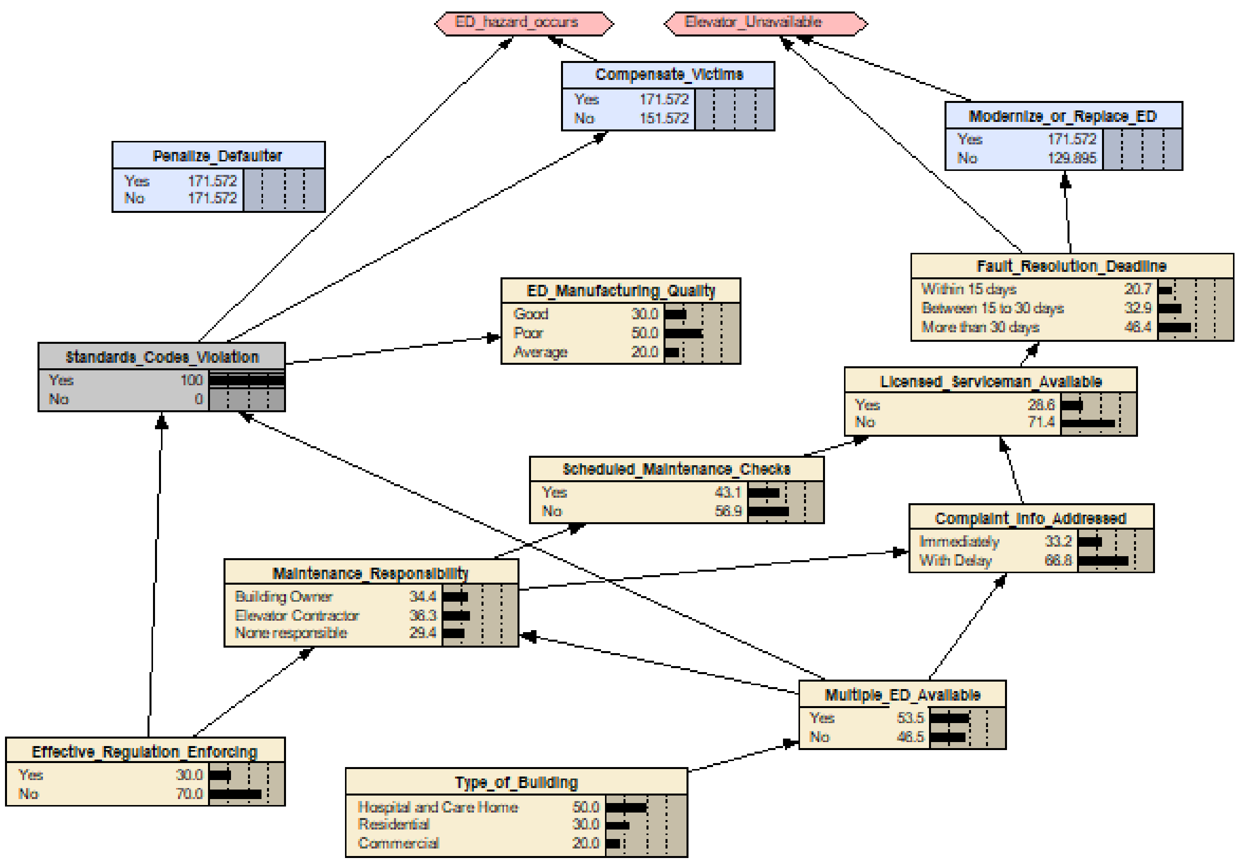


Figure 5.2: Decision node and variable states modified when one state is 100%

The variables it is linked to, have a conditional probabilistic association with it, so if it changes, all the other related variables' state probabilities will also change. When there is strong evidence that a particular state of a variable is certain, then the percentage probability for this state can be made 100% just with a click on the state label and the probability value for that state will turn to 100 and the other state will turn 0. Also notice the color change of the variable. Here, it is sure there has been a violation of the Standards and Codes, the expected utility for 'Yes' is 171.572 for "Yes" and 151.572 for 'No'. This means that the ideal decisions to make in this case are to compensate victims and to modernize or replace the ED. This value is determined not just through the NPTs of the nature nodes, but also through the NPTs for the consequence node "ED hazard occurs" because it is the variable that is associated with the consequence and the decision node as shown in the above figure. It is also worth noting that the decision on "Penalizing Defaulter" has no meaning here, i.e., the change made in node probabilities do not have any effect on this decision node in this particular scenario, as the states have equal expected utilities. So, it can be said that there is no action required.

A related scenario to this is shown in Figure 5.3. If we change the state of any other variable, the effect on the decision nodes and other associated variables can be seen. This can be done with any number of nodes.

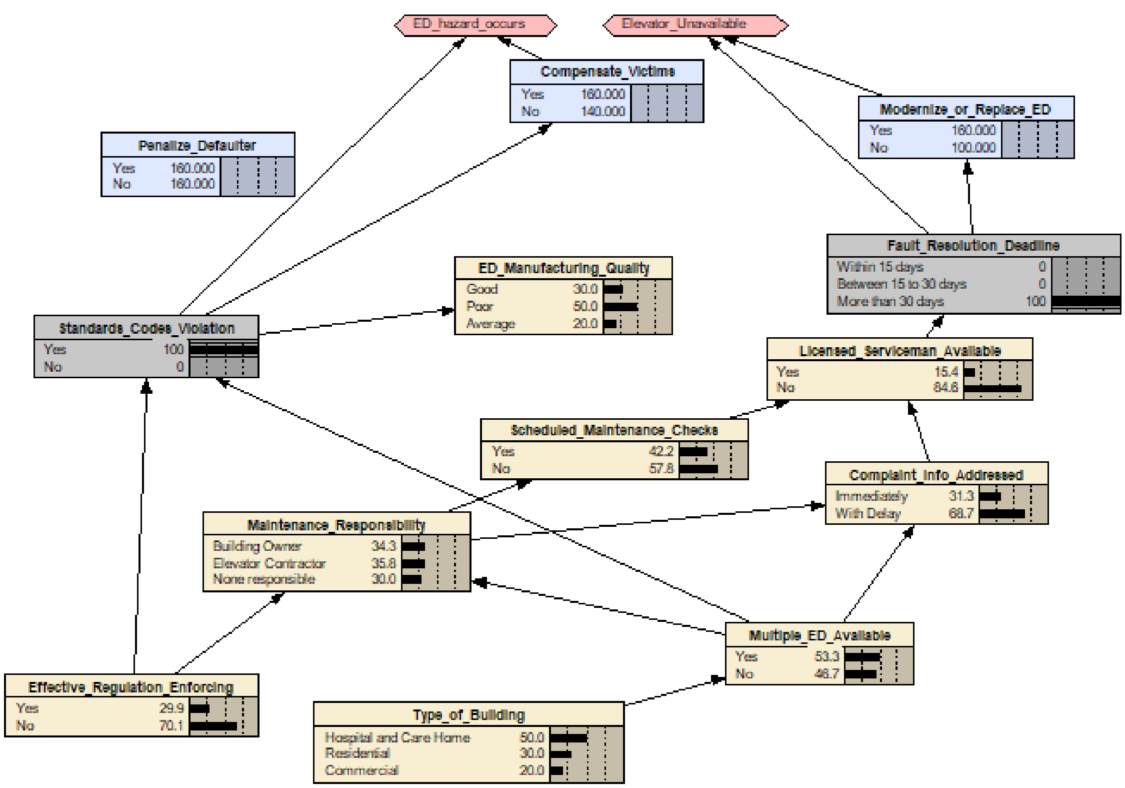


Figure 5.3: Decision node and variable states modified when two states are 100%

The main advantage of using Netica is that, upon obtaining stronger evidence of an event, any number of nature nodes can be changed any number of times as required. There is no need of running the model every time. It automatically recompiles and reruns as the changes in the network are made and outputs the updated probabilities and utilities immediately. Another useful feature in Netica is that, I can always go back to the original probabilities by just clicking on the state that I changed once again. I will know this when the color of the node changes to a light pinkish color.

The main idea here is that the ED authority should consider the state in the decision node that returns the highest utility value as the ideal decision to make. I am saying "consider" here because after all, it is only a model and not the decision maker. The ED authority is the decision-maker and they should evaluate how effective this advice returned by the model is.

Scenario 2

An interesting feature I found out while I was testing my model was, the probabilities of the variables can be changed real-time by just dragging the black bar next to each probabilities of the states back and forth. Notice in Figure 5.4, the variables that show a color change (purple) are the ones that I have tried to modify by dragging the black bar. Upon releasing the mouse, it can be seen that the probabilities for all the associated variables and decision nodes have been updated.

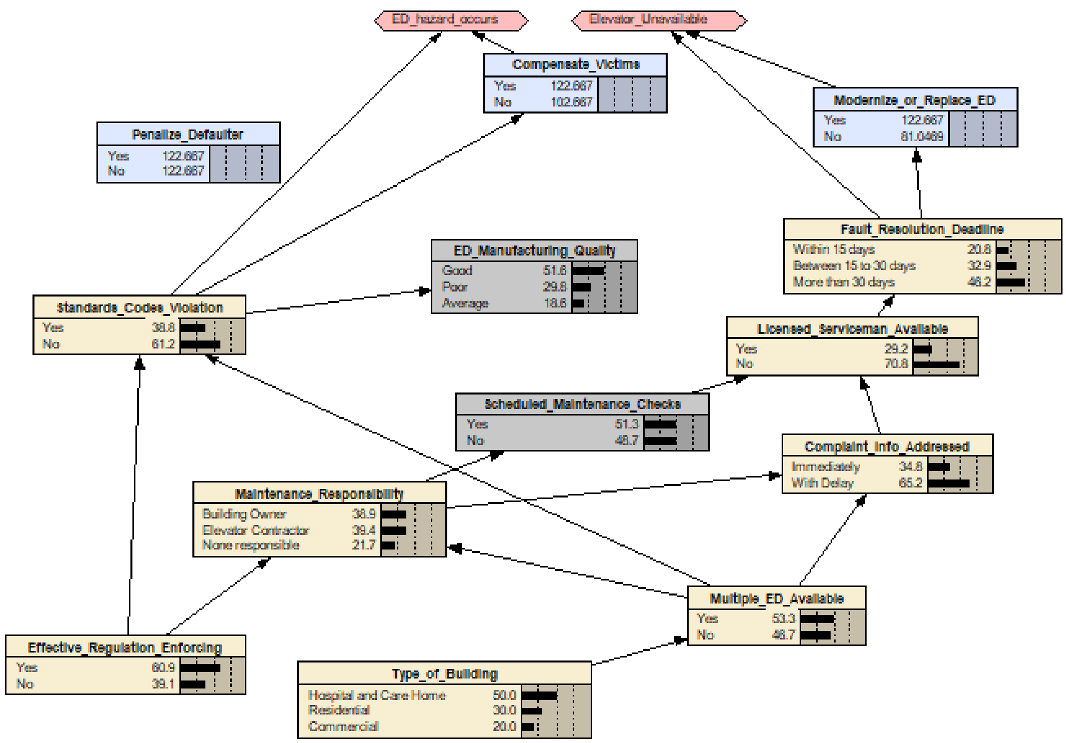


Figure 5.4: Updating state probabilities by dragging black bar next to the value

Scenario 3

One more interesting feature of Netica I found out during the testing of my model is shown in Figure 5.5. For any variable that has three states, it is possible to deselect one of the three states which we are sure will not be the case. In the below Figure, I have deselected ‘Poor’ from the “ED Manufacturing Quality” variable, indicating that I am sure the quality will not be ‘Poor’, but will either be ‘Good’ or ‘Average’. Similarly, for “Fault Resolution Deadline”, I have deselected ‘More than 30 days’ indicating that I am sure the fault resolution will not take more than 30 days but will be either ‘Within 15 days’ or ‘Between 15 to 30 days’. Similarly, “Type of Building” will surely not be ‘Hospital or Care Home’ but will be either ‘Residential’ or ‘Commercial’. The resulting changes in the probabilities of other variables and the utilities of decision nodes can be observed.

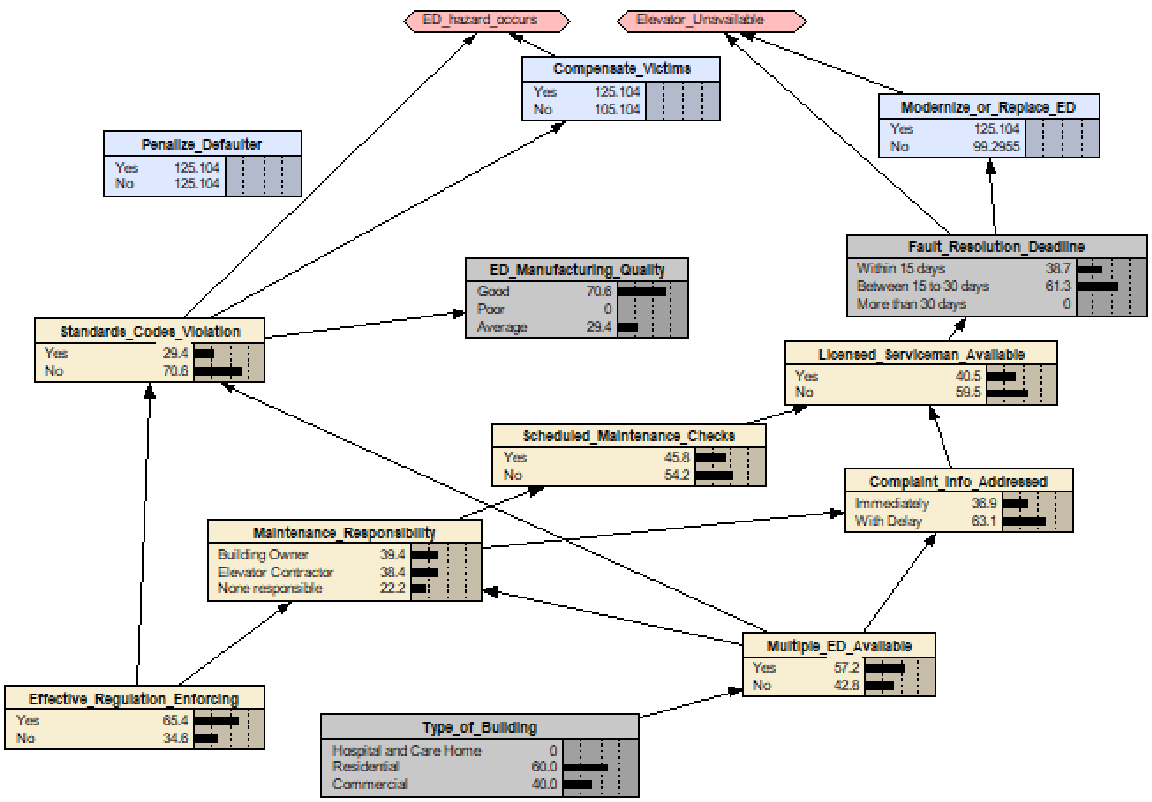


Figure 5.5: Deselecting a state in a three-state variable

Scenario 4

I can easily remove a node I do not need anymore from the Decision Net, probably because my scenario or situation has changed, that node will be meaningless to the user. In that case, all I have to do is delete the arcs to and from the variable first and then delete the node, by pressing the delete button on the keyboard or by right-clicking on the arc and node and selecting delete; or by clicking on Edit → Delete. Figure 5.6 shows the compiled version of my model after removal of the variable "Complaint Info Addressed". It shows the updated state probabilities of all the other variables and nodes. It is also easily possible to retrieve this back if it was done by mistake, by pressing Ctrl + Z on the keyboard, or by clicking on Edit → Undo. The only point that must be remembered is that the Decision Net must be compiled again for the changes to reflect.

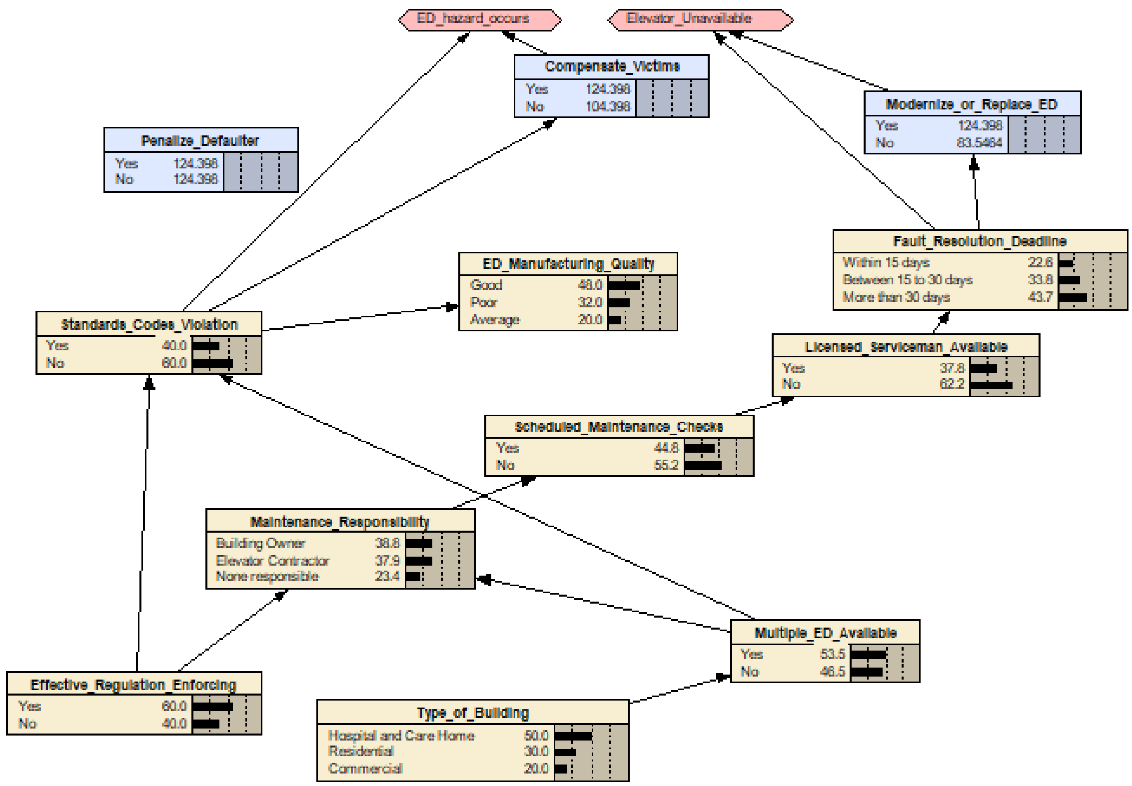


Figure 5.6: Removal of node from ID model

<u>Scenario 5</u>

Similar to the previous scenario, it is possible to add new links and nodes. I just had to drag and drop a new nature node or any kind of node as I wish onto the interface and proceed with the rest of the steps as usual (labeling, filling in the NPTs, creating links to the relevant variables and nodes). Figure 5.7 shows this. It can be added by either dragging and dropping, or by clicking Modify → Add. It can also be undone if required following a similar procedure as in Scenario 4.

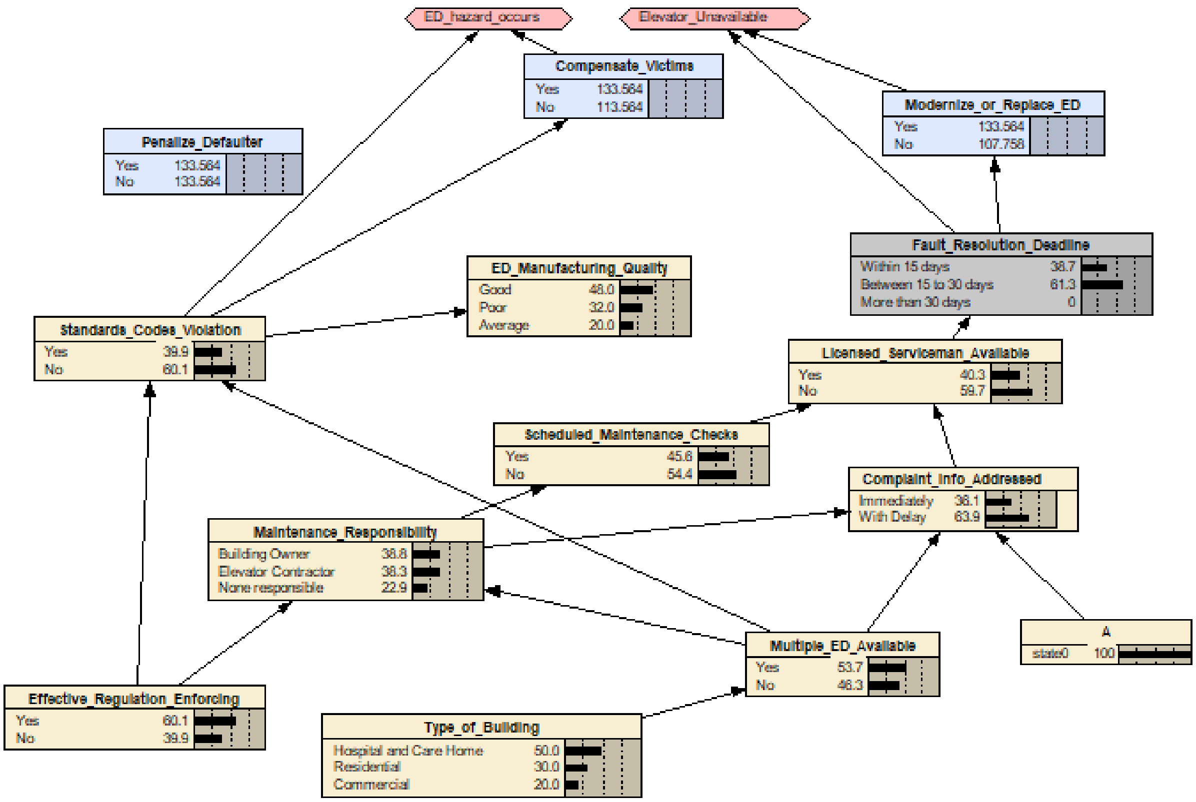


Figure 5.7: Addition of node into ID model

Scenario 6

Say suppose I have a situation with me, and I want to find the answer from my model. I want the model to advise me on a feasible decision. So, I want to decide on a course of action with the help of my model. For e.g., let the situation be the following. I own a commercial type of building that has multiple EDs available. I know the scheduled maintenance for all the EDs are happening. I also know that the EDs and the building have been built following all required standards and codes and they are manufactured by a well-known client. So, there is no issues of quality. The building is in a well-developed city with a fine government that ensures regulations are followed.

Despite having a perfect situation as a building owner, one day there occurs a problem. I receive a complaint from a customer that there seems to be some problem with the elevator. In fact, that day and over the next few days, I receive similar complaints from several customers about the elevators. I am not in town and out on a business trip, so I can't attend to the problem immediately. I try to phone someone responsible at the building, but he is out sick. I don't know if this problem is only with one elevator or if it is there with all the elevators. I start feeling a little stressed out. I don't want my customers to suffer because of the elevator unavailability. I don't immediately have the serviceman’s number with me, because I didn’t expect any problem to happen with the elevators, while I was away. I wouldn’t be back for another week as I am in a different country in a very important tour.

Next week, I come back, and I see the building is in a chaos. Elevators are not working, people are climbing stairs, people are sitting and lying on the floors; many are on leave and sick. I immediately go to my office and call the licensed serviceman. He says he doesn’t have a date available until next week. I try other licensed servicemen and they give me the same response. I explain the situation to him and ask him to come as soon as he has a date available. As I am honest to my work and people, I do not want to call any local serviceman without a license. Till then, I try to arrange some sort of a temporary arrangement to help people.

Next week he comes to my office and tells me that there is a serious technical problem with the elevator and it will take a month to get it fixed. He tells me it might be better to have it replaced, rather than repair it. It needs approval from the ED authority and it is a long process to get it fixed. I then go about working with the ED authority on the process to explain to them the situation.

So, this is the situation I have. I need to make a few decisions here. I don’t know who may have caused this problem. So, should I penalize any defaulter? I don’t know if I need to compensate or help the people of my building for the sufferings they have born. Although I said I will get on with the process by approaching the ED authority, I am not really sure if I should just repair it or should I really replace it? So, to help me decide what to do, I go to the ID model I have and input the above scenario exactly into the model by interpreting the variables of my model from the above situation. Figure 5.8 is what I have.

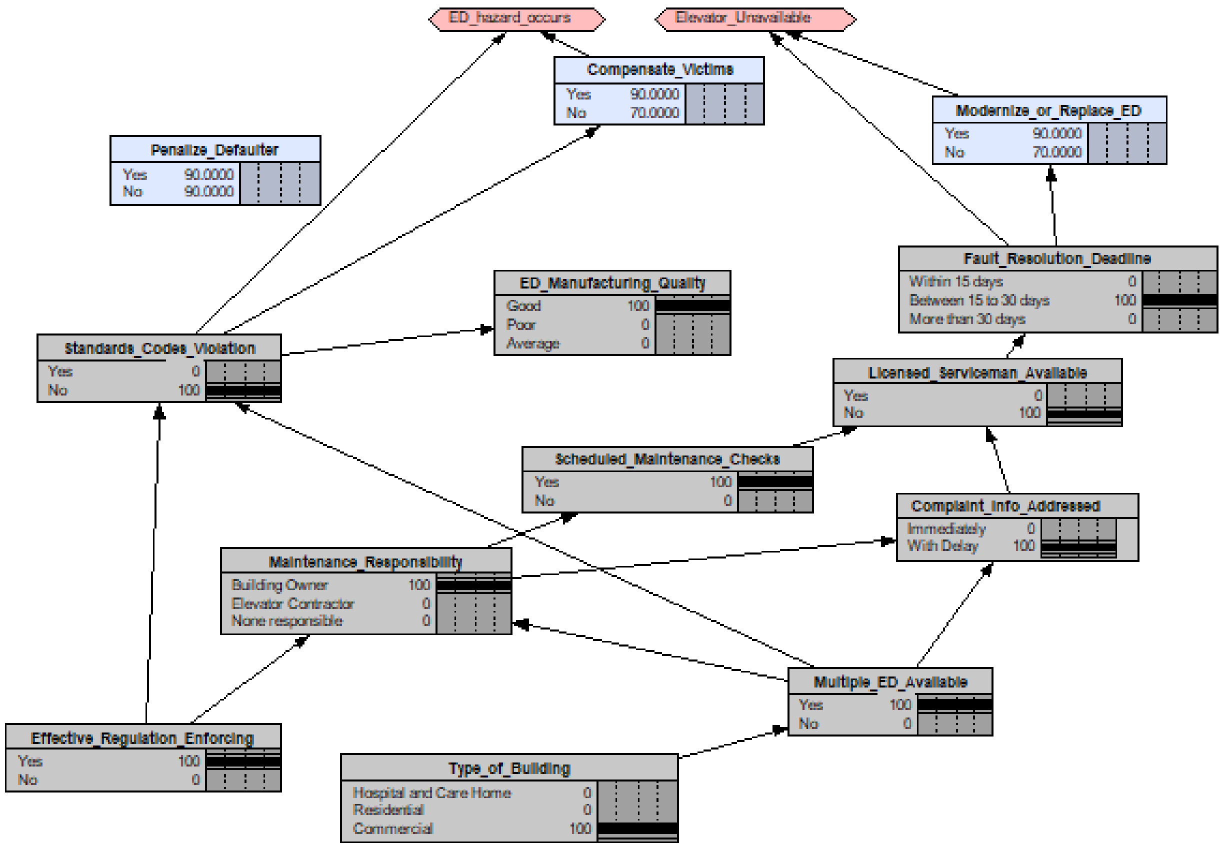


Figure 5.8: Example scenario interpretation in ID model

From the above, it is clear that I have answers to my three questions, i.e., I do not have to take any action on any defaulter, probably because I do not know who could have been the culprit here; I will have to compensate the staff in the building for the inconvenience I have caused to them. It is up to me how I want to do that. Most importantly, yes I have to replace the EDs.

5.3 Generation of Reports

Netica allows generation of a report of the decision net. This can be done by going to ‘Report’ tab and selecting ‘Network’. Figure 5.9 shows the general report of the ID. It shows the number of nodes (nature), decision and utility (consequence) nodes; the number of links; loops; separate networks (two because I have two top events); number of conditional probabilities and decision conditions.

The next type of report I can generate is the list of beliefs in the nature nodes. This can be done again by going to ‘Report’ tab and selecting ‘Beliefs’. Figure 5.10 shows a part of the report that contains names of the nodes and their beliefs in the NPTs (CPTs).

The next type of report is the ‘Elimination Order’ (Figure 5.11). This can be done by going to ‘Report’ tab and selecting ‘Elimination Order’. According to the Netica’s Online Help manual, it is defined as “the ordered list of all the nodes in the net, which specifies how to triangulate the net during compilation. Triangulation is the most important step in compilation, so the order is included when the net is saved”.

The next report is a ‘Junction Tree’ (Figure 5.12). This can be done by going to ‘Report’ tab and selecting ‘Junction Tree’. Netica’s Online Help manual says, it is also known as a ‘Join Tree’ and is “the internal structure that Netica uses for updating beliefs. It compiles a decision net into a Junction Tree for efficiency”.

I tried to do a sensitivity analysis on the nature nodes, but I was unable to as it is a decision net.

```
-------------------------------------------------------
Elevator_risk_availability_ID         18/09/24 13:42

       15   Nodes           (not including constants)
        3   Decision nodes
        2   Utility nodes
        0   Constant nodes
        0   Title or text notation entries
            -------------------------------------------
       18   Links                     (not disconnected)
        0   Disconnected links
        0   Time delay links
        0   Directed cycles              (without delays)
        5   Loops      (disregarding link directions)
        2   Separate networks    (ignoring constants)
            -------------------------------------------
       69   Conditional probabilities total
        6   Decision conditions
            -------------------------------------------
        0   Findings nodes (not including constants)
        0   Negative or likelihood findings nodes
-------------------------------------------------------
```

Figure 5.9: Network report

```
Complaint_Info_Addressed
Immediately    0.34439
With_Delay     0.65561

ED_Manufacturing_Quality
Good       0.48
Poor       0.32
Average    0.2

Effective_Regulation_Enforcing
Yes    0.6
No     0.4

Fault_Resolution_Deadline
Within_15_days            0.20772
Between_15_to_30_days     0.32886
More_than_30_days         0.46343

Licensed_Serviceman_Available
Yes    0.28858
No     0.71142

Maintenance_Responsibility
Building_Owner          0.3879
Elevator_Contractor     0.3786
None_responsible        0.2335

Multiple_ED_Available
Yes    0.535
No     0.465
```

Figure 5.10: Part of belief report

```
Type_of_Building
Effective_Regulation_Enforcing
Multiple_ED_Available
Maintenance_Responsibility
Complaint_Info_Addressed
Scheduled_Maintenance_Checks
Licensed_Serviceman_Available
Compensate_Victims
Modernize_or_Replace_ED
Fault_Resolution_Deadline
ED_Manufacturing_Quality
Penalize_Defaulter
Standards_Codes_Violation
```

Figure 5.11: Elimination order

```
Clique [Joined To]  Size   Member nodes (* means home)
 0  [1 3]             4   (*Compensate_Victims, Standards_and_Codes_violation)
 1  [0 2 4]           6   (Fault_Resolution_Deadline, Standards_and_Codes_violation)
 2  [1]               6   (*Modernize_or_Replace_ED, Fault_Resolution_Deadline)
 3  [0]               2   (*Penalize_Defaulter)
 4  [1 5 7 9]        24   (Multiple_ED_Available, Effective_Regulation_Enforcing, Fault_Resolution_Deadline, Standards_and_Codes_violation)
 5  [4 6]            24   (*ED_Safety_Regulation_Violation, Multiple_ED_Available, *Effective_Regulation_Enforcing, Standards_and_Codes_violation)
 6  [5]              36   (*Type_of_Building, ED_Safety_Regulation_Violation, *Multiple_ED_Available, *Standards_and_Codes_violation)
 7  [4 8]            24   (*Scheduled_maintenance_checks, Multiple_ED_Available, Effective_Regulation_Enforcing, Fault_Resolution_Deadline)
 8  [7 10]           12   (Serviceman_Availability, Scheduled_maintenance_checks, *Fault_Resolution_Deadline)
 9  [4]              12   (*ED_Manufacturing_Quality, Multiple_ED_Available, Standards_and_Codes_violation)
10  [8]               8   (*Complaint_Info_Passed, *Serviceman_Availability, Scheduled_maintenance_checks)
Sum of clique sizes = 158  (with sepsets = 216)
```

Figure 5.12: Junction tree

CHAPTER 6
CONCLUSION & FURTHER RESEARCH

6.1 Introduction

In this chapter, I will be discussing about the fulfilment of research objective; a few recommendations for the authorities; benefits and shortcomings of the model; some ideas for further research and improvement of the work; ending with a brief note on the future of EDs and any insights gained on the problem and model.

6.2 Fulfilling Research Objective

Going back to the problem specification in section 4.1, I did a detailed investigation on the Toronto, NYC and Mumbai ED regulatory control; building standards and codes; safety and law enforcements; maintenance in-charge; laws and regulations pertaining to EDs; hazard occurrences; problems and concerns faced by ED users in the regions; and various other aspects discussed in detail in Chapter 1. I converted all the secondary data and information I gathered (both quantitative and qualitative) from various secondary sources and presented them in the form of tables and diagrams for simplicity and ease of referencing during analysis stage.

In Chapter 2, I did a thorough evaluation of various existing risk modelling methods such as PNs, Bow-Tie, FTA, Fuzzy approach, ALARP, and BBNs in the application of analyzing elevator risks. I chose to model the problem using IDs (Decision Nets), which is an extension to BBNs. I made this choice considering the type of raw data I had, which did not have the most useful information that could be used as variables. So, I had to resort to a sort of 'Reverse Engineering' process where I had to work my way backwards and build my own dataset thinking about what information would be most useful. I was successful to a certain extent that I found a lot of useful information that I could use as variables to model the problem. I understood from my reading that BBNs offer flexibility while modelling and it does not require any data set and can model any type of situation or scenarios where even accurate quantitative data is not required. The model could be modified anytime upon obtaining stronger evidence. This rang a bell in my mind. I knew that I could model my problem using BBNs. Once I knew this, it was always going to be just an additional step of converting the BBN to an ID, which wasn't a difficult task.

I then went through various existing BN software and tools and chose to model my problem using 'Netica' by Norsys Software Corp because of its popularity and ease of use. I of course had to learn to use the tool and its features, which was a good learning experience.

Before I could draw my model, I of course had to decide on my variables, decision and consequence nodes based on the most relevant and accurate information from the data that would help me represent my problem. This helped me logically think through the whole problem and what I wanted to show and achieve from my model. I can say that having a good understanding of the problem and my objective of what I wanted to achieve, is what helped me create my model. Before creating the model in Netica, I hand-drew a draft model and then tried to build it using Netica. I filled in all the probabilities (beliefs) using my intuition and my understanding of the current ED risk and availability situation in the regions.

I compiled and ran the model. I tested it through a few sample scenarios by asking a few questions, requesting the model's advice on a decision. I basically played around with the model testing its strengths and weaknesses. I can say that my model is capable to a certain extent of outputting a decision advise for most of the questions that are based on the variables in the model. If it is not in the model, then the model has to be modified, recompiled and then rerun. The model will then be able to advice a better decision. Hence, I believe that my model has demonstrated and achieved the project objective to a certain extent, excepting for a few weaknesses and some useful benefits.

In simple terms, I just used the 'STAR' technique to tackle this project. I had my '**S**'ituation, i.e., the problem specification; '**T**'ask, i.e., my research question (what I had to achieve to solve the problem); '**A**'ction, i.e., building an ID that could model and answer my research question; and finally, '**R**'esult, i.e., running the model and testing if it answers my question. When I used this technique, I was able to bring a structure to my project and it helped me achieve what I wanted.

6.3 Usefulness of the Model

In terms of the reliability of my model, I think it is reliable to a certain extent (more on this in the next section), as it answers certain questions and advises me on a decision that is suitable. This can be seen from the scenarios in the previous chapter. The whole purpose of using an ID is to find answers to specific questions given specific scenarios and applying it on the model. The important thing to remember here is, ID should never be used to make simple, everyday personal decisions that can be decided otherwise by using common sense. It must only be used for real-time business purpose decision making, where there is actually a real problem. Another important point to remember is, the user must always ensure that the information they have is the closest they can get to represent the real scenario, otherwise the output generated by the ID can be surprising.

The advantage of using a tool like Netica is to show how the utilities of the decision node is impacted, considering the NPTs of the consequence nodes and while modifying the beliefs of the nature nodes. This shows scenarios where several events are combined, which cannot be done in other methods mentioned in Chapter 2, such as PNs or Bow-Tie methods.

The most important benefit of the model is that it can assist the end users of the model, i.e., ED regulatory authority, bring out effective solutions to problems and decide on what action(s) to take; even better if certain variable(s) change(s) or if the belief(s) become(s) more certain, closer to 100%. It can help them decide an action by looking at the impact on the top events as variables change.

Other uses are, it can assist with identifying concerns with certain combinations of events efficiently and thus focusing on these rather than those that do not cause severe impact on ED users. Stakeholders can have different beliefs and values. Decision Nets can help people share the understanding of the impact of events and decisions amongst different stakeholders. It allows them to talk about specific problems rather than generalizing them.

6.4 Shortcomings of the Model

The disadvantage of the model is that first of all, the selection of the below nature nodes is from my own perspective of the problem context. So, some of these may not be a suitable selection for analysis and hence to decide a course of action. It may have been ideal to have more number of nodes or different nodes, so that the change in the utility value and the decision advise output by the model can be observed. If the next person brings in different variables to the model, it would be interesting to see how the utilities and probabilities of the nodes change and how it affects the decision.

Another point in terms of reliability of my model and the reason why I said “to a certain extent” in the previous section is because, I must say that my model at the moment is a little ‘biased. This is because no matter what kind of input I give to my variables, I keep getting the same kind of decisions, although the utility values are different. For e.g., the ID is always giving higher utility for ‘Yes’ for “Modernize or Replace ED”. Similarly, ‘Yes’ for “Compensate Victims” and same utility values for both states in “Penalize Defaulter”. It could be because of the input choice, or the beliefs or the NPTs I have populated.

I will have to investigate more on this. So, the point is, it is possible that the decisions thrown by the ID can raise eyebrows as it may not have been what the user was expecting. This can happen in some situations.

The beliefs I have entered are again only dummy values based on my point of view as an ED user. I have no concrete numeric data to support the NPTs I have entered, although the events shown in my choice of nature nodes are representative of my data. i.e., these are real events that have taken place in the region. I framed all the nodes based on these events and fed in NPTs based on the likelihood of such an event occurring, which may not have been the ideal way of doing it, but I see that as a shortcoming in my model. There may always be other choices of variables that can be replaced with the existing ones.

Another shortcoming is that, I was using a limited (trial) version of Netica and felt at times that I was being controlled and hence could not expand my model as well as I would have liked to. I could create only a maximum of 15 nodes, inclusive of nature, decision and consequence nodes. This could have caused my model not to be the best model I could have developed and hence not completely ideal to represent the problem context in entirety. However, the bright side to this is that, with the few nodes I used, my goal was to capture a large quantity of information to model the problem, instead of developing several models. I believe I was able to do this to a certain extent.

6.5 Recommendations

The ED authorities and users who are going to use this model for advice or any kind of relevant decision making should firstly know that the ID I have developed is only a model and must not be used as the ultimate decision-maker. After all, it is only a model, and it just a representation of reality. The final verdict will always be taken by the concerned ED authority considering the output from the model as a guidance.

I would highly recommend ED authorities to use BBNs and IDs for modelling any future similar problems they may be faced with. It is a very useful technique to model complex scenarios with uncertainties and lack of data, like what I had. Of course, I have used and demonstrated only the basic features of Netica. It is a tool that has numerous applications in various industries and domains, with advanced features and even extensions to other programming languages, such as R statistical software, using ‘RNetica’ package [79].

I can confidently say that no ED risk and availability modelling studies have been done using IDs. I am probably the first to do it, so I think that is quite an achievement. Moreover, I am sure none of the ED authorities would have analyzed or thought about the fact that the ED risk modelling can be done using IDs, rather than other conventional methods like FTA.

6.6 Further Research

One possible area of further improvement of the work is probably going one step back and developing just a BBN model, representing the problem. If I were to do this project again, I would also attempt to create a separate BBN and / or an ID model for each region, that represents the ED availability situation in their region, instead of developing an overall model.

It would be interesting to do a before and after situation analysis. For e.g., the current ED availability situation is known and modeled. After using the ID model for decision support, are the authorities taking the necessary and right action? If so and post action is taken, they must run the model again using updated beliefs for the variables and consequences and check how different the utilities of the decision node is turning out to be. Have the values become more favorable or unfavorable to the authority? This would be a prospective area of study in the future, better if it is a long-term project so that the candidate can work directly with the client throughout the process.

Since there was no existing data set to work with (available publicly) from any of the regional authorities, which was one of the challenges I faced, this can be an area to deep dive into, probably reaching out to ED authorities directly for more useful data (not available publicly) for analysis. If this is obtained as a CSV or TXT file, data analysis can be performed through programming languages such as Python; statistical package such as R, or even data visualization tool for business intelligence, such as Tableau. In fact, R has a package called 'RNetica' that provides Netica functions inside R [79], so even this mixture can be experimented in the future. Alternatively, upon obtaining stronger data, other risk modeling methods such as PNs or Bow-tie method can be implemented to better quantify results closer to reality.

Most of the research and studies, including mine, related to elevators have been conducted using the most common type of EDs, such as passenger elevators, escalators and moving walks. It would be interesting to investigate risks and availability issues of other types of EDs such as wheelchair elevators; dumbwaiters; freight elevators, etc. and maybe investigate what their situation is in comparison to common EDs.

6.7 Future of EDs

According to [26], the fragile construction division in India, the second most populous country in the world, may lead to a huge market loss for elevator companies with respect to installations and maintenance of the existing ones [26].

However, as per the "7th International Elevator and Escalator exposition 2018" which was held at Mumbai in February this year, reports say that "the use of elevators and escalators see a growth rate of over 50% in the next four years in India". Industry experts also say that, "India will be one of the largest markets for elevators and escalators, as almost half the country is moving to the cities, which will see congestion, and this will be beneficial for the growth of the industry in Mumbai and in other parts of India.

Nevertheless, in the developed world, elevator companies see growth opportunities owing to the ageing population who rely on elevators, along with existing elevators that have exceeded its life expectancy and are running with poor energy efficiency and ought to be replaced" [32].

6.8 <u>Insights gained on Problem and Model</u>

From this project, I understood that there are various perspectives of looking at the problem of ED risk and unavailability. I looked at it from a user perspective, because I am a regular user of EDs. Now, what if I were a manufacturer of an ED, or someone who were part of the regulatory authority responsible for safety of EDs and buildings in an area? How would I see the problem then?

From a manufacturer's point of view, I would look at the risk and availability issue from a technical perspective and system design perspective. For instance, 'How can I improve the design or the mechanics of the system so that the landing of the elevator is smooth and there is no sudden jerk of the elevator when the floor is reached as is common with many elevators in the world today? Do I have the required expertise and technology available with me to minimize this risk?'

From a regulatory perspective, I would want to look at my security measures I have in the region to address the risk and availability issue. For example., 'In the case of a fire in an elevator or in a building, do I have enough firefighter rescue members and personnel from the disaster management team available within a specified distance range in the town or city, such that I can minimize the casualty and loss or damage to property as much as possible?' It would be interesting to look at the problem in such different perspectives.

Commenting on the modelling aspect, I must say that the initial model I developed by hand when I was in the brainstorming stage, was quite large. I then thought if this would really be helpful to the user of the model? The goal of modelling for me meant capturing lots of information in as few nodes as possible. The reason why I think this is because developing a model of a problem or almost anything has different perspectives. It depends on person to person. The way I modeled this problem, would not be the same as how someone else attempting the same problem would do. This perspective makes modelling interesting.

APPENDICES

PROJECT CONTEXT

Description

The Government of Ontario in Canada Technical Standards and Safety Authority (TSSA) has been conducting a study on elevator availability. This study has already led to proposed legislation that is gaining media attention. See https://www.tssa.org/Modules/News/index.aspx?feedId=a432fea8-34f2-4fb2-97ec-b393c44fc0eb&newsId=c30d9b40-0544-4e38-92d5-be3275000defand also other media discussions.

The Canadian study takes a broad systems view taking into account multiple perspectives since elevator reliability and availability have not only safety but also socio-economic implications. For example, consider the location of elevators in domestic, commercial and public buildings, consider who is responsible for the elevator operations and maintenance, consider the degree of power different stakeholders possess in contracting maintenance, consider the consequences for different stakeholder groups when elevators are not working, ...

Elevators might be taken for granted given their everyday use, but it appears that the "world of elevators" is more complex and interesting if we examine it more closely.

This MSc project aims to develop a system-level model to visually structure the Canadian elevator safety problem. information to support this is available in public sources (e.g. https://www.tssa.org/Modules/News/index.aspx?feedId=a432fea8-34f2-4fb2-97ec-b393c44fc0eb,4c142457-0d0f-4773-a511-7866672bbffa,ff34d029-6100-428b-87a6-89ed3918dcd4,7b882e28-3b4f-4044-ba7f-6df58a31ce1b,5b7aff3b-3f29-440e-b6f7-f3341638e717,3b0a683e-3289-4504-a528-320a2d741fa6,b32b6789-a2cf-4413-a8b2-cc829952ee7e,4ca86901-c2ab-453b-b95b-123f516c0c9f,f53a4329-8b60-4d38-acc2-ffff6c74d7f1,e018aaf8-86ba-4954-902c-489db3ded3c8&newsId=c30d9b40-0544-4e38-92d5-be3275000def)

The project can be developed in different ways depending on the student interest. For example, a comparison between the Canadian context and another country would be interesting to explore how risk is shared under different "system conditions".

The TSSA website, as for equivalent authorities in many other countries, have considerable data available on their websites. We also have contacts at TSSA who can contribute if and as needed.

Figure 1.6: Allocated project description

Figure 1.7: Location of Toronto, Ontario [80]

Figure 1.8: Model of ‘The One’ [81]

Figure 1.9: Location of NYC, New York [82]

Figure 1.10: ‘One World Trade Center’ [83]

Figure 1.11: Location of Mumbai, Maharashtra [84]

Figure 1.12: ‘Palais Royale’ under construction [85]

Figure 1.13: Elevator shaft [86]

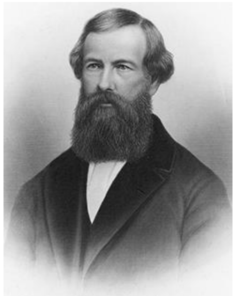
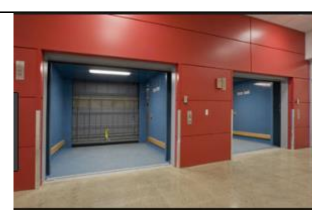


Figure 1.14: Elisha Otis [87]

Figure 1.15: Otis demonstrating free-fall mechanism in 1854 [88]

ED type	Description	Image
Amusement elevator	Found in amusement / theme parks to transport people up and down a ride	 Figure 1.21: Amusement elevator [92]
Wheelchair elevator	To transport the physically challenged; found in residential apartments; commercial buildings, etc.	 Figure 1.22: Wheelchair elevator [93]
Private elevator	Used to commute within a single house or an apartment	 Figure 1.23: Private elevator [94]

Sidewalk elevator	Found on road sides; used to move goods between basement and ground level	 Figure 1.24: Sidewalk elevator [95]
Dumbwaiter	To carry food items between floors and kitchen; usually found in hotels and restaurants	 Figure 1.25: Dumbwaiter [96]
Conveyor elevator	Primarily used in factories and manufacturing centers to transport goods between levels	 Figure 1.26: Conveyor elevator [97]
Public elevator	Same as passenger elevator, except that it is found in public areas outside of residential or official buildings, such as metro stations and airports	 Figure 1.27: Public elevator [98]
Freight elevators	Used to transport large goods between floors; usually found in factories, manufacturing centers and commercial buildings	 Figure 1.28: Freight elevator [99]

Manlifts	Usually found at construction sites to lift workers	 Figure 1.29: Manlift [100]

Table 1.4: Other types of EDs, description and images

CLIENT REPORT

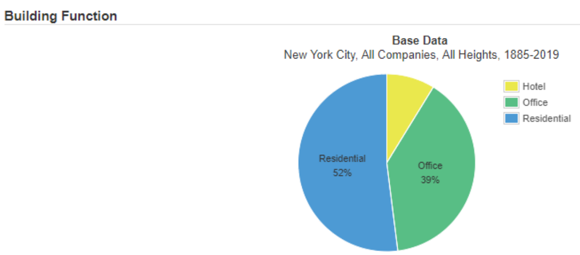


Figure 1.12: NYC building type

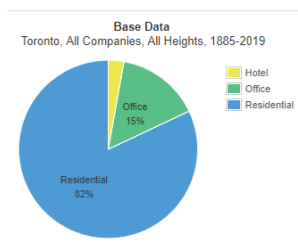


Figure 1.13: Toronto building type

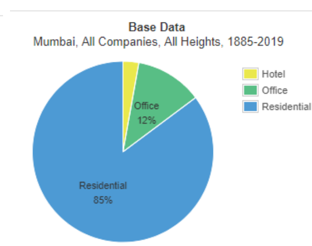


Figure 1.14: Mumbai building type

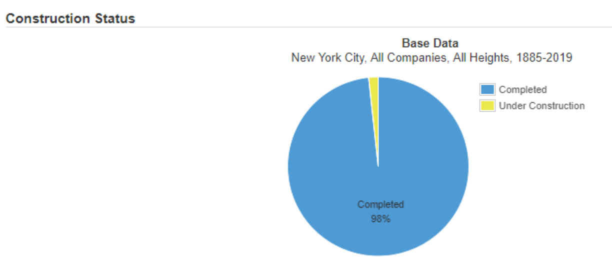


Figure 1.15: NYC building construction status

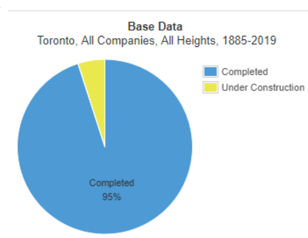


Figure 1.16: Toronto building construction status

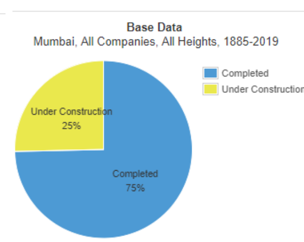


Figure 1.17: Mumbai building construction status

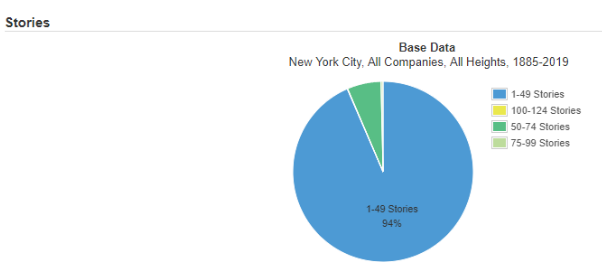


Figure 1.18: NYC building stories

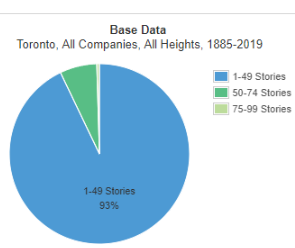


Figure 1.19: Toronto building stories

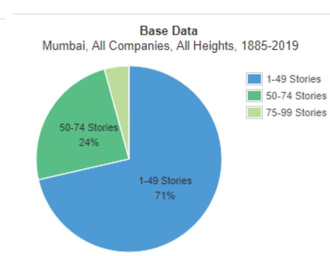


Figure 1.20: Mumbai building stories

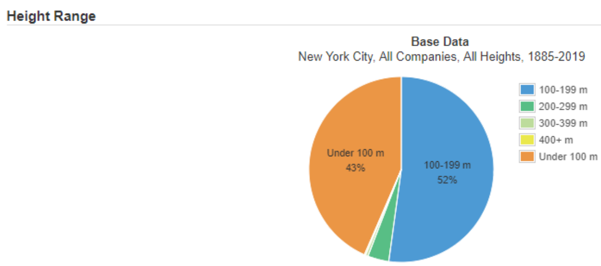


Figure 1.21: NYC building height

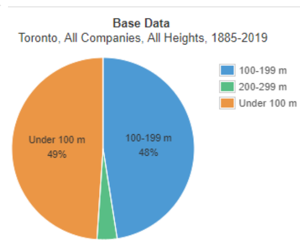


Figure 1.22: Toronto building height

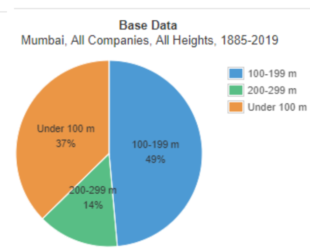
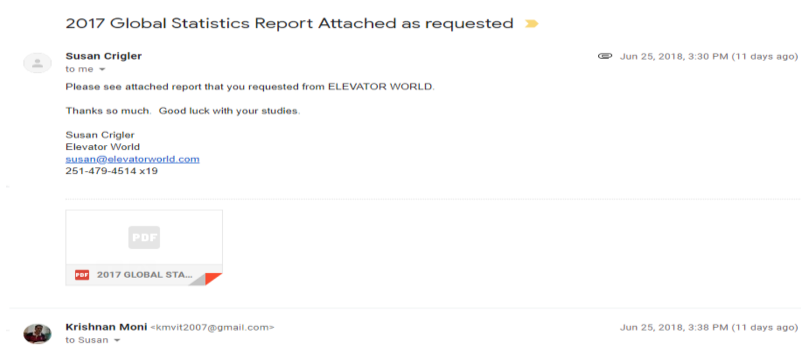


Figure 1.23: Mumbai building height

GENERAL

Figure 1 and 2 show the email exchange between me and Elevator World associate.



2017 Global Statistics Report Attached as requested

Susan Crigler
to me
Jun 25, 2018, 3:30 PM (11 days ago)

Please see attached report that you requested from ELEVATOR WORLD.

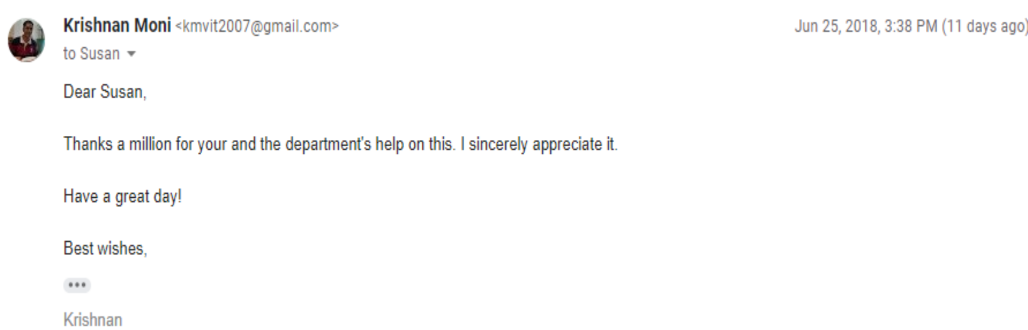
Thanks so much. Good luck with your studies.

Susan Crigler
Elevator World
susan@elevatorworld.com
251-479-4514 x19

2017 GLOBAL STA...

Krishnan Moni <kmvit2007@gmail.com>
to Susan
Jun 25, 2018, 3:38 PM (11 days ago)

Figure 1: Email exchange requesting information from Elevator World associate



Krishnan Moni <kmvit2007@gmail.com>
to Susan
Jun 25, 2018, 3:38 PM (11 days ago)

Dear Susan,

Thanks a million for your and the department's help on this. I sincerely appreciate it.

Have a great day!

Best wishes,

Krishnan

Figure 2: Email exchange requesting information from Elevator World associate

Figure 3 shows an email exchange between myself and a TSSA representative on a query I asked about EDs in Ontario.

Public Information Services <publicinformationservices@tssa.org> 4:52 PM (3 hours ago)
to me

Good morning Krishnan. Thank you for your request for confirmation of public information.

At this time, I am only able to provide you with the inventory count for the province of Ontario.
Please see page 22 of this Annual Report from September 2017: https://www.tssa.org/en/about-tssa/resources/Documents/Annual-Reports/ASPR-2017-Final-Report-Sept-2017.pdf

For a further search in our archives please complete our release of public information form found at https://www.tssa.org/en/about-tssa/release-of-public-information.aspx?_mid_=392 and email the completed form to publicinformationservices@tssa.org or through mail along with the appropriate fee. The fee is payable with credit card (Visa or MasterCard) or with a Cheque made payable to TSSA.
Although TSSA believes the information provided pursuant to your request is accurate, please note that TSSA does not warrant this information in any way whatsoever.

Kind regards,

Jan

-----Original Message-----
From: TSSA Customer Service <pectscs@atoracle.com>
Sent: July 24, 2018 8:47 AM
To: Public Information Services <publicinformationservices@tssa.org>
Subject: Re: Query on Elevator Devices in Toronto [REF:52896220890]

Hello, Is this an inquiry you may be able to assist with? If not, please advise. Thank you. Beverly.

REPLY TO: kmvit2007@gmail.com

---- Original Message ----
Dear Sir or Madame,

My name is Krishnan Moni. I am writing from University of Strathclyde, Glasgow, UK. I am a student of MSc Data Analytics. As part of my course, I am currently working on a project based on Elevator Safety and Availability.

I have a question. I am trying to find out if you have data on the approximate count of elevating devices in Toronto, specifically? I am trying to gather some data from various sources and I was not able to find this anywhere. It would be great if you could help me.

Thank you.

Yours faithfully,
Krishnan Moni

Figure 3: Email exchange requesting information from TSSA

TOOLS & SOFTWARE USED

There are a few tools and software which I used to carry out my dissertation. These are listed below.

1. Netica "6.05" by Norsys Software Corp. (To create IDs)
2. draw.io 9.1.3 (To create and label Spider Diagrams, Flow charts, ID model diagram, etc.)
3. Microsoft Word 2016 (To write-up the dissertation report; create tables and create a few diagrams using integrated Shape tools)
4. Microsoft Excel 2016 (To create Gantt chart and graphs)
5. Snipping Tool 10.0.17134 (To capture snapshots of diagrams, figures, tables and graphs)

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