MSc Program
Engineering Management

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IoT and the Future of Elevator Maintenance Business

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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09005525

Vienna, 22.03.2022

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Affidavit

I, **DR. PHIL. RONALD D'SOUZA MBA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "IOT AND THE FUTURE OF ELEVATOR MAINTENANCE BUSINESS", 90 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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_____
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ABSTRACT

The modern era of high-speed and safe vertical transportation began with the installation of the first traction elevators in 1913 in the Woolworth building in New York. Since that time there has been continuous development in elevator technologies and a remarkable growth in the global elevator industry.

IoT (Internet of Things) is said to be one of the most disruptive technologies today. What started as a development in communication technology has spread to many other industrial and business applications. The goal of this thesis is to investigate the application of IoT in the elevator industry. In doing so, the thesis aims to study the impact on key stakeholders: the elevator companies, customers, and elevator personnel.

A traction elevator is an engineering system consisting of sub-systems and electro-mechanical components. Once the elevator is installed, it is necessary to continuously maintain and inspect it for safe operation. Countries have regulations and standards governing these activities.

Elevator maintenance business is a profitable but labour-intensive. It covers such works as servicing, safety inspection, and call backs. A maintenance contract can add substantially to the building operating costs.

In the absence of IoT, the maintenance and safety inspections are carried out at fixed intervals, irrespective of actual usage. Without precise metrics regarding the real use since the last maintenance or inspection, customers and maintenance companies act on assumptions and periodic reports.

This thesis comes to the conclusion that IoT is transforming the servicing and inspection process, changing it from a periodic basis to an adaptive/predictive one. The locus of know-how is shifting from elevator technicians to artificial intelligence (AI). Elevator companies as well as customers are able to see the condition and performance of their elevators in real time and are able to make agile decisions. Overall, the IoT of elevators is leading to the development of new businesses for the companies, bringing additional benefits to the elevator owners, and facilitating the work of maintenance technicians and elevator inspectors.

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Academic and Personal Acknowledgments

The subject of my thesis was a natural choice but not before long deliberation with friends, colleagues, and my academic supervisor. The subject is ideal for me to combine my work experience with new knowledge I was able to gain from the MSc Programme at the Vienna Technical University. As IoT is going to be an integral part of industry 4.0, I was keen to gain in depth knowledge and understand its application in elevator business.

In this regard I am deeply grateful to my academic supervisor, Dr. Thomas Duda. With his critical but constructive inputs did this thesis reach its mark. It was a pleasure for me to work with Tom.

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Ronald D'Souza
Technical University of Vienna, Austria
March 2022

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CHAPTER 1
INTRODUCTION

> The space elevator will be built about 50 years after everyone stops laughing.
>
> Arthur C. Clarke (author of Ascent to Orbit, 1984)

1.1 Background to the Study

Digitalisation is in full swing at the current stage of Industry 4.0. Machines at production plants and industrial facilities automatically swap information, trigger actions, and control each other without human intervention. This exchange of information and decision making is possible with Industrial Internet of Things (IIoT).

Around 2015 the Internet of Things (IoT)[1] was introduced for elevators. It is primarily used for maintenance[2]. The core concept of IoT of elevators[3] is to connect them via internet to a central platform and collect real time data on their components and operation. The pooled information, or the big data, is analysed with Artificial Intelligence (AI). It is then used for multiple purposes such as: surveillance of the actual elevator traffic, understanding the condition of its components, and predicting the time of next service or inspection.

In the forefront of this innovation are leading elevator companies[4], or the OEMs. They are offering IoT hardware and services for existing elevators at a premium in their maintenance contract. They are also making IoT hardware as an integral part of their new elevators. Apart from the OEMs of elevators, some new entrants have started offering only the IoT

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[1] This author has opted for the term IoT for the purpose of this thesis as Industrial Internet of Things (IIoT), a subset of IoT, is mainly used in the production plants.
[2] In this thesis the term "maintenance" is used to include the business of maintenance and as well as related works (servicing, checks, inspection, breakdowns, and minor repairs).
[3] In elevator industry the IoT is also referred as "Internet of Elevators and Escalators", IoEE. Moreover, major elevator companies have created their own marketing and brand names such as MAX by TK Elevators and Schindler Ahead by Schindler.
[4] OTIS, Schindler, KONE, Thyssenkrupp, Hitachi, and Mitsubishi.

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hardware and services. Their services can be used independent of manufacturer or the maintenance contractor of the elevator, which gives flexibility to the owners.

Traction elevators[5] are the backbone of our modern, urban environment. It is estimated that around 20 million[6] elevators are in operation worldwide at the beginning of 2022. They move an estimated 5 to 8 billion passengers each day[7]. These elevators need to be regularly maintained, inspected, and ensured that they are safe for transportation.

As a mode of transportation, the elevators are unique engineering equipment. Unlike motor vehicles or ships, an elevator has a size as big as the entire distance it travels. Elevators are not manufactured ready to be driven out of a factory but installed component by component on a site. We use elevators routinely and without much thought about their condition. People normally neither own an elevator nor need to buy a ticket to use them. Yet, whoever owns an elevator (normally the building owner), has a legal responsibility to ensure that his elevator is safe for use.

Further, it is essential that the elevators function without breakdowns. The owners also wish to see that the asset value of their building remains intact. For that their elevators require appropriate and timely care.

The elevator companies generate their revenues in 3 areas: new equipment, maintenance, and modernisation. Among them the maintenance business is the most profitable one. The profit margin in maintenance business can be up to 50%, compared with less than 10% for new installations. Thus, although an elevator company might have higher sales in new installations, the bigger part of their profits come from maintenance business. Generally, the elevator companies generate about

[5] In this thesis the term "elevator" is used interchangeably with "traction elevator". However, except for the systems engineering, other aspects of this thesis are equally applicable to hydraulic elevators, the second group of elevators. Depending on the country/region, traction elevators make up to 90 to 100 % of all passenger and goods elevators.
[6] Source: Global Market Insights, 2021. https://www.gminsights.com/industry-analysis/elevator-market [last accessed 14.11.2021]
[7] The leading elevator companies claim how many billion passengers their elevators move every day, which the author believes is a qualified estimation. This author's estimation is based on their figures with a higher margin.

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35% of their revenue from maintenance business. As a reference, KONE, one of the major elevator companies, had the following sales revenue in 2020: 54% from new equipment, 32% from maintenance, and about 14% from modernisation[8]. Smaller companies typically have higher maintenance business, anywhere between 60 to 100%.

1.2 The Core Subject

The maintenance process of elevators is since decades based on routine, fixed-interval visits to the site by trained technicians and inspectors. In inspection they would carry out visual checks and tests using appropriate tools. This enables them to judge the condition of the elevator and to stipulate repairs, if necessary. Normally the same maintenance technician would visit the same elevator every month nearly on the same day and carryout the routine maintenance and visible checks. The same technician would also be sent to attend a breakdown or to complete minor repair. This enabled him to get accustomed to the equipment and develop a "feeling" for its condition. He would also meet the customer (or his representative) at the building while carrying out his work. The customer or building residents would inform the technician about any malfunctioning. This close interaction with the customer enabled the technician to react and do any necessary work. The technical knowledge and work experience of the technicians, as well as their interaction with customers, are thus vital for maintenance business.

As the Information Technology (IT) advanced in the 1990s, telemonitoring was introduced. This begun with direct 1 to 1 telephone connection from elevators to a central station, such as a rescue centre. Also, during the 1990s the programmable microprocessor controllers came into use in elevators. Their feature of event data and error log was especially helpful in solving breakdowns (Jon Halpern in Strakosch and Caporale, 2010, p 140). Upon receiving a call-back, the technician will reach the elevator, which could be miles away, and access the error logs through a test tool or through an HMI (human machine interface). During the maintenance

[8] KONE Corporation (2020), Annual Review, Espoo, Finland.

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too it is customary to evaluate the error log and understand the condition of the elevator.

1.3 Definition of the Research Problems

A review of the literature indicates the availability of sufficient publications, albeit in two distinct areas: elevator engineering and IoT. What is lacking is an integration of these two subjects, explaining the connection between the elevator engineering and IoT. Further, there is a lack of literature on elevator maintenance business. This thesis combines these three areas: elevator systems engineering, IoT, and elevator maintenance business.

The IoT is new to elevator technology and business. It does not belong to the core design issues of elevator engineering, such as the load capacity and speed. However, its application in elevators is becoming more and more visible. As the IoT is getting implemented in elevator maintenance business, it is important to understand the full scope of this application and how its business and application is managed. A detailed understanding of the topic is certainly a subject in engineering management.

The research problem begins with the enquiry "Why IoT is useful for elevator maintenance and inspection?". This leads to further investigation: Who are the main beneficiaries of this new technology? Is IoT a game changer for elevator maintenance business or is it only creating new value and opportunities in the existing business models? Why are the non-elevator companies offering IoT services? In the end, how IoT might impact key stake holders: the elevator companies, the customers, and the maintenance technicians and inspectors.

To understand the above, this study is conducted in and around the following interconnected areas:

- The systems engineering of elevators.
- The technical, business, and legal aspects of elevator maintenance.
- The technology of IoT and how it functions.
- Application of IoT in elevator maintenance.

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1.4 Research Aims and Objectives

The thesis thus focuses on the topics mentioned above. In this regard, these questions are addressed:

1) Why maintenance and inspection are crucial for elevators?
2) Which components in elevators are critical to safety?
3) What are the regulations regarding maintenance and inspection?
4) What is the architecture of IoT and how does it function?
5) How IoT is adapted for elevator maintenance and inspection?
6) Which new services are offered by maintenance companies?
7) What are the benefits for the customers?
8) Are there any other players in the business of IoT in elevators?
9) How does the IoT influence the elevator technicians?

The thesis elaborates how IoT is applied in elevator maintenance business. Comparing different aspects of the application, it sheds light on business opportunities and how they might progress.

1.5 Review of Related Literature

A standard work on elevator technology and elevator business is *The Vertical Transportation* in its fourth edition (2010) by John Wiley & Sons at New Jersey, USA. Its editors, George Strakosch and Robert Caporale, are well known veterans of elevator industry. Fourteen authors have contributed to this seminal work of 612 pages with 20 chapters. They begin with *The Essentials of Elevatoring* and end with *The Changing Modes of Horizontal and Vertical Transportation.* The book is wonderful source for all the essentials of elevators and their business, including maintenance. Nevertheless, as this publication was a few years before the dawn of IoT in elevators, a dedicated chapter or direct information about this subject is not available.

For the Systems Engineering, which is the second chapter of this thesis, substantial inputs are taken from *Systems Engineering of Elevators* by Phillip Andrew and Stefan Kaczmarczyk. Published in 2011 by Elevator World, Alabama, this book contains 558 pages of valuable information on engineering design and calculations. It illustrates elaborately on

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engineering of elevators, the foundation of the subject of this thesis. Another useful source used for systems engineering is the chapter *Specifications for the design of lifts or elevators* by Bangash (2006).

About 70% of the elevator components can be considered as mechanical. The *Elevator Mechanical Design* by Lubomir Janovský (1999, 3rd ed) gives excellent insights into diverse related components and their functioning.

Regarding the maintenance, the *Elevator Maintenance Manual* by Zack McCain, published by Elevator World, Alabama, seems to be a standard publication. It gives detailed technical information on the maintenance tasks and inspection. This manual has information of general nature, that can be used on elevators of any manufacturer. It also addresses customers relations and safety for maintenance mechanics.

Other useful sources on maintenance are manufacturers' manuals. They give good insight on the maintenance process and business. Regarding the regulations and rules on maintenance the publications by standard committees / regulation authorities from different countries (EU, UK, Singapore ...) give similar, if not identical, information. The regulation from European Standard Committee (CEN) *Maintenance for lifts and escalators – Rules for maintenance* is one of these.

Regarding IoT, plenty of academic publications of excellent standard and of recent dates are available. In this thesis two of them are referred and followed. *Introduction to IoT (2021)* by Sudip Misra, Anandarup Mukherjee and Arjit Roy is the first one. This is a Cambridge University Press publication and contains 414 pages. It gives comprehensive insight into the evolution and the emergence of IoT. Especially helpful are also the chapters on *Basics of Networking, Predecessors of IoT,* and *Internet of Things.* The second book is by Mansaf Alam, Kashis Shakil, and Samiy Khan (editors), (2020), *Internet of Things (IoT) – Concept and Applications,* published by Springer. With 515 pages and 22 chapters, this publication gives thorough insight from the *Foundation of IoT* to *Challenges Towards Development of Smart Manufacturing.* Both these books do not address IoT of Elevators.

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For the IoT of elevators a number of articles published in industry journals are referred. One such articles is by Clarissa Falge and Michael Schiller (2019): *The Internet of Elevators & Escalators*, in Elevator World Europe. One another early work worth mentioning is by Rory Smith published in Lift Symposium 2015. Some articles refer to particular technical process in elevators and not exclusively on IoT of elevator maintenance. However, many leading elevator companies and IoT service providers have published a number of articles on their webpages. They are excellent sources of knowledge on business methods and maintenance process and give valuable content for research on IoT of Elevators

1.6 Methodology

The theoretical part of this research is based on works published by industry experts, peer reviewed publications, and open information from leading elevator companies and IoT service providers. The practical part comes from direct interaction with R&D experts, field mechanics, and elevator consultants. This interaction took place in informal talks and in discussions forums in Facebook. Adding to all this is author's own work experience.

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The study was conducted by step-by-step exploration of the following interconnected subjects, the last step being the analysis and conclusion.

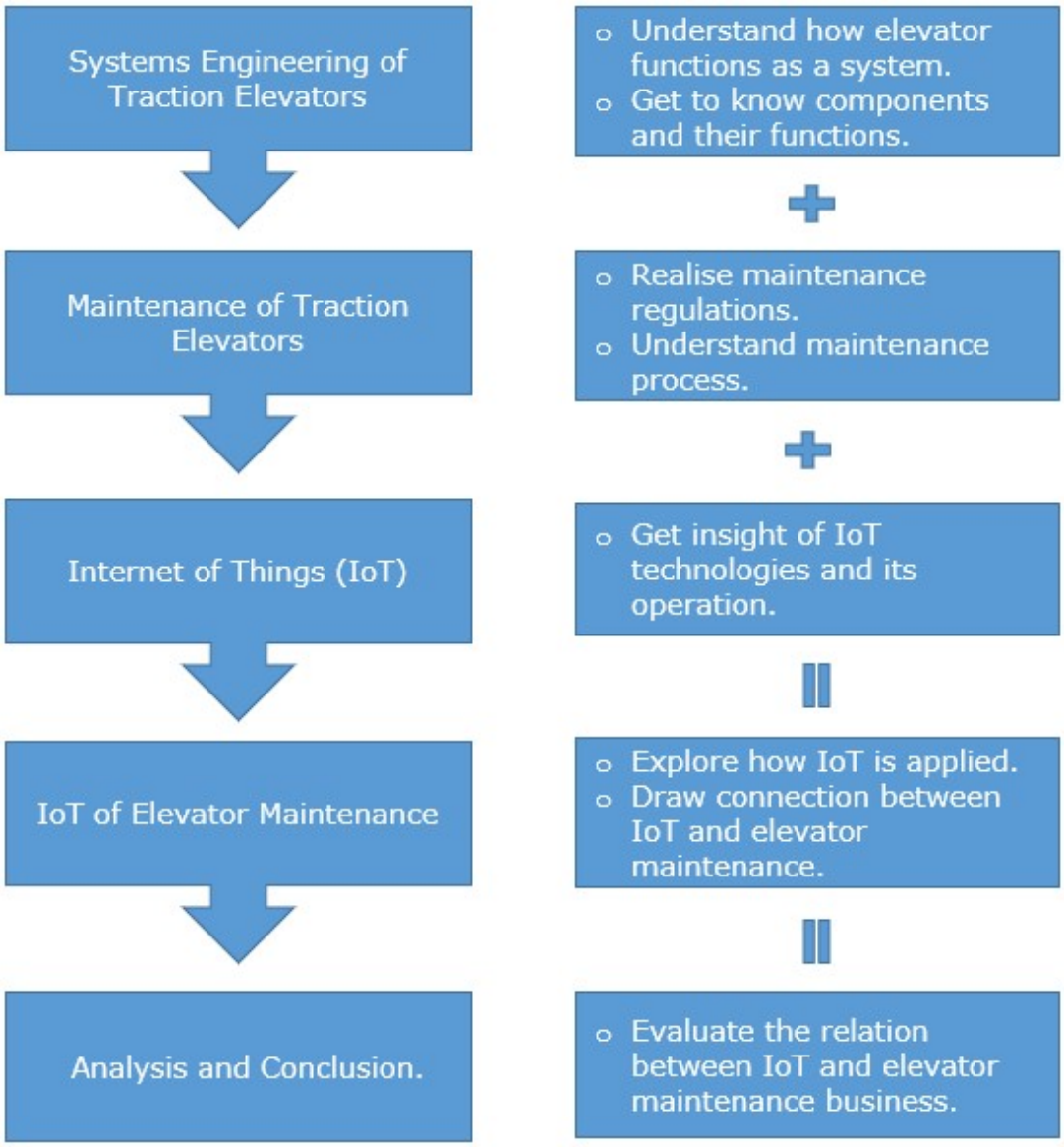

Figure 1: Research methodology

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CHAPTER 2
SYSTEMS ENGINEERING OF ELEVATORS

> Life is like an elevator. Up and down, just make sure you get off on the right floor.
>
> Keith Douglas, English poet of World War II

2.1 Introduction

Understanding the systems engineering of elevators will give a better understanding of the maintenance and inspection of elevators. This chapter is therefore intended to give an overview of different parts, components, subsystems and how they are integrated to function as an elevator.

Systems engineering can be defined as an interdisciplinary field of engineering and engineering management. It focuses on how to design, integrate, and manage complex systems over their life cycles. The elaborate definition of systems engineering is available from the International Council on Systems Engineering[9].

The traction elevator is a good example of systems engineering. A straightforward definition on this is provided by Andrew and Kaczmarczy (Systems Engineering of Elevators, 2011, p 12): *"… in an elevator the individual components are brought together to provide a system which will carry the required load at the required speed over the necessary travel"*.

A typical elevator system has numerous mechanical, electrical, electronic, and hydraulic components. Several of them are grouped as subsystem, which makes it easier for design and assembly. In the end, the subsystems are integrated into forming the elevator system. Obviously, the system design of an elevator should be as such that each and every component, as well as the subsystems, must match one another and perform together for the elevator to function as required throughout its lifetime.

This chapter lays the groundwork for following chapters. It helps to understand the of need maintenance and how it is managed with IoT.

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[9] https://www.incose.org/about-systems-engineering/system-and-se-definition/systems-engineering-definition [Last accessed 27th September 2021].

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2.2 System Overview

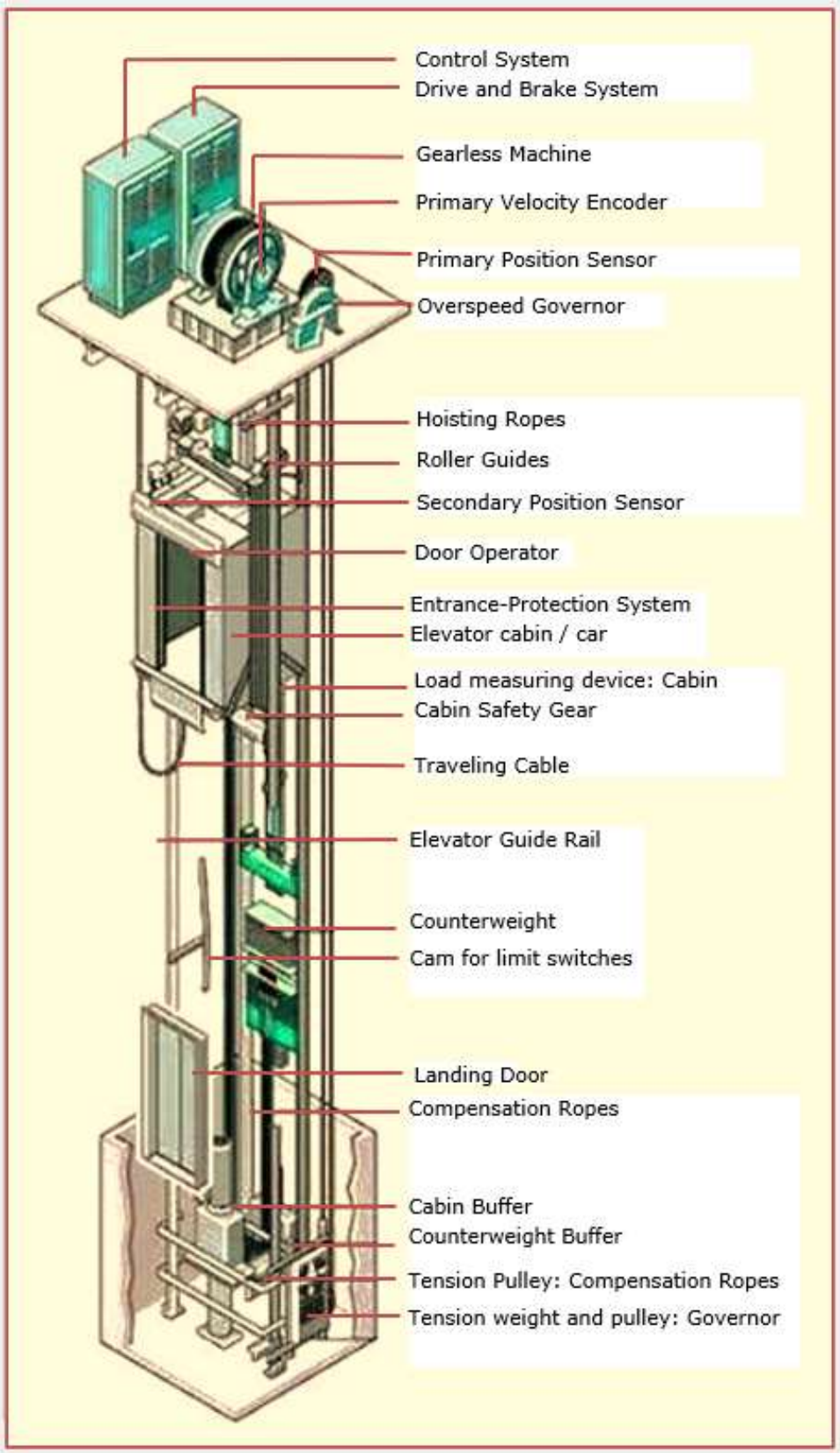

Figure 2: System overview of a typical gearless traction elevator

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Figure 1 shows an overview of components of a gearless traction elevator, having a separate machine room. It has 1:1 reeving and direct suspension. These types of elevators are designed to carry heavy load (1,000 – 3,000 Kg) and travel in highspeed (commonly in the range of 2 to 8 m/s). They are typically used for high-rise buildings where the traffic is intense.

For the purpose of this research the elevator system is categorised in five subsystems[10]: 1) Hoistway equipment including the guide rail system 2) Elevator cabin including its door operation 3) Landing doors including its locking system 4) Machine room components including traction machine and hoisting ropes 5) Controller and the drive system.

2.3 Codes and Design Standards

All countries follow certain codes and standards in designing and installing elevators. There are three major international standards: EN 81 (European Norm), ASME 17.1/CSA B44 (USA and Canada), GB 7588-2003, (Chinese National Standards[11]). Many countries follow one of these codes or have their own national codes that can differ from the above. The regional elevator manufactures follow the national codes. The multinational elevator companies generally follow an international code, unless the national code is more stringent or mandatory.

The EN 81 is mandatory in all member countries of the European Union (EU). It should be noted that top three global elevator companies (Schindler, Thyssen Elevators, and KONE) have their headquarters in Europe and follow EN 81 as their leading code. Many non-European countries take guidance from EN 81 to create their own national code.

The key purpose of the standards is to create uniformity and to ensure safety. This is done by placing limitations on designs and requiring concrete requirements. For example, as per EN 81 an elevator must have at least 3 steel ropes of 12 mm diameter with a minimum margin of safety of 12.

[10] This categorisation is not a standard, it depends primarily on the R&D department of a company.

[11] Although applied mostly in China, this code is considered as an international code because of the size of market size.

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Over the years the design requirements have become more stringent. One such requirement is that the doors must detect obstacles while closing without being touched, which requires to install infrared detection in the doors. The current elevator codes are created not only to ensure safety of passengers but also people working on elevator. Hence installation of MRL elevators was permitted in the USA after several years it was permitted in Europe, as it took time to make the required modification to ANSI code (Donoghue in Strakosch and Caporale, 2010, p 483).

2.4 System Design

Traction elevators come in a number of designs to meet different needs: required traffic capacity (load, speed), travel height, building type (residential, hotel …), building architecture, engineering feasibility, cost, and so on.

The maintenance and inspection efforts differ to a good extent depending on the elevator design. For example, is there a separate machine room? Today, separate machine rooms are used only in case of high speed, high-capacity elevators. Up until early 2000 a machine room, constructed directly above the hoistway with a separate entrance, was the norm. A machine room makes it easier to access and safer to work. The drawback it is that machines rooms consume valuable roof-top space. Hence a machine room less (MRL) design is preferred by building owners and architects. The headroom space in hoistway is limited. A MRL design is riskier for maintenance technicians and inspectors when the need to work on machine and other components placed at the top of the hoistway.

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Below is a short table of the main designs and their features.

Design	**Features**
Separate machine room (MR).	Key components such as hoisting motor, controller, and speed governor are placed in the machine room. Accordingly, the layout of the roping, suspension of the cabin etc. changes.
Machine room less (MRL)	The machine and the speed governor are installed directly at the top of the hoistway. The controller is also placed inside the hoistway or integrated into the top floor landing door frame.
1:1 reeving	In 1:1 reeving one end of the suspension rope is connected directly to the cabin and the other end directly to the counterweight. The rope speed is equal to the elevator speed.
2:1 reeving	Both rope ends are anchored to the ceiling. The suspension to the cabin and counterweight is done by means of an attached pulley through which the ropes are passed. The speed of moving rope is half of the elevator speed but the lifting capacity for the hoisting motor is doubled.
Direct suspension / underslung	In direct suspension the ropes are attached to the upper cabin frame. In underslung the ropes are passed over the pulley attached to the bottom of the cabin frame.
Single wrap / double wrap	The double wrapping of the wire ropes on the traction sheave enables higher tractive capacity. However, this is more damaging to the rope. In high-speed elevators, double wrapping is the only feasible method to achieve sufficient tractive capacity in all conditions.
Single cabin / double-deck cabins	Most commonly, each elevator has one single cabin. However, in order to increase capacity, double-deck cabins are used in high-rise buildings. This increases the traffic capacity and also the complexity of inspection and maintenance.
Bank of elevators	Installing several elevators in one big hoistway adds intricacy to the design. This can also reflect in maintenance and inspection work.
Glass elevators / special purpose elevators	Glass means heavier cabin and the doors, requiring higher traction and bigger motors. The special purpose elevators can have uncommon designs such as placing the hoisting machine at the bottom of the hoistway.
Multimedia cabin	These cabins have flat screens on which the customer is able to display information such as weather reports and place marketing advertisements. For maintenance purpose this creates additional requirements.

Table 1: Key designs and their features

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As can be seen from the above, traction elevators can have different system designs, which increases the complexity. For example, the use of double-deck can increase the traffic. However, "the use of double-deck units may present as many design problems as it solves" (Montesano, in Strakosch and Caporale, 2010, p 522).

Depending on building type, traffic, and customer requirements, different system designs are applied. The following is an overview of it for the new installations under the current technology.

Building type	**Common system designs**
Residential or office buildings up to about 20 floors (approximately 60 meters travel height).	- Machine room less (MRL) - Direct drive (gearless machine) - Wire ropes or flat belts - Underslung suspension - Speed between 1.0 to 2.5 m/s - Option of multimedia cabin.
Transport elevators such as airports or railway stations (3 to 6 floors).	- MR or MRL - Geared or gearless - Wire ropes or flat belts - Speed of about 1.0 m/s - Option of multimedia cabin.
Goods elevators up to 3 to 6 floors	- MR or MRL - Geared - Wire ropes - Speed of about 0.5 m/s - 2:1 reeving factor
Tall and super tall building having 20 floors and above	- Separate machine room - Direct drive (gearless machine) - Mostly wire ropes - 1:1 suspension with double wrap. - Speed between 3.0 to 6 m/s is most common. With speeds of above 10 m/s cabins with air pressurisation. - Double-decker cabins - Multimedia cabins

Table 2: Building types and suitable elevator systems

The different system designs reflect directly in the required maintenance tasks as well as the maintenance process. If there is a breakdown, the

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elevator company sends a qualified technician who is able to work on the system of that elevator. The elevator can be put back into operation quickly and correctly only if there is a clear understanding of the system design of the elevator in question. The technicians thus need elaborate training to work on different types of elevator designs and configurations. It is the technical knowledge of the technicians and their ability to interact with the clients that makes the maintenance business a success for a company.

2.5 The Hoistway Equipment

The hoistway also goes with the term lift well[12]. It is the vertical tunnel in a building, the pathway for elevator travel. The equipment in the hoistway is normally not visible from outside, except in such cases as glass elevators.

The maintenance technicians and inspectors need to travel on the top of the cabin, so that they can inspect the components installed in the hoistway. To facilitate this the cabin top is fitted with an inspection switch, that allows the technicians to take control of the elevator. Once the inspection switch is switched on, the elevator will not respond to car or landing calls. Using the up and down buttons located in the inspection switch, the cabin can be moved up or down in a controlled speed. This enables the stopping of the elevator at any place to carry out the maintenance or inspection.

For design engineering purpose the hoistway can be divided into three sections: the pit, the travelling section, and the headroom.

2.5.1 Components in the Pit

The pit is the bottom most end of the hoistway. All elevator codes[13] stipulate requirements on dimensions of the pit, which is meant to provide safety space for anyone working in the pit.

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[12] Hoistway is the term used in North American code ASME A17, whereas the European code EN 81 uses "shaft", based on British English. It is quite common in the industry to use these two terms interchangeably.

[13] For example, chapter 5.2.1.5 of the European Standard EN 81-20:2014 (Safety rules for the construction and installation of lifts – Lits for the transport of persons and goods).

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Components and sensors	Purpose
The cabin and counterweight buffers and the monitoring switches.	Reducing the impact of momentum, in the case of uncontrolled travel to the pit.
Tension weight for speed governor rope and switch.	Keeps the speed governor rope under tension, enabling it to function.
Stop switch and the inspection switches (the later depending on the code used at the time of installation).	The stop switch disenables the normal operation of the elevator. The inspection switch enables the operation of the elevator in a controlled manner.
Speed supervision switches / sensors.	These supervise the speed of the approaching elevator at the bottommost floor. In case the speed above the limit, there will be an emergency stop.
Rope tension weight and monitoring switches.	Keeps the compensation ropes under tension in all travel conditions.
Pit Ladder and monitoring switch.	For accessing the pit from the floor.
Cover for the counterweight.	Prevents accidents by moving counterweight.

Table 3: Components in the pit and their purpose

The pit also contains components that require regular maintenance and inspection. The following is table of components in the pit and the purpose for they are installed.

Below is a visualisation of the pit components and hydraulic buffers. The contact switches mounted on the buffers and the suspension pulleys deliver the information to the elevator controller if they are on or off. The controller in turn will communicate this information through IoT to the central cloud computers. In the event of a breakdown, such information will be available to the technician when he gets the notice to attend the breakdown. This enables him to come prepared to the site.

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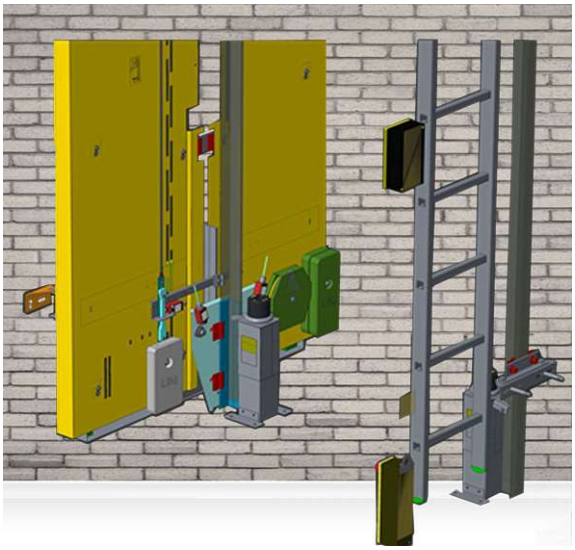

Pit set with ladder and other components

Typical hydraulic buffers

Figure 3: Pit set and hydraulic buffers with their contact switches
Source: Schindler

2.5.2 Components in the Travelling Section

The travelling section of the hoistway equipment contains mainly the guiderails and their brackets fixed to the wall. The guide rails are made of steel. The size of the guiderails and the distance between the brackets is calculated to withhold the extreme pressure that might be implied on them. This extreme pressure can arise in the instances such as safety gear action when the car is travelling in full speed and full load in down direction.

For the maintenance purpose we need to ensure that the guide rails have not become loose between their joints and from their fixation to the brackets. Another important issue would be to ensure that the guide surface is sufficiently lubricated – in case sliding guide shoes are used. In case of roller guide shoes, the guide rails do not require lubrication. A visual inspection can detect any loosening of the joints. However, this will be time consuming as the technician need to travel the whole hoistway. With vibration sensor placed on the cabin, any distortion in travel smoothness is detected. Also, the exact position of the distortion is localised.

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2.5.3 The Headroom and Machine Room Components

If the design of the elevator is machine room less (MRL), then the headroom contains the traction machine and the speed governor. It might also contain the controller and the drive. The access to these components is done at the topmost floor, through the elevator landing door.

For the maintenance technician it is cumbersome and also risky to access the components in a MRL elevator. The space is limited, and the maintenance and inspection are done from a tiny space. The technician needs to be very careful not slip into the hoistway, which can cost him his life. Accidents and injuries not uncommon with MRL elevators.

Apart from the components mentioned above, there are other components in the headroom that need regular visual inspection. They are:

Component / Sensors	**Purpose**
Top speed supervision switches / sensors.	These supervise the speed of the approaching elevator, which should always be reduced as it comes near the topmost floor.
Other sensor such as smoke detection.	In some countries it could be mandatory to install such sensors.
The overspeed governors and monitoring switches.	Overspeed governors detect cabin speed (in some instances also the counterweight) exceeding its range and if required, to operate the safety gears.
Slack rope detection.	These detect if the main traction ropes ropes/belts have become slack, which can happen if the car or counterweight is blocked in the hoistway for any reason.

Figure 4: Components at headroom

2.6 The Elevator Cabin and its Door Operating System

The cabin is a complex subsystem of an elevator. The complexity depends on design requirements, which are mainly the travel height, speed, and the rated load. In high-rise building it is common to have two cabins assembled on top of the other (double-decker). Such a constellation makes it possible to serve two floors at the same time and transferring double the number of passengers using one hoistway. At the same time such complexity increases the maintenance and inspection work.

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The major component of this subsystem is the cabin door and its operation. The cabin doors are motorised whereas the landing doors not. It is the cabin door that moves the landing doors along with it. Hence the components of a cabin door need to be closely monitored for wear and tear and to avoid breakdown.

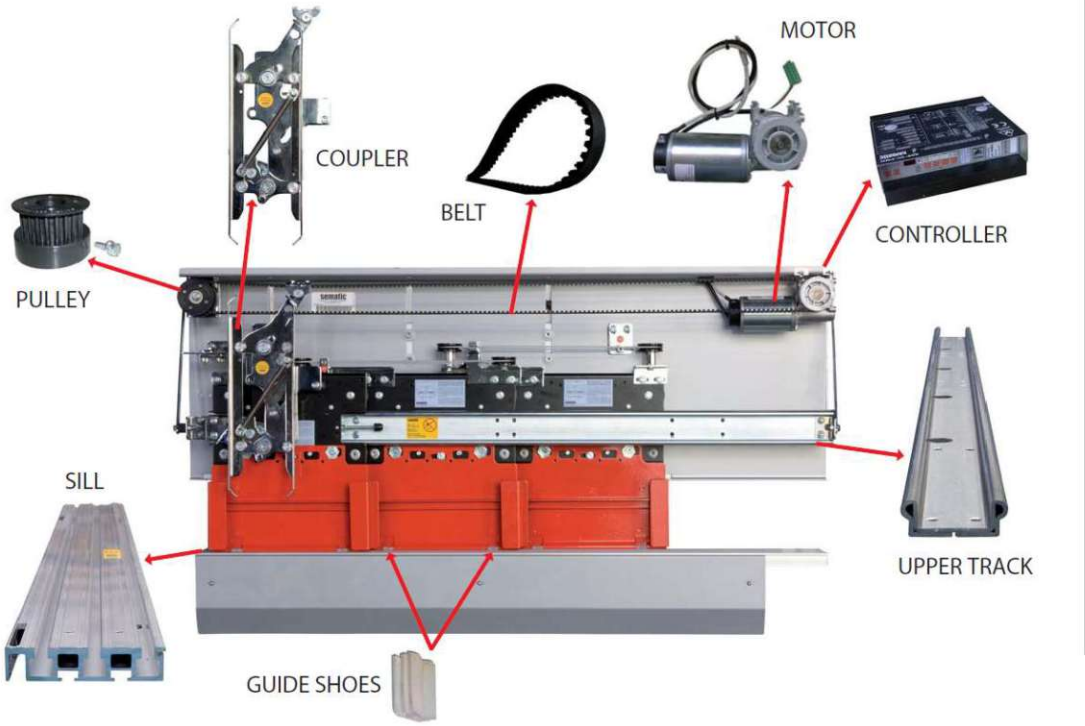

Figure 5: A typical elevator cabin door with its components
Source: Sematic/Wittur

The door operation system has several components out of which the following can be said as the major one: the motor, the connecting belts, the door coupler for coupling the landing doors, and the door hanging rollers.

Because of constant operation many of these parts can become worn-out or damaged and cause breakdown. With IoT the supervision of the doors becomes easier. For example, if the door closing and opening duration is constantly monitored, a deviation can be seen if one of the door hanging rollers has become defective. This will trigger a message that can be relayed to the owner of the building and as well as to the nearby technician.

Another sensor that each cabin door contains is the light curtain to detect any object obstructing the doors while closing. This obstruction could be

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passenger, or, in some cases, the "fail safe" modality of the sensor itself. A majority of elevator breakdowns have their roots in the car and landing doors. Hence, the car door operation needs to be constantly monitored and thoroughly inspected for any wear and tear.

2.6.1 The Landing Doors

The elevators have at least one landing door for each floor, sometimes there could two landings for practical reasons. As mentioned earlier, the landing doors open in tandem with the car door and are powered by car door. A breakdown can happen if for any reason the door is blocked, or not opening and closing fully. The landing door-lock is also a safety component, the failure of which can cause hazardous situation. Codes require that landing doors should have fire protection for the building concerned. They also should withstand high static force, applied horizontally. This is to prevent any persons running or moving towards the door in a speed (for example a sitting on a wheelchair).

The landing door components slightly differ from the car door. They are also less complex. Nevertheless, their maintenance and monitoring are equally important. In high-rise building inspecting each and every landing door takes time. Visual inspection of each part is also difficult as some smaller parts could be hidden. The real time monitoring of landing doors can thus save time and it is effective. The closing and the opening speed of the doors is directly connected with managing the traffic of the building. In designing the elevators strong attention is given to have an optimal speed. While lower speed will affect the traffic, higher speed will increase the door kinetic energy, which limited by the code to prevent hitting a person and causing bodily harm.

Often the landing doors can be blocked or slowed down because of debris in its sill. This can eventually lead to a breakdown. If the elevator is connected by IoT, this probability of a blockage can be detected early. As the work would include just the cleaning, this can be done by the building facility management as well.

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2.7 Main Motor, the Brake, and the Traction Pulley and Ropes

In the case of a separate machine room (MR) all the components are placed in a machine room, which in most cases is directly above the hoistway. The main motor, or the hoisting motor, is placed in a machine room if the elevator was designed to have machine room. Otherwise, as mentioned earlier, the hoisting machine and the speed governor are place in the hoistway headroom.

The hoisting machine is the heart of the elevator and comes in all sizes and capacity. They are to be monitored for vibration, temperature, and general operation. The motor winding can get burnt if the ambient temperature (which is the case in tropical regions) is high and the ventilation didn't function. To replace a burnt motor is costly and time consuming compared with good maintenance and inspection.

All elevator motors have one thing in common, they have at least two independent brakes. Elevator brakes, unlike the brakes of a car, are always kept applied and open only when the elevator is moving, that means while the motor is turning. In all other situation the brake remains applied, so that there is no unwanted movement of the cabin. The brakes have tension springs that are operated either with a magnetic solenoid or by hydraulic power. The brake should be designed to stop and hold the fully loaded elevator in all extreme situations.

The brake is a safety component and needs regular inspection for tear and wear. Luckily, all modern motors are stopped not by the brake but by their drives. These control the speed and bring the elevator motor to zero speed before the brake is applied to hold the elevator. This function has reduced the wear and tear dramatically.

The traction pulley has the grooves over which the ropes are passed. The traction is created because of the friction between the ropes and the grooves, which in turn depends on the ratio between the cabin weight and the weight of the counterweight and the wrapping angle. The traction elevators required to have enough traction to hold 125% of the rated load. However, traction should not be too high – it should not lift the cabin or the counterweight in case the other is blocked or resting on the buffers.

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This is a mechanical design required to prevent movement in extreme situations and ensure safety to the people. With the usage the ropes or the traction grooves might get worn out and there can be slipping of the elevator causing extremely dangerous situation. To prevent this regular monitoring is required. Visual inspection during maintenance is one method of monitoring. Sensors and the software that accurately calculates the slip in each trip is another method of verifying if we have sufficient traction.

2.8 Controller and the Drive system

The controller processes all the signals given to the system by passengers operating the elevator (Strackosch and Caporale, 2010, p 43). It is actually the brain and the heart of an elevator that oversees each and every function of the system. It ensures that the doors are closed or opened, gives signals to the actuators to power the motor, and supervises all the safety circuits. For the IoT, it can be the hardware that connects with the internet and transmits information to the cloud computers.

The controllers have at least two different voltages, one for the safety circuits and one for its own operation. The safety circuit voltage is usually 24 or 48 volts. For its own operation the voltage could be in the range of 5 volts, the standard for microprocessors. When a controller is switched on, it usually checks its own health first. Thereafter it checks all the safety circuits that must be on for the doors to start closing. Thereafter controller enables the closing of the doors and verifies that the doors are locked, and signals are received from the lock contacts. After the elevator starts moving, its position is accurately monitored by means of suitable components, such as a magnet tape that is installed from top to the bottom of the hoistway.

Current microprocessor control systems have advanced algorithms and logic control that is adaptive. They provide more distributed control and more advanced communication systems to eliminate wires; they allow and provide for complex user interfaces and contain advanced self-test and troubleshooting features. The systems can monitor the usage, read temperature probes, call central dispatch systems, and inform the maintenance provider that service is required. In all, even the most

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advanced modern elevator controller is still a finite state machine that performs the same basic functions that have been performed on automatic elevators for the past 50 years, but with more bells and whistles, more features and states, fewer relays, higher reliability, and more efficiency.

Advanced algorithms and adaptive logic control are used in today's microprocessor control systems. They offer more distributed control and advanced communication systems to remove wires, as well as complex user interfaces and powerful self-testing and troubleshooting capabilities. The systems can track consumption, scan temperature probes, send alerts to central dispatch, and notify the maintenance provider when service is needed. Overall, even the most sophisticated modern elevator controller is still a finite state machine that performs the same basic operations as automatic elevators have for the past 50 years, but with more features and states, fewer relays, improved reliability, and efficiency (Strackosch and Caporale, 2010, p 139).

2.8.1 The Drive System

Any new installation today uses an AC motor with a drive system to control the acceleration, speed, and deceleration. This enables smooth starting and stopping and also has advantage for the wearing of the brake. Without the drive the elevator will start at a fixed speed, and the stopping is done by just switching of the power and applying the brake.

The elevator motors typically operate on 3 phase power, with or without permanent magnets. There are two types are drive systems that most commonly used: ACVF or VFD and VVVF. The ACVF, as the name suggests, controls the speed of the motor by varying the frequency. The VVVF, on the other hand, controls the speed by varying both the voltage and the frequency.

The drive needs several parameters for its operation: the load in the elevator, the next floor it is going to travel (travel distance), and if all the relevant safeties are closed. Although the drive does not contain any movable parts and does not require maintenance as such, it requires

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monitoring for correct and trouble-free functioning. A bug in the software used in the drive can also cause malfunctioning and breakdown.

The drive is also required for managing the energy regeneration, if installed. The energy regeneration is possible in elevators in two instances: 1) there is more than half the load in the cabin and the elevator is moving down 2) there is less than half the load in the cabin and the elevator is moving up. Due to the potential energy of gravity, the counterweight or the cabin move the motor, which in turn can operate like a generator producing electricity. This can be then stored or fed to the grid.

Figure 6: A typical elevator controller with integrated drive
Picture source: BSB Asansör

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The elevator controller shown above is of a size used in MRL elevators. Compared to those used in MR elevators, this controller has space for all components including the drive and storage batteries for emergency evacuation. In case of controller that is used in MR elevators, most of the components are squeezed inside the landing door frame of the top floor. The drive and battery the packs are installed inside the hoistway on the wall.

2.9 Conclusion

An elevator has multiple number of components and functions. They work together as system and contribute to the safe functioning of the elevator. The failure or malfunctioning of one of the components can cause the elevator to breakdown. Of all the components the safety components such as the door locks are extremely important. Their malfunction or non-function can create a hazardous situation.

All elevator components are locally monitored by means of switches, contacts, and any type of sensors. Their condition is supervised by the elevator controller. The controllers today are microprocessor based and are able to register events. They can also be connected to an IoT gateway to transfer real-time information to a central platform for further analysis.

The technology and the design of traction elevators have steadily evolved over the time, providing faster and safer vertical transportation (Andrew & Kaczmarczyk, 2011). Certainly, the trend will continue.

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CHAPTER 3
MAINTENANCE OF TRACTION ELEVATORS

> Everyone should be able to do one card trick, tell two jokes, and recite three poems, in case they are ever trapped in an elevator.
>
> Daniel Handler (author of "A Series of Unfortunate Events")

3.1 Introduction

Elevator care and maintenance include preventive maintenance, attending breakdowns, safety testing, and replacing worn out components. The maintenance work of an elevator is not much different than maintaining any sophisticated engineering equipment. Without proper care the elevator is not safe. A worst scenario is getting trapped in an elevator.

Three core reasons can be mentioned for maintenance: 1) ensure safety through regular inspection 2) prevent breakdowns by repairing or replacing worn-out parts in advance 3) upkeep the lifespan of the elevator through service and care. As per regulations maintenance and tests are required for the safety of the passengers as well anyone working on the elevators.

It is utmost important to have properly qualified and trained personnel to conduct maintenance related works. An elevator system is made of diverse mechanical, electrical, electronic, and sometime hydraulic components. Some elevators could be simple in their technology, but many are highly sophisticated and manage continuous traffic in high rise buildings.

In the previous chapter the elevator system engineering was presented, giving an insight into the diversity of the components and the complexity of their functions. This chapter will address the process and other issues related to maintenance, inspection, and attending breakdowns. It will also touch the obligation for safety and the requirement of maintenance and periodic inspection, as reflected in diverse government regulations.

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3.2 The Business and the Management of Maintenance

A typical OEM has thousands of elevators under maintenance contracts in a city of a couple of million inhabitants. The periodic maintenance process therefore needs proper resource planning. The main resources are qualified manpower, material, and the route planning for service technicians. The route planning is important as the elevators are spread all over an urban or semi-urban area. The time duration for travelling between different units can be substantial, especially considering the traffic condition. Therefore, it is quite common that if a technician is despatched to one area to carry out maintenance on one day, he will be given further tasks in the same area. However, if the technician is not qualified or certified to work on certain types of units, someone qualified need to be dispatched.

The routine maintenance (servicing) requires from 30 minutes to several hours. This depends on the type of unit and customer requirement. The time required for maintenance or inspection depends on the elevator travel height, usage, and the type of the elevator. During the work the elevator can't be used for transportation. Hence care is taken in planning the routine visits based on the customer types, such as hospitals, so as not to disrupt the normal operation. In such cases it is a general practice in the industry to coordinate with customers regarding the date and time of work. In normal cases it is the elevator company that sets a date for the routine maintenance or inspection works and the customers are not informed.

Depending on the maintenance contract, attending the breakdowns is either inclusive or charged extra. However, if a breakdown occurs because of misuse or influenced by other issues such as extreme weather, this is billed outside of the maintenance contract. Also, if the breakdown happens out of the normal working hours, attending the same is charged.

Customers who have purchased elevators from one OEM prefer that their elevators are maintained by the same company after the installation. However, the OEM maintenance contracts are normally priced higher than that of smaller companies. Hence the customers might opt for smaller companies and switch maintenance contract down the time. Sometimes customers choose a different maintenance contractor as soon as the

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maintenance under guarantee[14] from the OEM is over. If this happens it can be a loss of future revenues as the new elevators are sold with a narrow profit margin. The smaller companies are mostly price competitive for the maintenance. Often, they are local companies who also are able to respond faster in case of a breakdown.

Figure 7: A Schindler technician working below the cabin

3.3 Need for Maintenance and Inspection

Zack McCain writes in his well-known industry publication *Elevator Maintenance Manual*, "Maintenance is required for safe, efficient, and reliable operation of elevators …" (McCain, 1999, p 13). According to Louis Bialy (2020) "Maintenance and inspection have been recognized for many years as essential functions to ensure the safety of elevators". With periodic visits, the condition of an elevator can be evaluated directly. This will ensure that the unit is safe for use. Failure to maintain an elevator properly will lead to breakdowns and even accidents.

[14] The maintenance under guarantee depends on the sales terms, usually six months or one year. The OEMs always try to bind the customers to their maintenance contract. One method of doing this is to sell maintenance contracts lasting several years along with the new elevator.

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Elevators, being electromechanical equipment, need periodic maintenance. For efficient and reliable operation, a systematic maintenance programme is essential. As the elevator ages, even with quality maintenance, wear and tear will affect the components, requiring replacement (Nicholas Montesano in Strakosch and Caporale, 2010, p 517).

The maintenance plan should suit the type of elevator, its usage, its age, and where the elevator is in use (hospital, airport, residential complex …). Also, the environmental conditions such as humidity, ambience temperature, dust etc. will influence the type and frequency of the maintenance.

Maintenance and inspection are typically not the same. The preventive maintenance contains lubrication, routine adjustments, and replacing worn-out parts. On the other hand, a dedicated inspection is required to evaluate the elevator from a safety perspective. Here it is required to assess the risks considering the age of an elevator, its function, the load it transports, and its position in the building. An inspection determines if the elevator is safe considering its condition, how it is maintained, and at which place (train station, office …) it is in operation.

Included in the maintenance plan or separately, the elevators undergo periodic inspections. The purpose of inspection is to verify that the components are functioning as required by means of suitable tests. In addition, the inspection must also verify that crucial components, such as traction ropes, have a lifespan at least until the next inspection is due.

3.4 Regulations for Maintenance and Inspection

The fundamental reason behind a regulation is obvious: to ensure minimum safety under all conditions for users and anyone working on elevators. In addition, the regulations define the legally responsible entity for the upkeep and the safety of the elevators. The rules normally outline which components need to be inspected and how often.

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Most countries have their own regulations concerning the operation of elevators. The regulations can differ also within a country, according to the province or a state. The regulations can be informative or normative[15].

3.4.1 European Standard

The European Committee for Standardization (CEN) has its standard EN 13105:2001+A1 (2008) "Maintenance for lifts and escalators – Rules for maintenance instructions". It defines maintenance as "all the necessary operations to ensure the safe and intended functioning of the installation and its components after the completion of the installation and throughout its life cycle".

The European Standard EN 13015:2001+A1 (2008) is an informative standard, giving "guidelines for maintenance". Its scope is to specify "the elements necessary for the preparation of the instructions for the maintenance operations" (EN 13105:2001+A1, 2008, p 3). Basically, this standard is concerned with the intended functioning of new elevators after it is installed. Elevators which are already in operation and were installed before the above standard are not covered in this standard. However, it can be used as a reference for the existing elevators as well. Very interestingly, this standard does not cover tests and inspections. Thus, the normative part seems to have been left to the national regulations.

This European standard recommends risk assessment in developing methods and priorities for maintenance. It defines what must be included in maintenance and gives elaborate and specific information to the owner of the installation and as well as to the maintenance organisation.

3.4.2 Other Regulations

A good example of inspection regulations can be seen in the UK as defined in *The Lift Operations and Lifting Equipment Regulations* (LOLER) 1998[16].

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[15] The "informative" guideline tells "what" should be done and leaves it open "how" to do it. This gives the flexibility to apply the best possible method among several possibilities. The "normative" regulation, on the other hand, must be applied exactly as stipulated.

[16] https://www.hse.gov.uk/work-equipment-machinery/passenger-lifts.htm [last accessed 21.12.2021]

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As the regulation is concerned with the safety of working people, it is under the authority of UK Health and Safety Executive (HSE). The key message in the regulation is that if one owns, or manages, or have control over a lift (elevator), then he is required to ensure that the elevator undergoes a "thorough examination" at regular intervals. The regulation further stipulates, without much elaboration, that the examination should be carried out by a "competent person". The LOLER 1998 differentiates between "Preventive Maintenance" and "Thorough Examination". As mentioned earlier, preventive maintenance is about works such as lubrication and cleaning, whereas the examination or inspection is about tests to determine the condition of the elevator from a safety perspective.

The LOLER 1998 also specifies the interval for thorough examination. In case the elevator is used at any time for transporting people (as against goods only), then the examination is required every six months. If it is used solely for transporting goods, which is often the case in factories, then inspection once every 12 months is sufficient.

In the USA, elevator maintenance regulations are in the competencies of Department of Labour. They are covered under Occupational Safety and Health Administration[17] and managed in association with the American Society of Mechanical Engineers (ASME). As in the UK, here too periodic inspections not exceeding 1 year between them are required. In addition, thorough maintenance is required at least once every six months. Depending on the usage this can be done even every month. The code stipulates which components need to be checked. Among them are controller, electrical wiring, measuring gauges and meters. It is also required to inspect the elevator operations such as closing and opening of the doors, floor to floor travel, and emergency and safety equipment.

In Singapore, the "Lift, Escalator and Building Maintenance Regulations 2016[18]" deals with maintaining elevators. Accordingly, the maintenance

[17] https://www.osha.gov/lawsregs/regulations/standardnumber/1917/1917.116 [last accessed 21.12.2021]
[18] https://sso.agc.gov.sg/SL/BMSMA2004-S348 2016?DocDate=20160722 [last accessed 10.01.2022]

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should be carried out once every 3 months or according to manufacturers' recommendations. Naturally, manufactures recommend maintenance at shorter intervals. The testing (inspection) is required to be done at least once a year. Interestingly, the testing needs to be carried out in the presence of an independent Specialist Professional Engineer (SPE). The Singapore code stipulates registration for elevator service contractor with the Building and Construction Authority (BCA).

It is helpful to understand that some codes might not stipulate mandatory maintenance. In such cases, they make the periodic inspections mandatory. In other words, for the inspection to succeed, the periodic maintenance is required. If the elevator was not properly maintained, it unlikely to pass the inspection.

3.5 Components Needing Maintenance and Checks

In the past, a good amount of elevator maintenance work was cleaning and lubrication. In modern elevators with advanced technologies, this has been reduced by installing fever moving parts not requiring lubrication.

Hence, most of the maintenance is inspecting the functioning of the components. In a traction elevator there are certain components the functioning of which must be guaranteed at all times. These components are directly related to safety.

According to Health and Safety Executive of UK Government, the following components are mandatory (but not exhaustive) in "Through Examination".

- Landing and car doors and their interlocks
- Worm and other gearing
- Main drive system components
- Governors, Safety gear
- Suspension ropes, Suspension chains
- Overload detection devices
- Electrical devices (including earthing, earth bonding, safety devices, selection of fuses, etc)
- Braking systems (including buffers and overspeed devices)
- Hydraulics.

Table 4: Components needing periodic examination
Source: Health and Safety Executive, UK

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The above can be said as a general process, which the elevator companies follow. The frequency of this maintenance can depend on parameters such as the usage or the OEM's recommendation. Even the code authorities generally ask the elevator owners to follow OEM recommendations regarding safety and maintenance of the equipment. The OEM recommendation in turn is an average based on their experience.

Component / Operation	**Function**
Overspeed Governor	Detects, the movement of elevator cabin or its counterweight above the rated speed. In this case it breaks the safety circuit. If the speed further increases, then the overspeed governor will trigger a mechanical system that will jam the car or counterweight to its guide rails.
Motor brake	The brake needs to hold the fully loaded elevator at all times. In older models, the brake is used to "stop" as well as "hold" the motor.
Landing door locks	It must be ensured that the landing doors remain always closed and locked. That means the maintenance technician need to check each and every door.
The pit buffers	The pit buffers reduce the impact in case cabin or counterweight hit the pit.
Suspension ropes	The suspension ropes are meant to carry full load. In case of steel ropes, they are lubricated with special oil. With coated ropes this is not required. Nevertheless, they need to be checked for wear and tear.
Electric safety devices	Most of these are used in the form of safety circuits containing electronic components. A visual inspection of these is generally not possible. Normally such devices are created "fail safe". In case of malfunction, they fail in such a s way that they stop elevator from functioning.
Movement of elevator, closing of doors, and any other technical operation.	The movement of elevator is inspected for noise or vibration. The doors should detect hindrance while closing and must open back. Similarly, there could be elevator specific operations and functions that need checks. These are defined by the elevator manufacturer.

Table 5: Key components and their function

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3.6 Types of Maintenance contracts

Elevator maintenance companies generally conclude a maintenance contract, lasting one or several years, with the building owners. A onetime maintenance work is not very common. Different types of maintenance contracts are offered, which differ from one another in the scope of services and material included.

Type of Service	**Method of Application and Contract**
Preventive maintenance	This is the most common scope of a maintenance contract. Here the company will send trained technician at specific intervals (usually once a month) to carry out the maintenance tasks defined in the contract.
Attending call backs	This service meant to put back the elevator into operation if there is a breakdown. This could be all inclusive, means the company will send a technician as soon as a breakdown or malfunction is reported. This service increases the price of maintenance contract. The companies also offer a reduced service, such as any call back normal working hours is free of charge and the rest is charged.
Mandatory inspection and safety tests.	This could be included in the main part of the contract or can be organised as a one-off task.
Coverage for components and parts having shorter life span.	If included in the contract, the maintenance contractor will replace the parts free of charge, when they are worn. This is a kind of insurance for the building owner.
Coverage for major parts such as the hoisting motor.	In this instance the elevator company takes responsibility for all components, including in some instances the machine. This type of contract is most costly. However, for the owners this enables to set their expenditure in advance and plan better.

Table 6: Types of maintenance services
(based on OTIS and Schindler)

The choice of a particular type of maintenance contract depends on such factors as where the elevator is installed, how much it is used, who are the

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owners etc. A privately owned residential building of up to 10 floors might go for a maintenance contract with medium services. A high-rise hotel complex, or a government owned building with high usage might opt for "all inclusive" contract.

3.7 The Maintenance Process

Once the elevator maintenance contract is signed, it is integrated in the planning and process tools of the maintenance contractor. The elevator is then assigned to a maintenance programme. The programme will have the details such as when the next maintenance is due and the scope of work.

The technicians, who are always out in the field, are contacted via company specific apps. The apps will inform the technicians about the extent of maintenance work, the time available for the particular work, building address, and any other information.

On the site, by using a test tool or a computer, the technicians are able to see the event and error logs from the controller. The event logs help them to judge if a component had not functioned as it was supposed to be. Finally, with the help of event log the technician is able to change a part in advance, thus preventing a potential breakdown (Jon Halpern in Strakosch and Caporale, 2010, p 141).

3.8 Qualifications and Knowhow of Maintenance Technicians

The elevator maintenance business is labour intensive and requires well qualified and trained technicians. In UK, the USA, and in a few other countries the maintenance technicians are required to complete exams and get a professional certificate. Elevator maintenance technician is a well-paid profession in skilled workers' category. They need to have good technical knowledge in mechanical, electrical, and electronic areas.

It is common to differentiate the function of an elevator technician depending on his knowhow. A technician with lower qualification might only do such tasks as lubrication and visual checks. Whereas a technician with higher knowledge would attend breakdowns and conduct safety checks and inspections.

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One other important task of an elevator technician is to liaison with the customers. In huge complexes where there are a number of elevators are in operation (airport, huge residential complex ...), it is important for the maintenance contractor to have a good rapport with the client. Here an energetic and customer friendly maintenance technician is required. In certain cases, the maintenance technicians might do tasks of a sales executive by selling parts or repair works.

Figure 8: A KONE technician in the machine room.

One of the key issues in this study is to evaluate how IoT might influence the job of elevator technicians and inspectors. Currently, the same maintenance technician and inspector covers the same elevators periodically, thus getting to know the elevator technically. Doing that they are also able to build closer relations with the customers or facility managers. All these activities give them steady and continuous overview of the condition of the elevator and customer wishes. During the regular visits they write a report if any parts are worn-out and need immediate replacement. The maintenance company will then make an offer to the customer, who will then take his decision whether to go ahead with the proposed work. With the IoT this process is going to be different.

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3.9 Conclusion

Elevators, once installed, need periodic maintenance as well as inspection (tests) to ensure safety and functional reliability. The maintenance contains routine tasks such as lubrication, whereas the inspection will put components into test, such as functioning of the safety gears and brakes. Inspection verifies that the elevator is safe, whereas routine servicing keeps the elevator in good working condition.

The maintenance programme and the intervals are based on the parameters set by the manufacturer, code requirements, or other relevant and known values. These in turn are mostly on averages of everything, especially the usage of an elevator and its components.

Countries have their own regulations and standards specifying how often an elevator need to be maintained and/or tested. The frequency of tests can depend on factors such as in which kind of building it is in operation and the amount of traffic it has. In most cases the codes follow the recommendation of OEMs about the frequency of services and tests.

Elevator companies have different types of maintenance contracts. They establish a framework for work to be done and parts to be replaced in case of wearing out. Generally, this includes preventive maintenance according to their plan, attending call backs during normal hours, and one or two safety tests in a year. The contract might include replacing minor or major components free of charge. The maintenance technician is the first one to notice any changes to the condition of the elevators under his responsibility and report the same. With IoT, the data analytics and AI are probably going to take over this task from the maintenance technician.

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CHAPTER 4
INTERNET OF THINGS

> We've heard a lot about the Internet of Things – I think we need an Internet of Women.
>
> Christine Lagarde IMF Managing Director

4.1 Introduction

So far the thesis shed light on elevator system engineering (chapter 2) and the maintenance of elevators (chapter 3). This chapter will present IoT, the prelude to IoT of elevator maintenance. It is crucial to understand the IoT technology and general process of its application so as to understand why its application in elevator maintenance.

Four unique components make up an IoT system: sensing devices, connectivity, data processing, and an user interface. A sensor can be an on/off switch producing discrete input/output (I/O) or a device generating analogue signals such as the temperature sensor embedded in an electric motor. These inputs are transferred to a central computer (cloud) using different types of connectivity: cellular, WiFi, or connecting directly to the internet via ethernet. The data collected is then processed with specific software which is generally termed as big data analytics or artificial intelligence. These programmes are able to clean the data, analyse the same for required information, and give outputs. The interface enables making use of the outputs in a meaningful way. This could be a connection to another machine or just a screen to see the condition of an equipment.

4.2 IoT Definition

The IoT enables unification of physical objects within a virtual world. Devices and machines are connected to each other and to the internet. They are able to capture relevant information about their own status or their direct environment. This information is continuously collected and transferred via internet. The collected information can be monitored, analysed, and made to trigger functions of other machines.

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A short and clear definition of IoT is given by Gartner Research: "The Internet of Things (IoT) is the physical objects that contain embedded technology to communicate and sense or interact with their states or the external environment[19]". Another definition is given by ORACLE: "The Internet of Things (IoT) describes the network of physical objects - "things" - that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet. These devices range from ordinary household objects to sophisticated industrial tools[20]".

The original internet was intended for sharing simple messages. Today it has evolved for connecting all sorts of "Things". These things could be any sort of a physical objects such as machines in assembly lines, components, sensors, actuators, household appliances, cameras, and so on.

4.3 Explaining IoT

Hina Gupta explains that IoT is the part where Information Technology (IT) and Operational Technology (OT) join (in Alam et al, 2020 p 6). She further clarifies that the IT domain consists of "things" such as servers, databases, and applications. They transmit on the network and are controlled by IT. On the other hand, OT is generally concerned with the industrial work and includes "things" like sensors and devices connected to the machines and other equipment. The OT supervises devices and processes on physical systems. Before IoT, there was a wide distance between IT and OT. They worked independent of the other, having little necessity for them to interact with each other.

[19] https://www.gartner.com/en/information-technology/glossary/internet-of-things [accessed on 20.11.2021]
[20] https://www.oracle.com/internet-of-things/what-is-iot/ [accessed on 20.11.2021]

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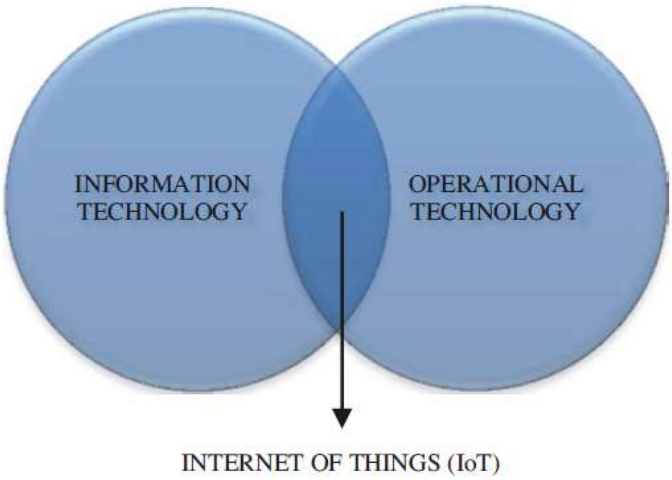

Figure 9: Venn diagram depicting IoT
Source: Alam et al, 2020, p 6

The basics of IoT is a permanent internet connection of all appliances for the purpose of collecting real time information and ultimately making use of this information. The internet connected physical devices or systems must be capable of sensing their physical environment intelligently. This is achieved using low-power and low-form-factor embedded processors and sensors onboard the gadgets. These processors and sensor are able to transmit information over the internet to central processors.

Subsequently, IoT can be considered as a collection of interconnected gadgets, machines, and tools. These are made up of sensors, actuators and processors that connect to the internet via wireless technologies. According to Hina Gupta, "IoT can be treated as the extension of the contemporary internet services to enclose each existing object" (in Alam et al, 2020 p 4).

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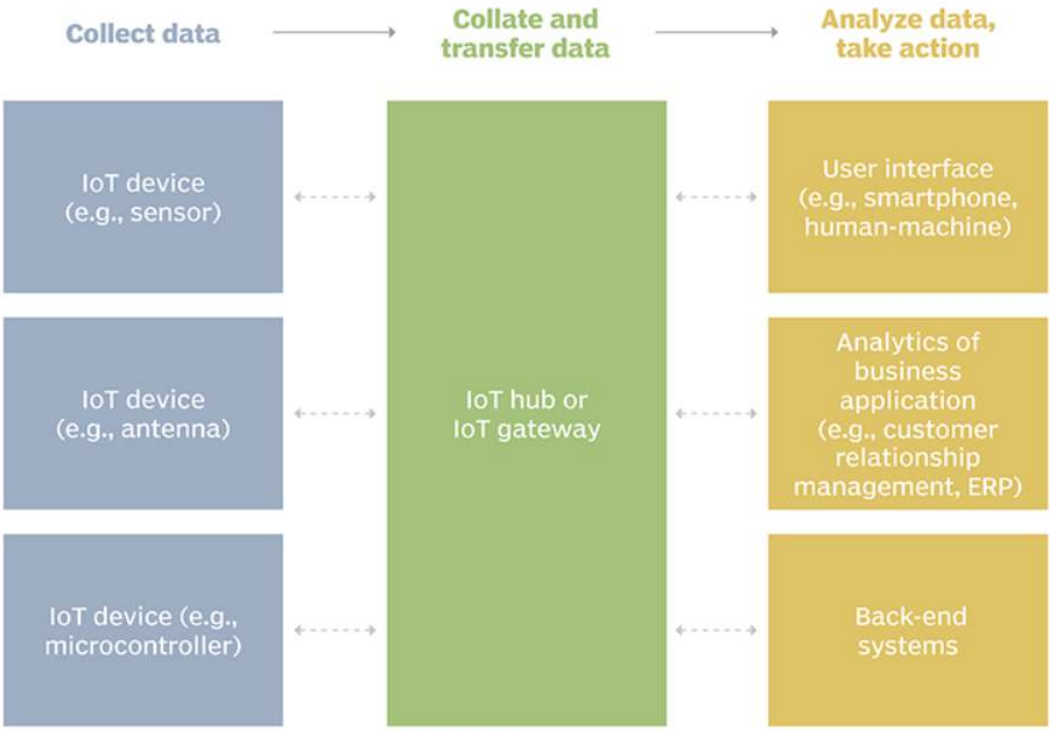

Figure 10: Example of an IoT System
Source: IoT Agenda[21]

4.4 Predecessors of IoT

Many of the technologies that are today part of IoT were in use for a while. They were applied separately for sensing, decision making, and automation tasks. These are continued to be used or in many instances re-engineered for IoT. Important of these are Wireless Sensor Networks (WSN), Machine-to-Machine (M2M) Communications, and Cyber Physical Systems (CPS) (Misra 2021, p 48).

4.4.1 Wireless Sensor Networks

As the name suggests, wireless sensor networks (WSN) is a networking concept that makes use of spatially distributed and interconnected sensors for collecting information pertaining to their surrounding environment. The information is collected centrally. The sensors are not standalone devices but a combination of sensors, processors, and radio units – referred as

[21] https://internetofthingsagenda.techtarget.com/definition/Internet-of-Things-IoT [last accessed on 06.01.2022]

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sensor nodes. The sensed date is communicated wirelessly to a remote server. The sensor nodes are generally low power and distributed in an ad hoc, decentralized fashion. Typically, several slave nodes transmit data to a single master using low-power short-range wireless transmission such as Zigbee or Bluetooth. The master node then aggregates the data from slave nodes and forward it to a remote server through internet or cellular connectivity. The stored data on the server can be accessed by an user or a subscriber to the system from other locations over the internet.

The sensors can be divided into two types: scalar and vector. A scalar sensor gives ambient values but can't provide information on the changes in these values with respect to distance or space. A temperature sensor is a good example of this. A vector sensor gives precise values and their changes for every point of space it covers. A camera that monitors movements is a good example of vector sensor.

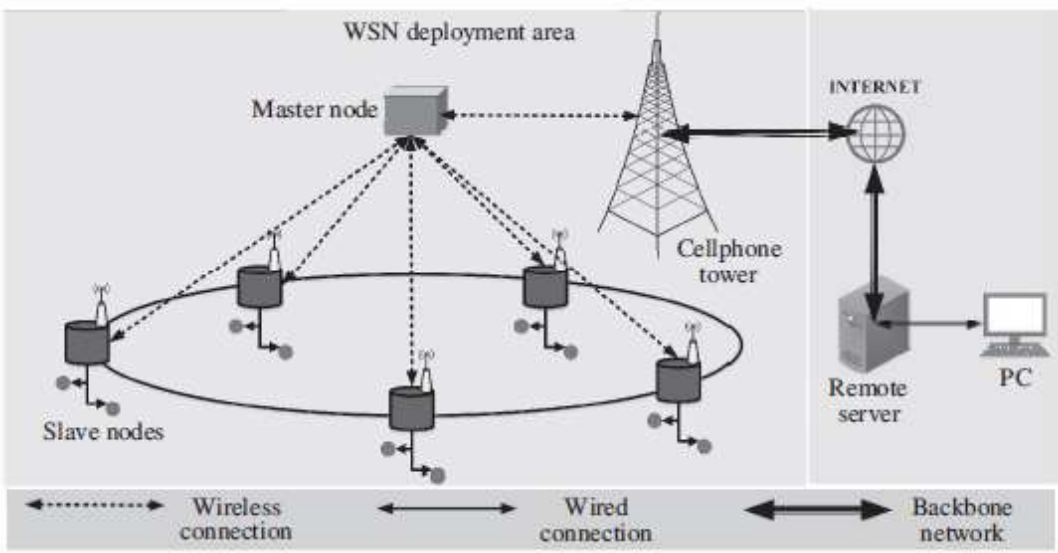

Figure 11: A typical WSN deployment
Source: Misra 2021, p 50

The WSNs are widely used. Nevertheless, some serious limitations are observed when implementing security imposed by resource limitations in memory, computing, battery life, and bandwidth. Security is a major challenge as IoT has number of "things" and the system itself can be very open. Some other distinguishing features of WSNs are: fault tolerance, scalability, log life time, programmability, affordability, heterogeneity, and mobility (Misra, 2021).

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4.4.2 Machine-to-Machine Communications

This concept, as the name suggests, entails a scheme of communication between two or several machines without human intervention. As Misra (2021, p 57) suggests, the task of any sensor network is the sensing of a physical environment and converting the acquired data into a tangible output in the form of numbers using sensors. In M2M communication the sensed data from a particular data is collected and then processed and evaluated. Based on the evaluation a decision is made for most valid and optimum course of action. In the end of process, actuators are put into operation to modify or adjust the sensed environment.

One of the early uses of M2M communication was undertaken by utility companies for meter reading. This made obsolete the requirement for an employee to go to every house to take the meter readings. M2M communication would collect the data and the billing was done every month automatically.

Modern microprocessors have enabled low-cost computing individually in each machine in a manufacturing factory. Unlike in the past, it is not necessary to send data to a central server and compute what needs to be done with all the available data. Each device and machine can pass information to other connected machines and decide for the optimal action to be taken.

4.4.3 Cyber Physical Systems

Cyber physical systems (CPS) integrate sensing, computation, control and networking into physical objects and infrastructure. They are connected to the Internet and to each other. These systems operate in a highly multidisciplinary domain that requires knowledge from a variety of disciplines, including mechanical, electrical, computing, electronics, and others (Misra et al 2021 p 65). They are primarily intended to monitor and control physical processes associated with enterprises and industries. The concept of human-in-the-loop, which is an intrinsic feature of many CPS-based solutions, is the most interesting aspect of CPS. The human-in-the-loop notion essentially means that humans are involved in the CPS control

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cycle. The inclusion of a mandatory feedback system distinguishes CPS from other paradigms such as WSN and M2M.

A CPS's typical operation contains the components depicted in figure 11. The sensory system detects the surrounding environment. Several networked sensors generate data for the environment at the same time, which is transferred over the Internet to a processing and control unit. Feedback is delivered to the actuators controlling the condition of the environment for which the sensed data was transmitted based on the intelligent monitoring and control algorithms in the control unit. The changes are sensed once more and forwarded to the controller using the previously configured flow. The algorithms determine whether or not the desired state of the environment has been attained, and they continue to deliver updated feedback to the actuators until the required state has been obtained (Misra, 2021).

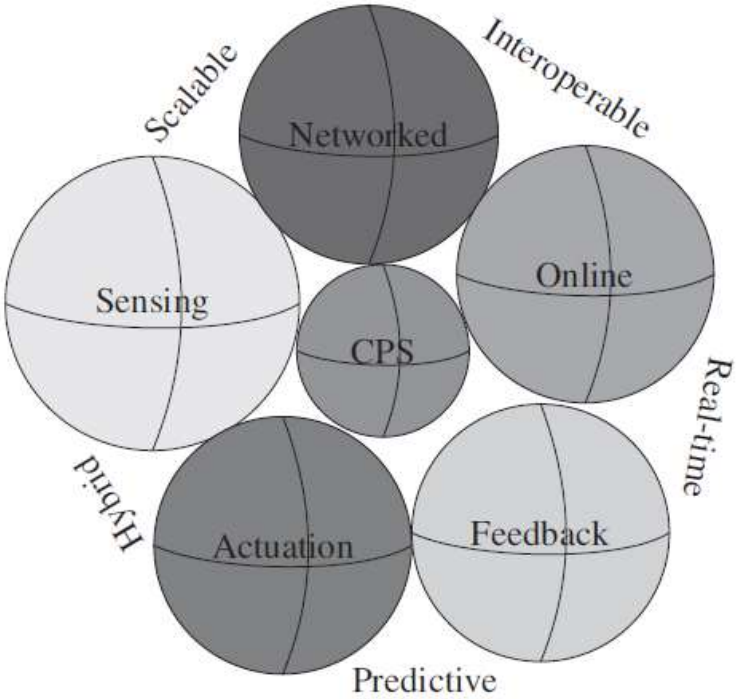

Figure 12: The basic overview of CPS features
Source: Misra, 2021, p 66

Some features that generally characterise CPS are: Real timeliness, Intelligence, Predictive, Interoperable, Heterogenous, Scalable, and Secure. The real timeliness is required for effective control of the area of deployment. Intelligence and adaptive decision making are essential for

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upkeeping the CPS-based functionalities. The predictive feature of CPS enables projection of outputs and events based on past behaviour under similar constraints and situations.

Interoperability or compatibility of the CPS allows smooth interaction between all software and hardware deployed. Often these come from different vendors and manufacturers and need seamless integration.

Heterogeneity of CPS is reflected in different types of actuators, sensors, processors, and data formats being used. Scalability is required to accommodate the bandwidth used in various sensing types (scalar or multimedia). Security of CPS is utmost important as all traffic flows through a network and eventually over the internet. Therefore, care is required to block unauthorised use or hijacking of CPS.

The above characteristics of CPS are reflected fully in the IoT as it has developed out of CPS.

4.5 Evolution of IoT

The IoT, as we see it today, is a result of a series of technological paradigm shifts over a few decades (Misra et al 2021 p 80). The key part of IoT is to provide inter-device communication across the globe. Today, the IoT can provide seamless connectivity between objects using Radio Frequency Identification (RFID). The foremost goal of IoT is to make the environment intelligent (Alam et al, 2020 p 7). Due to the concept of digital electronics, micro-electromechanical system, and nano technology etc., the existence and functioning of IoT environment is possible. All these technologies come together to provide the ability of capturing data, providing connectivity, computing and storing data for usage. The sensors, actuators, RFID, Bluetooth and WSN etc. are embedded into physical items to turn them into “SMART” objects. These smart objects use IoT to communicate. A object is termed smart if it is capable of describing its own possible interactions, having the ability to sense, compute, and communicate wirelessly.

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An object or device is classified as smart object on the basis of characteristics consisting of sensors/actuators, memory, communication device, power source, and processing unit.

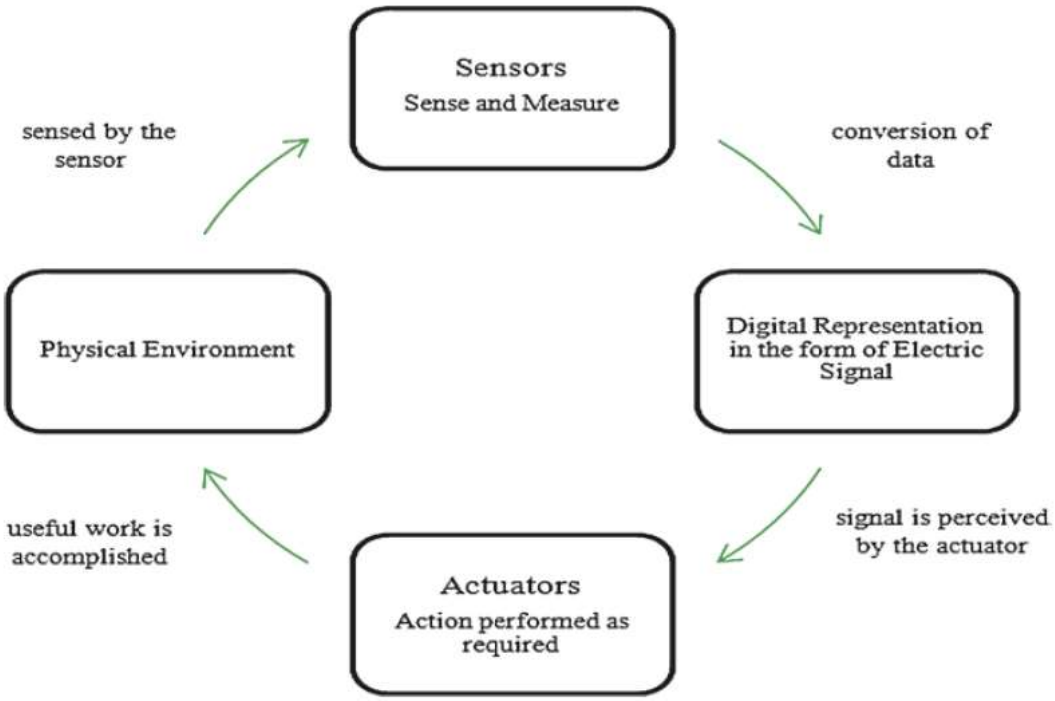

Figure 13: Relations between sensor and actuator
Source: Alam et al, 2020, p 10

Sensors embedded in the devise helps the smart object in sensing and measuring the changes in the environment. This could be the sensor embedded in an electrical motor to sense or measure its temperature. The measurement is converted into digital representation and is passed onto some other computational unit for use by other devices. A variety of sensors are available to measure different quantity and quality of the physical and virtual things in the environment.

The actuators are compliments to sensors. The data arising from sensor is processed, analysed, and used to produce productive results. The sensed data/information is used now to trigger actuators to accomplish a particular task. For example, a sensor on the motor will detect and measure the changes in the motor temperature. Eventually the controller can trigger the actuator, which could be a pneumatic piston to pen the ventilation window.

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4.6 Conclusion

The Internet of Things is a network of interconnected computing devices, mechanical and digital machinery, or people with unique identifiers. It has the ability to transfer data without human-to-human or human-to-computer interaction. The fundamentals of IoT are collecting inputs through sensors that measure motion, temperature, air quality, light, and almost anything one can think of. Information is collected from a number of sources, analysed together for a particular action, and used to trigger other machines or any kind of operation without human interference. IoT can connects devices with other devices by means of IoT platforms.

At the first stage of IoT the signals flow from hardware, i.e., machinery to software. In the second stage, the information flows back from software to hardware. As the data collected from the machines is huge and analysing it requires high computer power, the cloud computing is used. The more the data is collected, the accurate will be the analysed results.

The IoT is applied in elevators by utilising the parts and components which have embedded sensors and on/off switches. With AI and data analytics the signals collected are analysed and useful information prepared. In the end, this information directly transferred to machines or an interface such as display on a dashboard for humans.

A simple example of IoT application is watering the soil in a farm. A farmer can use a moist sensor dug in the soil to check if the water is adequate. Watering too little or two much is bad for the crops. Instead of farmer watering the system, the sensor can be made to trigger the irrigation system automatically when the soil moisture drops to a certain level. However, the IoT can receive information on weather forecast through its internet connection. Thus, it will know when it is going to rain and decide not to water the crops as they will be watered by the rain anyway.

Without a question, the Internet of Things is currently being implemented in a number of areas. As Misra (2021, p 306) suggests, the IoT technology has revolutionised the industrial as well consumer sectors rapidly since its inception. According to Vilmate, a software development company, "… IoT technologies are successfully re-engineering businesses and modifying

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optimal ways of running them. These technologies affect nearly all the existing industries: healthcare, insurance, smart buildings, manufacturing, transportation & logistics, retailing, and more[22]". The real power of IoT is in the concept of both collecting information and acting on it without the need for human interference.

[22] https://vilmate.com/blog/the-internet-of-things-future-is-coming-5-iot-trends-for-2018/ [accessed 10.01.2022]

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CHAPTER 5
IoT OF ELEVATOR MAINTENANCE

> Don't find customers for your products. Find products for your customers.
>
> Seth Godin, American author

5.1 Introduction

It is typical for industrial companies to provide after-sales customer services in the form of maintenance for their equipment, spare parts sales, software upgrades, and more. The IoT now has opened new proportions for such services provided by industrial companies (Friedli et al, 2021).

Maintenance contract for an elevator includes all kind of related work: servicing, attending breakdowns, replacing minor parts, and also inspecting the elevators for safety and performance. How often an elevator needs servicing was mostly determined by the OEM, which in turn was based on the test results during the design phase of the components. The maintenance work and its process required human judgment and expertise.

How does this change with the IoT of elevators? What do the elevator companies offer to the customers that entice them to pay for these services. And which are the hardware and software used by the leading companies? This chapter investigates key issues of how IoT is being implemented in elevator maintenance process and business.

5.2 IoT of Maintenance

Matt Bellias writes in his blog at IBM, "The science of maintenance is on the cusp of a transformations[23]" because of IoT (Bellias, 2017). At the beginning of 2022, there is ample indication of IoT being used in maintenance of plant machinery. The benefits of using IoT for maintenance is well documented and elaborated. As the Industry 4.0 is advances and

[23] https://www.ibm.com/blogs/internet-of-things/maintenance-evolution-prescriptive/ [accessed on 11.12.2021]

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the IoT as well as new Big Data solutions emerge, predictive maintenance begins to play a strategic role in increasing operational performance of any industrial facility (Vicencio et al in Peñalver and Parra, 2020, p 121). Compared with planned or other types of maintenance processes, the predictive maintenance allows reducing equipment faults or service disruptions. This undoubtedly contribute to increasing efficiency and reducing cost. A study published by Roland Berger in 2020 claims that predictive maintenance decreases the downtime by 14-19% and save 5-10% cost on repairs[24].

IoT implication for maintenance is straight forward: the new types of sensors embedded in the equipment and in their components provide information about the condition of the equipment, how extensively they are getting used, and how worn-out are they. This information is collected in different circumstances and from different machines of same category as the big data. The saving, sharing, and analysing all these data is vital (Castillion et al, in Butun, 2020, p 161). This process is used for different purposes. Predicting the next maintenance is one of them.

5.3 Application Method in Elevators

Most part of the elevator components have sensors or contacts. As an example, the closing and opening of the doors is supervised by their individual lock contact. Similarly, the brake contacts and sensors, temperature sensors in the motor, etc. are being used even before the IoT. Their operation is observed and locally recorded, supervised by the elevator controller. If these components are connected via internet in a practical and useful way, we have the IoT of Elevators.

[24] https://www.rolandberger.com/en/Insights/Publications/Game-changers-in-the-elevator-market.html#!#&gid=1&pid=2 [accessed on 08.03.2022]

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Data Collection
Component data, such as door movements, trips, power-ups, car calls, error codes, etc., is collected connected elevators worldwide.

Precise diagnoses
This data is sent to the cloud. Algorithms analyse patterns and compute the equipment's operation. Remaining lifetime of components is determined.

Predictive intervention
Precise diagnostics are delivered to the technician in real time, indicating where intervention is required.

Figure 14: The flow from data collection to predictive intervention
Source: Thyssenkrupp Elevators

The basics of IoT for elevator maintenance consists of

- Collecting data and real time information by means of embedded systems (processors, sensors, and communication hardware).
- Transferring the Data to central computers.
- Big data and advanced analytics / artificial intelligence.
- Feedback to maintenance operations.

The general idea is to collect data from as many elevators as feasible, then utilize the big data and machine learning to determine when certain maintenance operations are required. When there is enough data, it is even possible to start forecasting breakdowns and thereby eliminate them through proactive maintenance management.

IoT has multiple uses in elevator maintenance. Using the operational data for analysis or predictive AI, it is now possible to predict when the equipment needs maintenance. The maintenance trend is moving away from "planned, routine" maintenance practices towards "predicative" maintenance practices. The idea is to reduce physical maintenance visits and at the same time streamline operational processes and workflow.

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5.4 Prescriptive Maintenance and Pro-active Troubleshooting

The switches and sensors of elevator components (Chapter 2) transmit information on their condition. This has enabled to move beyond planned maintenance, which was previously associated with high material and labour costs, inefficiencies, and lower operational time of the elevators (Bendl and Schiller, 2021, p 160). They state that the codes and standards have the framework for accommodating the new maintenance process, which is prescriptive as against the planned one. Following Bendl and Schiller (2021), "Since prescriptive maintenance doesn't just analyse but also recommends suitable courses of action, it constitutes a paradigm shift that's making it possible to move from a prediction of when an event happens to a respective preparation of what has to be done".

Normally when an elevator stops operating or malfunctions, the building residents or the caretaker would notice it and inform the maintenance contractor. This can be termed as reactive troubleshooting. Using the big data and algorithms, the IoT of elevators provides advance information about the wear and tear of the components. This gives time for the maintenance contractor and the owner to react. In October 2021 KONE reported they could solve 75% of the expected breakdowns interactively on elevator where IoT is installed.

Regarding the repairs, the owner can also schedule it so as to have least disturbance to the elevator traffic. He is thus able to plan future costs based on the advance information of potential repairs or breakdowns.

With the help of IoT it is possible now to supervise and ensure that elevator components and the entire system is functioning as expected. The periodic maintenance, which was common up until now, is slowly giving way to predictive/adaptive maintenance based on big data and artificial intelligence.

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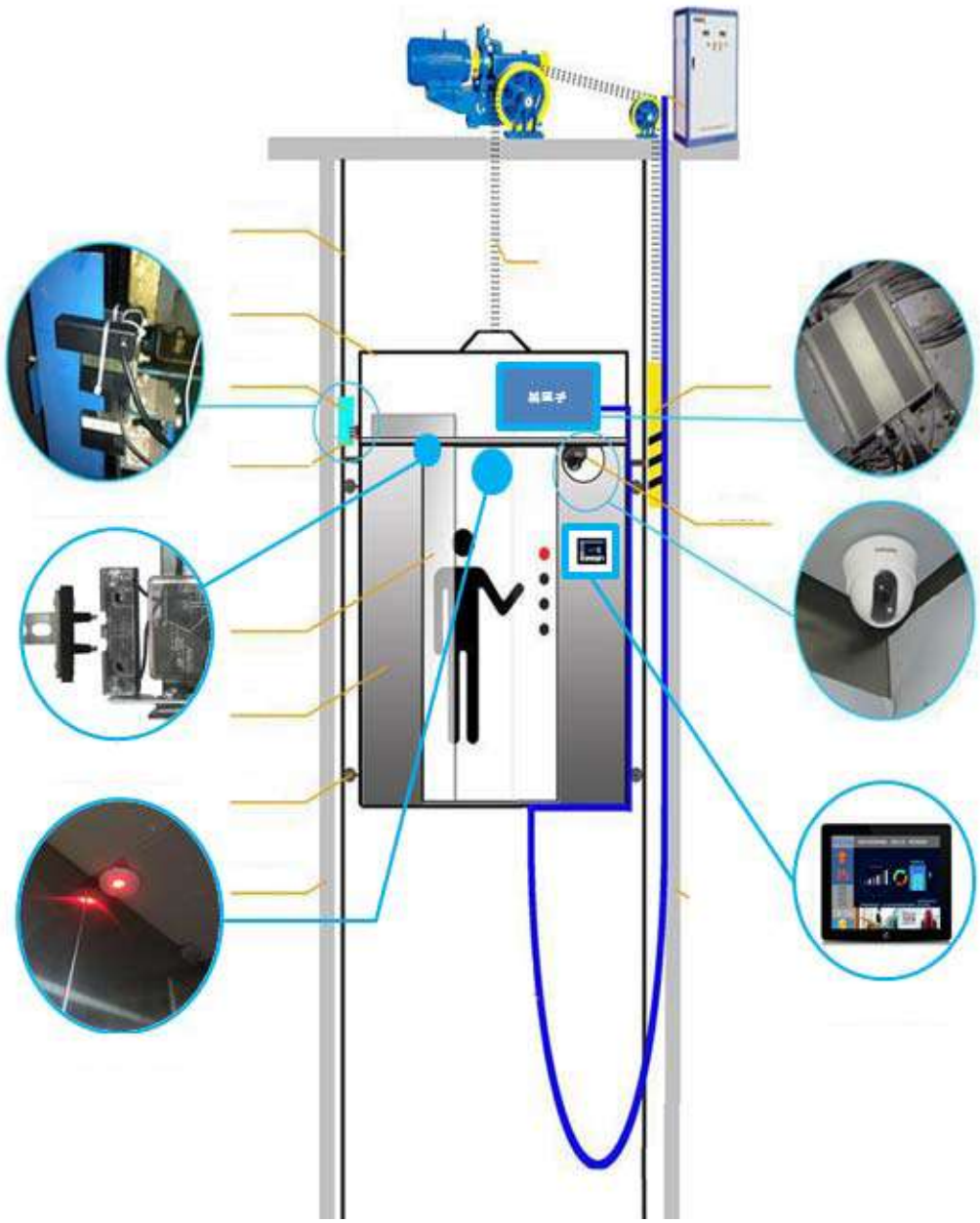

Figure 15: Sensors for IoT monitoring
Source: http://iotconnect.com.sg/smart-elevator/

Penny (2018) states the following ten benefits of IoT in elevators:

1) Monitoring Operating Conditions of the elevators
2) Predictive Maintenance (forecasting)
3) Remote Diagnostics and Troubleshooting (avoiding call backs)
4) Real-Time Notifications (useful for both the maintenance company and the customer)
5) Behavioural Insights

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6) Avoided Downtime
7) Increased Product Reliability
8) Flexible Communication Standards
9) Less Frequent Replacement
10) Enabling Better Facilities Management (monitoring).

5.5 Monitoring and Information Access to Customers

Whereas in a production plant or factory the machinery is owned by a company, the elevators are normally owned by third parties. At first this situation seems to be problematic for the companies. They might not see benefits for them for sharing information they collect via IoT with their customers. There are also technical and cost issues.

However, the elevator companies seem to have found a great business opportunity for them. They offer access to customers for additional charges. Their selling argument for these services is that the customers are able to see in real time the performance and condition of their elevators. The customers are able to access information via Apps on smart phones or directly via a personal computer.

This access to information has several benefits for customers having multiple units, such as an airport or a hospital. The customer or their facility managers are able to know directly if the elevator needs a maintenance or repairs. The customers are also able to see the history of past works or maintenance visits.

While offering the IoT services, the elevator companies underline the benefits to customers. Some of the convincing points they put forward are the real time monitoring of elevators, maintenance only when required as against the fixed interval, and ultimately cost saving.

5.6 IoT of Elevator Maintenance by Leading Elevator Companies

As mentioned earlier, all elevator OEMs are now offering IoT hardware and services to their customers. They offer it under their own unique product and marketing name. All the major companies have established a cooperation with other IT companies for cloud computing, hardware, and as well as bigdata analytics.

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5.6.1 Schindler

Schindler sells its IoT services under the marketing name "Schindler Ahead" and calls it "The Building Internet of Things". Its selling strategy is that the customers will benefit from better access to real-time equipment data, which in turn will enable the customers to identify possible service issues and help better cost planning. As the customers will have insights about component lifetime, it will allow for better planning of repairs.

It says that "Data generated from connected equipment provides advanced analytics enabling Schindler to predictively identify, analyse and resolve possible service issues before they occur. This reduces and eliminates downtime, saving you valuable time". With their app "Schindler Ahead ActionBoard", Schindler offer building owners and facility managers interactive access to operational, performance, and commercial data about their equipment portfolio. Schindler Ahead is able to run apps, stream multimedia content, and even handle emergency voice calls.

Their FieldLink is the tool that connects their service technicians with Schindler Ahead. Through this tool they are informed about their next maintenance task or the next call back to attend. The Schindler Ahead real-time analytics provide gives enables them the predictive maintenance.

Schindler manages data centrally as well locally. The analysis of both together gives them better insight into the patterns and correlations that arise from factors such as weather variation's due geographic locations.

Schindler Ahead uses 4G/LTE connectivity. It uses Edge Computing and Edge Analytics for rea-time analytics, data filtering, and data knowledge generation at data source. It is partnering with GE Digital for operating system.

5.6.2 OTIS

Otis, the number one elevator company, has released it's IoT service under the brand name Otis ONE. It is cooperating with AT&T for the IoT Technology. According to Perry Zheng, President of OTIS China, their "offerings bring field professionals and customers into the data-insight-action loop and make elevator systems more visible and predictable".

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According to Otis, their IoT solution provides transparent information, proactive communications and predictive insights. It offers continuous visibility of the customer's full elevator portfolio and allows field professionals and customers to drill down into precise unit-specific information. As a result, the Otis IoT Solution helps field teams make faster and more informed decisions and enables Otis to improve elevator performance and reduce downtime for building owners and passengers.

Otis is building on their foundation of historic data and leveraging the IoT to take to suit customer's individual needs. They too collect data automatically and interpret in the cloud via big data analytics. These insights provide continuous visibility to the customer their units and form predictive algorithms that improve overall performance. The goal for Otis is faster response, more-informed decisions and stronger relationships between their team and their customers.

5.6.3 KONE

KONE calls it IoT service KONE 24/7 Connected Services. Like other OEMs, also KONE presents its services as "state-of-the-art diagnostic technology" and "round-the-clock monitoring" that benefits their customers by saving time money by predicting problems before they happen. It further offers its customers an online dashboard to keep them informed on the status of their equipment. The customers get transparent information based on which they can plan the required work for their elevators. By late 2021 KONE has 200,000 connected elevators worldwide.

The idea is to offer information to the customers about upcoming maintenance needs and identify any potential issues before they cause problems. KONE also offers to connect the building doors to their cloud-based service. They declare by using their artificial intelligence-based analytics smarter decisions are made for predictive maintenance. Their technicians get through IoT tools timely alerts about the work to be completed.

KONE is partnered with IBM and uses it's Watson platform. Like other elevator companies, also KONE's services are mainly used for

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maintenance. The data is collected in the cloud, analysed, and the information used by both KONE and its customers. The IoT allows them round the clock monitoring of the equipment in their portfolio.

5.6.4 Thyssenkrupp Elevators

Thyssenkrupp (TK), which can be said as fourth largest elevator company in the world, has teamed with Microsoft. TK calls it's IoT services MAX. It spent two years with Microsoft developing MAX and started offering the same in 2015.

Based on Microsoft Azure cloud platform, TK uses the combination of cloud technology, Big Data and machine learning to make their IoT based maintenance "an invaluable asset for building owners and custodians". As per TK, their MAX gives their customers the benefit of data-driven maintenance service based on clear and transparent data and hard facts. The customers readily get real-time information about elevator's operations, performance and service history. TK further claims that their "IoT solutions dramatically increase elevator availability by reducing out-of-service situations through real-time diagnostics[25]".

At the beginning of 2020, TK said that they have installed their IoT services on more than 82,000 elevators in the U.S. and 128,000 elevators in 10 countries worldwide. The key slogan from TK is "digital service packages for improved building management and maximum elevator uptime". They offer 3 different service offers under MAX: Plus, Pro, and Premium.

MAX Plus provides property managers with real-time elevator status updates and traffic patterns; MAX Pro allows technicians to take immediate action when an equipment failure has been detected to reduce equipment downtime; and MAX premium provides the service of predictive maintenance. Below is an overview of their services and costs[26].

[25] https://max.tkelevator.com/global-en/ [last accessed on 28.01.2022]
[26] https://www.tkelevator.com/us-en/service/max-digital-services.html [retrieved on 22.02.2022]

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Solution Features	MAX Plus	MAX Pro	MAX Premium
IoT connection with MAX virtual coach	Yes	Yes	Yes
Web portal and mobile app access	Yes	Yes	Yes
Email notifications	Yes	Yes	Yes
MAX traffic statistics	Yes	Yes	Yes
Real-time status and failure alerts	Yes	Yes	Yes
Auto response / dispatching	No	Yes	Yes
Social distancing service	No	Yes	Yes
No charge running on arrival guarantee	No	Yes	Yes
MAX team monitoring (concierge)	No	No	Yes
Predictive intervention	No	No	Yes
Monthly subscription	$10	$35	$95

Table 7: Typical services and their monthly costs
(Source: Thyssenkrupp)

The services for IoT are in addition to the maintenance costs. In this way the IoT enables to generate a monthly revenue for the elevator company.

5.7 IoT Services by non-Elevator Companies / New Entrants

While the leading OEMs offering IoT based services to their existing customers, a few specialised companies have entered this market who are offering these services to all both the customers and as well as smaller elevator companies.

This certainly is going to be competition that can be ignored by the big players. The service from these new entrants has certain advantages. Their hardware can be installed on almost any type of standard elevators. This is especially beneficial to owners who are having several buildings with elevators from different OEMs. In this case they can have one type of

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hardware installed for all elevators and they are able to monitor their elevators using only one app.

In Europe, the TÜV SÜD offers IoT services through their brand "Lift Manager". TÜV SÜD is a notified body, an organisation authorised to inspect elevators. They have invested their expertise and know-how in Lift Manager, which facilitates predictive maintenance and monitoring of elevator condition.

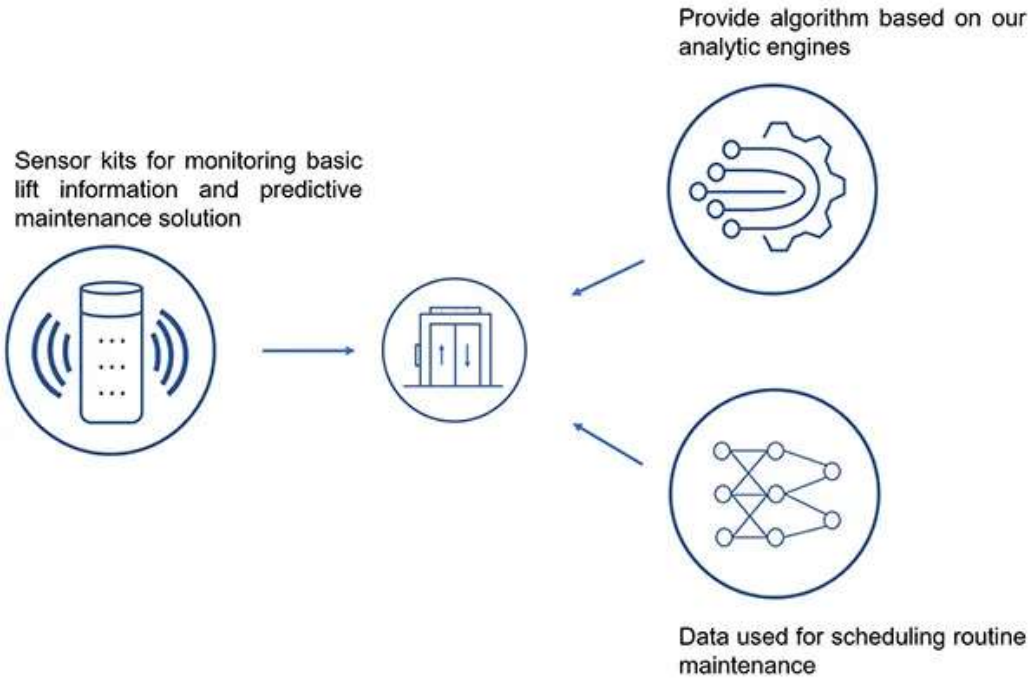

Figure 16: Overview of IoT service by TÜV SÜD
(Source: TÜV SÜD)

TÜV SÜD claims that their IoT services help save on maintenance costs. It is claimed IoT predictability can potentially reduce maintenance visits and thus save cost for maintenance. As with the OEMs, it is possible for the elevator owners to monitor their elevators and have a control over the operating and maintenance costs[27].

[27] https://www.tuvsud.com/en/industries/real-estate/lifts-cranes-and-conveyors/lifts-and-escalators/lift-manager [retrieved on 12th January 2022]

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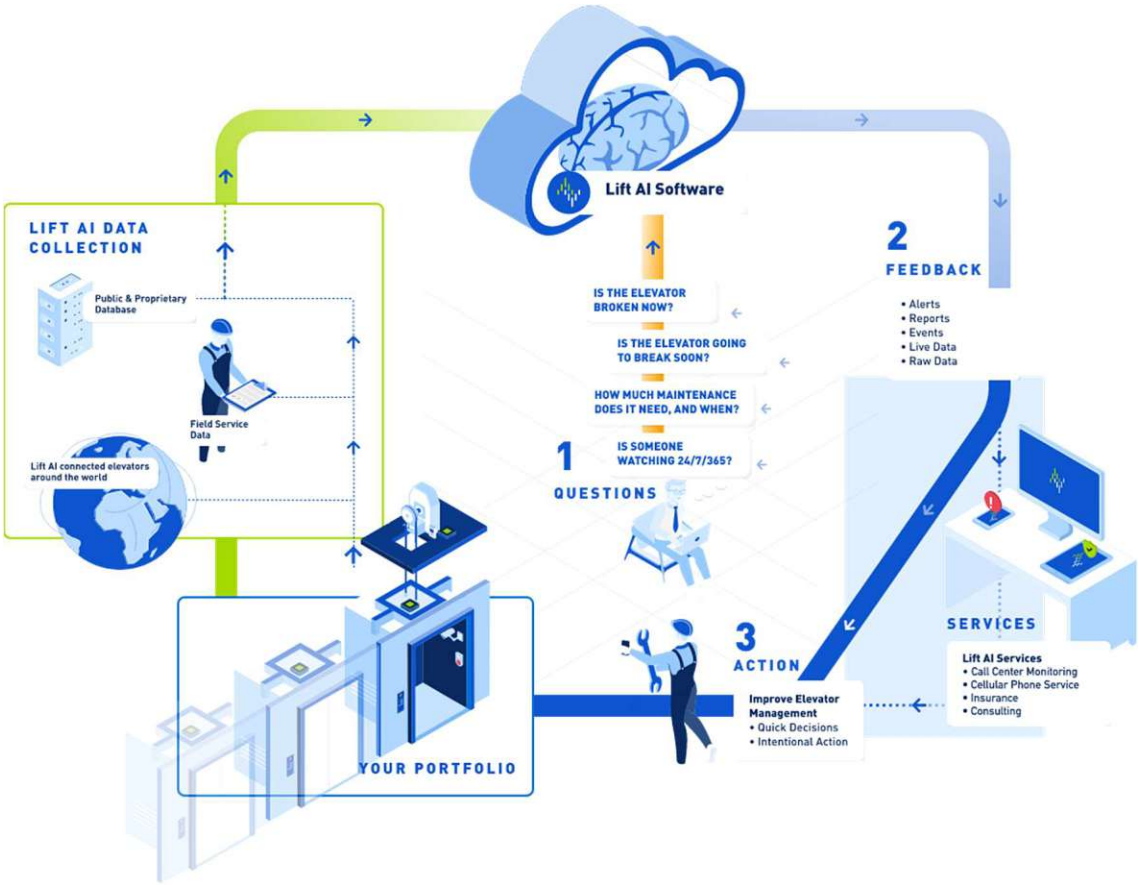

Figure 17: Overview of elevator monitoring
Source: Lift AI[28]

The Lift AI seems to be a budding company in the USA offering a full package of IoT facilities. Their hardware is to be installed on the cabin. It connects through its own cellular network and transmits data to a public and proprietary data base. Using their own artificial intelligence software (Lift AI), it gives detailed feedback. This includes alerts if the elevator has stopped, regular reports, log events, as well as live data. The customers are thus able to see the performance of their elevator. The Lift AI enables them to make the decision and take action such as calling for maintenance.

The percentage of new installation compared with the existing elevators are very small. Hence, this market seems to be quite attractive to newcomers and independent providers of IoT. In this area not only smaller but also renowned companies such as BOSCH are delivering the hardware

[28] https://www.liftai.com [retrieved on 10th January 2022]

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as well as software. The solutions provided by smaller companies are sometime pretty straightforward. BOSCH has developed a pair of sensors one of which is placed on the cabin, and one is to the door[29]. These are plug-and-play units that are installed within 30 minutes on the cabin roof. Their hardware does not require a wired connection to the elevator control system and may be installed on any elevator, regardless of brand or model. The unit has acceleration sensors to detect and record elevator condition data such as current position, travel movements, the number of door openings, and any unscheduled elevator downtimes. All malfunctions are documented in a traceable manner.

5.8 Monitoring with and without Sensors and IoT

Many elevator components have embedded sensors, such as the temperature sensor of the hoisting motor. Some other sensors are actually the contacts and safety switches which get actuated in certain conditions. Depending on the function, the activation of the sensor or switches would either delay (time until the cooling of the motor) or cause a permanent breakdown which requires human interference (overspeed governor switch activated). All these sensors and contacts are connected to elevator controller. The IoT interface transmits the signals from these sensors and switches to the cloud enabling constant monitoring, analysis, and ultimately the enabling timely and faster decisions by the owner and maintenance contractor. The timely decision is required for predictive maintenance. And faster action is required in case of a breakdown or if a breakdown is about to happen.

Below is a table comparing the process and actions without and with IoT. It gives an overview of important components and their related function and gives an idea how predictive maintenance is enabled and how a faster call back response is possible.

[29] Statement from Mr. Michael Baer, Senior Product Manager at Bosch Service Solutions. Source: https://www.smart-industry.net/smart-elevators-giving-iot-a-lift/ [last accessed on 06.01.2022]

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Component and Function	Impact	Detection without sensors and IoT	Detection with sensors and IoT
Lubrication of elevator guide rails.	Cabin vibration and noise during travel. Higher energy consumption.	Report of noise and vibration from the users or building caretaker. Detection by the technician during the planned maintenance visit (earliest once in every month).	Vibration monitoring sensor on the cabin. Detection of higher power requirement by the motor. Immediate information to the maintenance contractor, responsible technician, and to the client.
Brake. Required to hold the elevator at rest and to brake and hold in case of emergency stop during full-load and downward acceleration.	Critical safety issue. The elevator can move away from the floor while loading and unloading with open doors and people can get crushed. Potential hazard of cabin crushing on the buffers.	Visual checks or error readings from the controller during periodic maintenance. Manually initiated functional tests during periodic inspection. Several months gap between the visits/tests.	Sensors and contacts measure the brake liners, brake tension, and function. Once in a day automatic test for brake function. Immediate information in case of failure.
Door operating motor and system. Safe and smooth door closing and opening.	If the doors are blocked, it will increase travelling time and cause delay. Eventually there will be a breakdown. Door noise and vibration will be irritating.	Visual checks of door rollers, contacts etc. during periodic maintenance. Calls from the client/users about malfunction.	Sensors and switches monitor and measure the door closing and opening time, door motor temperature, and door and lock contacts. Continuous analysis of the data. Automatic message, pinpointing on which floor the door is having a fault.

Table continues.

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Table continued from previous page.

Component and Function	Impact	Detection without sensors and IoT	Detection with sensors and IoT
Sufficient traction is required in all conditions: full load down, empty car up, acceleration and deceleration, emergency stop, cabin or counterweight resting on buffers …	Slippage of ropes, difference in levels between the car and the floor, loss of traction and uncontrolled movement of the car.	Periodic tests, usually once a year.	Continuous monitoring for rope slippage. Detection of wire brakes in traction ropes. Based on the signals from the controller, the AI algorithms are able to state the traction condition.
Monitoring the primary safeties.	Malfunction or breakdown.	Some of the malfunctions (such as the condition of the pit buffers) can be detected during maintenance or inspection. A breakdown is reported by the caretaker or by telemonitoring, if installed.	Constant monitoring of the safety circuits. Exact information to maintenance contractor regarding which safety contact is open. Technician can come prepared to attend the particular call back.
Report of breakdown.	Non availability of the elevator.	Normally noticed by the caretaker after some time. He reports this to the maintenance contractor by a call or email. The maintenance contractor will inform the responsible technician.	Immediate detection by the controller and information flow directly to the maintenance contractor and to the caretaker through IoT interface. Autonomous and immediate action by the technician / customer.

Table 8: Monitoring with and without IoT and Sensors

5.9 Conclusion

Elevator maintenance business and the process has evolved over the years, in tandem with the design and ever evolving technologies. The

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various forms of maintenance have included service for prevention of breakdowns, attending breakdowns, usage-based, condition-based and task-based servicing. Using IoT, cloud computing, and big data and a new form of maintenance process, the adaptive maintenance has arrived.

The study in this chapter shows that the maintenance related decisions are shifting to data analytics and artificial intelligence. This is possible as the using most of the existing sensors and contacts embedded in their components. The controller, the brain of the elevator, is itself able to a great extent which data need to be transferred. This data is transmitted through internet, which could be analysed in cloud computers.

Elevator maintenance companies are racing to offer services based on IoT to their customers. They sell IoT hardware and associated services. This enables the customers to monitor the condition of their elevators in real time. They can then take immediate and accurate decisions related to their elevators. Based on the information transmitted by the sensors, the maintenance process is getting shifted from periodic to a predictive one.

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CHAPTER 6
ANALYIS AND CONCLUSIONS

> Don't find customers for your products. Find products for your customers.
>
> Seth Godin, American author

6.1 Introduction

The research in this thesis comes to the conclusion that the IoT of elevators has initiated fundamental changes to the process as well the business of maintaining elevators. Thereby it is going to affect the three key stake holders: elevator maintenance companies, elevator owners and the users, and the elevator technicians and inspectors.

The analysis showed that the IoT of elevators will enable the customers to have a better supervision of their units. Thereby they are able to monitor the operation and health of their elevators in real-time and also take decision with regard to maintenance, inspection, and repair. Until now, such decisions were based on the recommendations by the maintenance companies.

The study also foresees that because of IoT of elevators, the maintenance companies will move away from a rigidly planned maintenance programme they used to offer so far to the customers. Instead, they will offer a predictive and adaptive maintenance programme based on the real use and condition of the elevators. For the companies this will help to increase efficiency and reduce cost. They will pass at least some of it to the customers. Hower, the IoT of elevator also bringing risks to the established companies with strong competition from small and new entrants.

The investigation further shows that the IoT is having an influence on the job of maintenance technicians and inspectors. On the one hand there is a risk that their knowledge and expertise will become redundant. On the other side, they are able to make use of IoT data analytics to support their tasks such as safety inspection and trouble shooting. The IoT can also help them to become independent maintenance service providers with direct dealing with the owners of the elevators.

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6.2 Overview and Comparison

The IoT of elevators has enabled new services which are very helpful. However, it might also disregard some human services. The table below makes a key comparison for a better overview.

	With IoT	With Telemonitoring	Without IoT or Telemonitoring
Possibility for direct and real time monitoring by customers.	✓	✗	✗
Full range of information regarding the condition to the maintenance contractor.	✓	✗	✗
Possibility of direct information to the responsible technician.	✓	Partially	✗
Direct and immediate reporting of a breakdown.	✓	✓	✗
Analysing the condition of a component based on the average usage of identical components on some other elevators.	✓	✗	✗
Predicting breakdowns and the requirement of maintenance.	✓	Possible with additional human analysis.	Possible after an inspection at site by the technican.
Personal interaction with the customers by a technician to understand the need of a particular customer.	✗	Partially	✓
Judgements requiring human experience, such as knowing traffic condition to a site at a particular time.	✗	✗	✓

Table 9: Comparison of IoT and Telemonitoring

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6.3 New Technologies, Old Business

Elevators were always maintained to ensure safety, smooth functioning, and to enhance the lifespan of the equipment. The maintenance business is a profitable one. However, it is labour intensive and requires well qualified technicians and inspectors.

The research shows that the future of elevator inspection and maintenance process is changing. The elevator companies are able to analyse the elevator behaviour based on the data collected through IoT. This enables them to judge the optimal maintenance requirement. Compared with the process now, which is routine planned maintenance, the predictive maintenance can save labour costs.

According to KONE, a leading elevator company, the traditional elevator maintenance is calendar based, with various components serviced or parts replaced based on estimated times of wear and tear[30]. KONE says that this has a drawback. That is because the same process is applied for all elevators, irrespective of several other factors: extent of use, environmental conditions, age of the elevator – just to mention a few. With the old method the customer might end up paying for services his elevators don't need. Or probably his elevators need frequent maintenance because of higher use. In the case of fewer periodic maintenance visits, the elevators might breakdown often, causing transport disruption in the building.

The IoT of elevators, on the other hand, collects data from elevators round-the-clock through information transmitted from the elevator controller and other embedded sensors in the components. The cloud computers then analyse this information with analytics software, namely, artificial intelligence. In the end, the IoT is able to predict when a problem is approaching. The maintenance plan is then adapted accordingly. The building owners are informed about the plans. Altogether, this can increase the efficiency of building's vertical transportation system.

[30] https://www.kone.com/en/news-and-insights/stories/IoT-makes-its-mark.aspx [accessed 12.12.2021]

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6.4 Business Opportunities for Elevator Companies

The investigation shows that all leading OEMs are now offering IoT based maintenance services. Some of them started early, TK Elevators as far back as 2015, and all with their own brand names. Compared with smaller companies, or newcomers offering only IoT service, the bigger companies have no doubt advantages at multiple fronts.

One of the advantages they have is the amount of data. The leading OEMs have all over the world in the range of millions of elevators in their maintenance portfolio. If a majority of these are connected through IoT, they are able to collect more data from different types of elevators as well under different conditions they are operating. The more data is available the accurate the analysis will be. Undoubtedly this helps them for far accurate analysis and ultimately provide better maintenance solutions to the customers.

The leading OEMs are now integrating IoT hardware in their new elevators and are offering IoT based maintenance along with the sale of new elevators. Their business policy is to bind the customer at the time of selling a new lift by installing their own hardware and the software. In a study published by Roland Berger (Game Changers in the Elevator Market, 2020), it is expected that the predictive maintenance and other new technologies "will change the game for incumbents and potentially pave way for new entrants".

All leading companies are trying to strengthen their market position by offering IoT based services. By offering newer maintenance related services, they are able to increase their revenues significantly. The study from Roland Berger (2020) comes to the conclusion that customer saatisfaction and willingness to pay for a better service experience increases as a result of predictive maintenance. In an investors conference on 28.10.2021 Henrik Ehrnfooth, President and CEO of KONE, stated that customers are ready to pay for the IoT based services[31]. "It is transparency

[31] https://www.kone.com/en/Images/KONE_Q3_2021_Transcription%20-%2028%20October%202021_tcm17-110991.pdf [retrieved on 10.11.2021]

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for them. These services improve their (elevators') life and long-term asset management (of the building). This is an improvement compared with short term plans they had. Fledged digital services are contributing to our growth".

In a conference call with investors, Silvio Napoli, Chairman and CEO of Schindler, mentions that the customers where the IoT has been installed are "less risky" to leave Schindler. That means the customers could be really happy with the services offered and transparency they notice having IoT monitoring. It can also mean that IoT works as a barrier for leaving Schindler's maintenance contract and move to a price-worthy offer from a third party.

It is clearly visible that the leading elevators companies are integrating IoT into their mainstream business models in their own way. They are striving to achieve three goals: a) to improve their own maintenance process and increase efficiency b) to increase revenues by selling IoT hardware and related services c) bind customers to their maintenance contract.

The research further shows that the OEM elevator companies are not offering IoT hardware and services that for elevators of competitors or produced by third parties. This has given a business opportunity for new entrants whose IoT facilities can be used by all: elevator owners, smaller elevator companies, and even freelancing inspectors and technicians. Their hardware can be easily installed on an existing elevator, independent from who is the manufacturer. The research also shows that elevator owners have advantages in certain situations if they choose independent IoT facilities.

The study brings to light that smaller IoT companies can become a formidable competitor for the OEMs of elevators. One way of dampening this competition is to train their technicians in digitization so that there is an overall increase in service, quality, and efficiency.

6.5 Advantages for Customers

In high-rise buildings and building complexes the availability of elevators is extremely important for transportation. Well maintained and trouble-

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free elevators also crucial for the asset value of the building. The research shows that the elevator owners are eager to track the health and the availability of their elevators directly. The IoT gives them all information they need: the breakdowns, usage, and the next maintenance due. For this service they are ready to pay a premium over their monthly maintenance costs.

One other key benefit for the customer is that he can have higher trust in reports generated by IoT as against reports submitted by a technician. The technician can make a judgement based his knowhow and experience how much a component is worn out and when it might need a replacement. The IoT prediction, on the other hand, is based on tens of thousands of past cases. It has higher objectivity compared with human judgements.

The customers would be better off by taking services from independent non-elevator providers. This gives them independence and the ability to make decisions without being influenced by an elevator company.

All maintenance companies claim that because of IoT predictive maintenance is offered, which is cost saving. However, the research shows that this cost saving is not clearly explained. It seems to be somehow accepted that the predictive maintenance will be fewer visits to the sites than in the case of planned maintenance. However, the research in this thesis did not find any evidence that this is true.

6.6 Chances and Risks for Technicians and Inspectors

Currently it is the knowhow of elevator inspectors and maintenance technicians that helps to evaluate the condition and the safety of elevators. For that they spend quite some time on the elevator and carryout foreseen tests using appropriate tools. Now the IoT of elevators are collecting information on movements of the elevators. This helps to manage the required works and ultimately the inspectors might become redundant. The IoT can predict maintenance requirements and impending failures with a fraction of the time and effort it would take a human technician to perform that kind of analysis (Penny, 2018). Clearly, this is a potential risk for technicians and inspectors whose knowledge was their asset.

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Instead of following a standard work procedure for the maintenance, the technicians will need to follow the instructions generated by the IoT. The artificial intelligence will determine this based on the data it has not only from that particular elevator, but thousands of elevators. The IoT is certain to make accurate decisions.

Any new technology has the potential to disrupt the current status-quo. New technologies destroy jobs. But they also create new, better paid jobs where higher knowledge and skills are required. History has shown that the people who don't see this trend have lost. It is advisable that the technicians gain newer knowledge to remain fit in the market.

According to Schiller and Bendel (2021), "despite all the advances in machine learning, elevator and escalator service and maintenance, full digitalization is not able to cope with the complexity and change of the elevator and escalator service business by itself". In their opinion the maintenance will remain "human-centric", meaning that the role of technicians and inspectors should not be underestimated despite the massive advances in machine learning and the resulting predictive maintenance.

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6.7 IoT Services from non-Elevator Companies

Unlike the IoT from OEMs, these can be used on elevators different manufacturer. Although they might be not useful for high-rise complexes such as business centres and airports, they certainly have several advantages where they can be applied.

	OEM	**Independent**
Application	Mostly for OEM elevators only	Elevators of all manufacturers
Cost	High	Medium to low
Benefits for customers	The OEM has more data on similar equipment – possibly better application.	Can have only one app to monitor all the elevator he has.
Business opportunity for smaller elevator companies	The OEMs are generally not willing to provide.	Strong advantage in offering new services without the need to invest in new infrastructure.
Inspectors and technicians	Availability of in-house knowledge, if employed with OEM.	Possibility to become a freelancer.

Table 10: Comparison: OEM and independent service providers

6.8 Further Thoughts and Issues not Addressed

One issue that was not given attention in this thesis is the security and incidental risks in IoT. Unauthorised access to the IoT infrastructure can open a gateway for observing or even controlling elevator operation. Cyber criminals might use this to collect ransom by threatening to shut down the elevator transportation. Also, the customer data might be stolen. There is ample literature about the danger of security breach in IoT and the measure to prevent the same. The elevator companies do assure that they are extremely vigilance to protect customer data. Further investigation in this area is beyond the scope of this thesis.

An important is that might be worth investigating is if the elevator companies share data and insights which collect on the components is shared with its producer. This would assist them in quality and design

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improvement. Today no single elevator company is producing the components by itself. Majority of the components are manufactured by third party suppliers and directly delivered to the installation site. These include the guide rails, buffers, ropes, car and landing doors, speed governors, and almost every component used in elevator. The third-party suppliers can certainly make use of the data to improve their product quality.

One of the key ideas behind maintaining elevators is to prolong their lifespan. In the past, the lifespan of an elevator was expected to be as long as the building itself, especially for the key components. This was achieved by utilising solid materials, such as the thickness of steel to build cabin and doors. Currently, the life span of some subsystems such as the motor and controllers are reduced to 15-20 years. In such situation the whole maintenance business might need a re-evaluation.

Although the thesis answered some key questions, a few other related issues might need further investigation. Four such issues are: 1) How the component suppliers can use the data analyses from IoT to improve their products 2) How companies are managing the knowhow of their technicians to match the new technological developments. 3) Are customers preferring smaller independent companies offering IoT services only over the all-in-one services offered by bigger companies. 4) How the general trend of reduced lifespan on many components and subsystems is affecting the whole concept of maintenance. Finally, 5) how the IoT is going to affect the current codes and regulations concerning the maintenance of elevators.

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List of Abbreviations

ACVF	Alternate Current Variable Frequency
API	Application Programming Interface
CPS	Cyber Physical Systems
D2D	Device-to-Device Communications
HMI	Human Machine Interface
I/O	Input/output
IIoT	Industrial Internet of Things
IoEE	Internet of Elevators and Escalators
IoT	Internet of Things
IT	Information Technology
M2M	Machine-to-Machine Communications
OEM	Original Equipment Manufacturer
OT	Operational Technology
PCB	Printed Circuit Board
RFID	Radio Frequency Identification
VLSI	Very Large-Scale Integrated Circuit
VVVF	Variable Voltage Variable Frequency
WSN	Wireless Sensor Networks

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Annex A (informative) of the EN 13015:2001+A1 (2008)

Typical examples of checks to be taken into account in maintenance instructions.

General	Check all components are clean and kept free from dust and corrosion.
Pit area	Check for excess oil/grease at bottom of guides. Check the pit area is clean, dry and free from debris.
Anti-rebound device and switch (where fitted)	Check for free movement and operation. Check for equal tension of ropes. Check switch where fitted. Check lubrication.
Buffers	Check oil level. Check lubrication. Check switch where fitted. Check fixings.
Drive motor/Generator	Check bearings for wear. Check lubrication. Check condition of commutator.
Gear box	Check gear for wear. Check lubrication.
Traction sheave	Check condition and grooves for wear.
Brake	Check braking system. Check parts for wear. Check stopping accuracy.
Controller	Check cabinet is clean, dry and free from dust.
Overspeed governor and tension pulley	Check moving parts for free movement and wear. Check operation. Check switch.
Main rope diverter pulley(s)	Check condition and grooves for wear. Check bearings for abnormal noise and/or vibrations. Check guarding. Check lubrication.
Car/Counterweight guides	Check for film of oil where required on all guide surfaces. Check fixings.
Car/Counterweight guide shoes	Check guide shoes/rollers for wear. Check fixings. Check lubrication where necessary.

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Electric wiring	Check insulation.
Lift car	Check emergency lighting, car buttons, key switches. Check fixings of panels and ceiling.
Safety gear(s)/Ascending car over speed protection means	Check moving parts for free movement and wear. Check lubrication. Check fixings. Check operation. Check switch.
Suspension ropes/chains	Check for wear, elongation and tension. Check lubrication only where intended.
Rope/chains terminations	Check for deterioration and wear. Check fixings.
Landing entrances	Check operation of landing locks. Check doors for free running. Check door guiding. Check door gaps. Check wire rope, chain or belt when used, for integrity. Check emergency unlocking device. Check lubrication.
Car door	Check door closed contact or lock. Check doors for free running. Check door guiding. Check door gaps. Check wire rope or chain when used for integrity. Check passenger door protective device. Check lubrication.
Floor level	Check stopping accuracy at landing.
Final limit switches	Check operation.
Motor run time limiter	Check operation.
Electric safety devices	Check operation. Check electric safety chain. Check correct fuses are fitted.
Emergency alarm device	Check operation.
Landing controls and indicators	Check operation.
Well lighting	Check operation.

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Lift Ai	https://www.liftai.com
Liftinsight	https://www.liftinsight.com
Mitsubishi	https://www.mitsubishielectric.com/elevator/index.html
OTIS	https://www.otis.com
Schindler	https://www.schindler.com
TK (Thyssenkrupp)	https://www.tkelevator.com/us-en/
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