Analysis of investment budget for quality target “$SAIDI_{total}$ 90 by 2030”

Overview /Background of Project “Investment budget for $SAIDI_{total}$ 90”

entellgenio

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Overview and Background of Project "Analysis of Investment Budget for $SAIDI_{total}$ 90"

1 Theory "How to manage infrastructures best"

1.1 Overview

Infrastructures are the "pillars" of modern world. Every day, you need electricity/gas and water to have your morning coffee and you drive to work by using a train. Normally, we do not think about that and we only note the "absence" of infrastructures if there is no clean water or no electricity. Life becomes pretty "uncomfortable" if there is a lack of supply. An availability of the infrastructure at any time of the day and few – or even no - interruptions during the whole year would be perfect. Reasons for interruptions are manifold. Besides external influences like storms, ice and snow or "bad luck", the state and age of a grid are essential reasons for blackouts of infrastructures.
The Asset Managers task to keep infrastructures in a good and reliable state by continuous maintenance and renewal, what is needed to keep infrastructure in working during long term period, is highly complex. The challenge thereby is to bring the desired technical quality of the infrastructure, the legal obligation to provide e.g. electricity, the cost cap and the regulatory requirements in line. Therefore, sustainable Asset Strategies have to be developed to achieve highest reliability.
One of the key indicators for the quality of electrical infrastructures is SAIDI (System Average Interruption Duration Index).
How many companies come to SAIDI as low as possible and to the lowest number of damages of their grids? And how can grid operators come to optimal decisions and strategies with regard to the maintenance and development of their assets for the future without risk? When do companies have to invest considering tight budget and demographic change?

1.2 Asset Simulation and Asset Optimization

The Asset Simulation is a transparent and practice proven-in-practice method to control complexity and therefore help derive sustainable and sound Asset strategies. In a first step, the targets with their associated parameters, possible Asset Management measures and the existing interdependencies and correlations between these factors are summarized and mapped in a causal loop diagram.
In the second step, aging chains for single asset segments, respectively for asset groups are defined with stock and flow diagrams. These diagrams describe the life cycles of the respective single assets and assets groups. Every aging chain is divided into single state categories that characterize the state of the asset. Depending on the state category, the effects of Asset Management measures on the asset is described. As such, dynamic feedback, delays and non-linear relationship between influencing factors and targets become transparent.
In the third step, a dynamic Asset Simulation Model is developed – based on the description of mathematical correlations and the merger between causal loop, stock and flow diagrams. Based on the developed model, different asset strategies can be calculated, evaluated, analyzed and interpreted in detail. By starting the simulation, all defined targets for all asset groups are calculated within a very short time. The simulation results of the targets then are shown as diagrams or value tables. Additionally, the key levers can be identified by parameter variation and sensitivity analyses. The Asset Management thus gains – quasi without any risk (see chapter 3)– a significant better understanding for possible long-term effects of its planned measures. For Asset Management, the definition and implementation of reasonable Asset Strategies therefore is improved substantially.
What is the "best" or "optimal" asset strategy concerning business relevant restrictions?

Typical strategies require the adaption of several hundred decision parameters. When choosing a strategy, opposing targets have to be considered. Furthermore, each change of strategy leads to a re-selection of the whole parameter set with regard to the considered time period.
That means that over thousands decision-making factors have to be selected optimally. Therefore, so called evolutionary optimization methods are used successfully in the tool. The optimizer module searches automatically and efficiently for the best solution within such complex decision spheres.
The Asset Manager decides which values should be optimized, e.g. cost, quality and risk. The optimizer then sets different decision parameter combinations and simulates for each of these combinations the assets over the considered period. The best result or a set of best results of the simulation with respect to the objective is returned to the optimizer. Based on this last best result, the optimizer selects a new set of decision parameters with which several simulations can be performed again. The optimizer iterates this run as often until the objective converges i.e. until no further essential changes occur. The Asset Manager then receives this calculated optimal result. This is the "optimal" strategy in form of parameter combinations for decisions.
The optimization of Asset Strategies requires economic and technical (incl. safety) constraints (so called restrictions). An important task is the elaboration of the necessary restrictions. The optimization approach described here uses predefined "meaningful" restrictions with regard to Technical Asset Simulation. However, it is of course possible to define "own" restrictions as the system configuration is highly flexible.

1.3 Overview Asset Management Process

In Figure 1 the necessary connections via interfaces between the three roles Asset Owner, Asset Manager and Asset Services within the asset management process are shown. It is also shown which applications are used by elektrilevi.

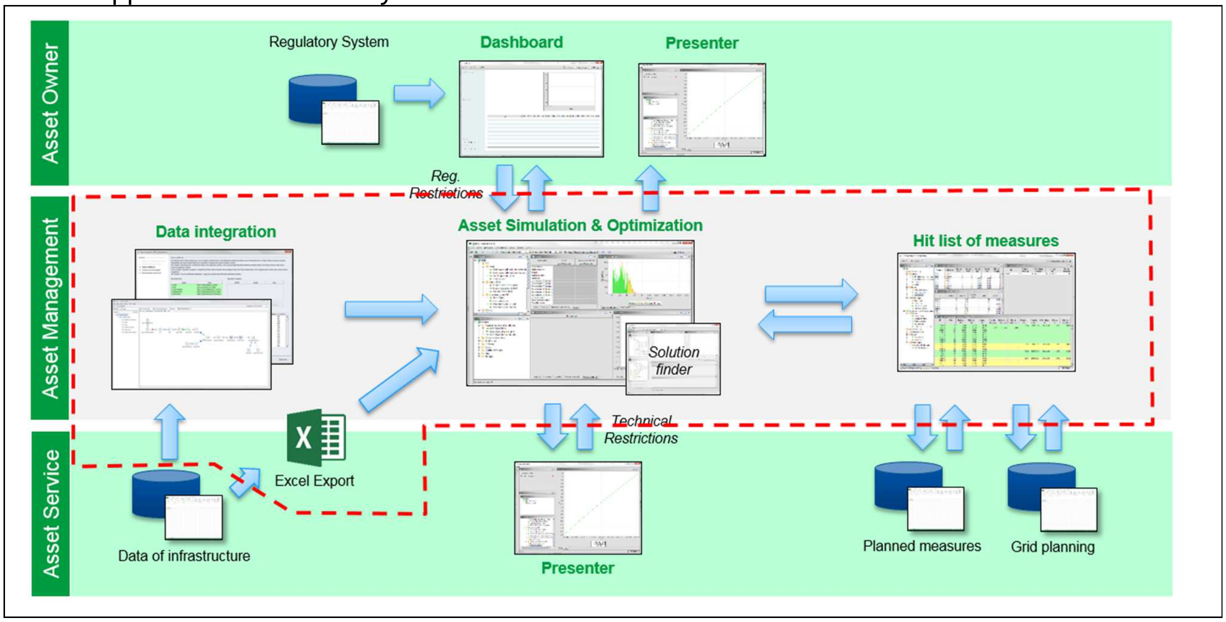

Figure 1: Overview – Complete Asset Management Process

2 Methods “Systems Dynamics” and “Evolutionary Algorithms”

2.1 System Dynamics

The dynamic behaviour is thought to arise due to the Principle of Accumulation that means, that all dynamic behaviour occurs when flows accumulate in stocks (System Dynamics Society 2016)

2.1.1 Causal-Loop-Diagram

Conceptually, the feedback concept is at the heart of the system dynamics approach. Diagrams of loops of information feedback and circular causality are tools for conceptualizing the structure of a complex system and for communicating model-based insights. The causal loop diagram describes the link and interaction between different system components.

Correlations have either positive, negative or positive and negative effects. Examples:

- Bigger asset-stock means higher grid value
- The more demounting are realized, the less actions are necessary for the operation of the remaining assets.
- The asset-stock according to the properties and condition of the asset tree can have both positive and negative effects on the quality of supply.

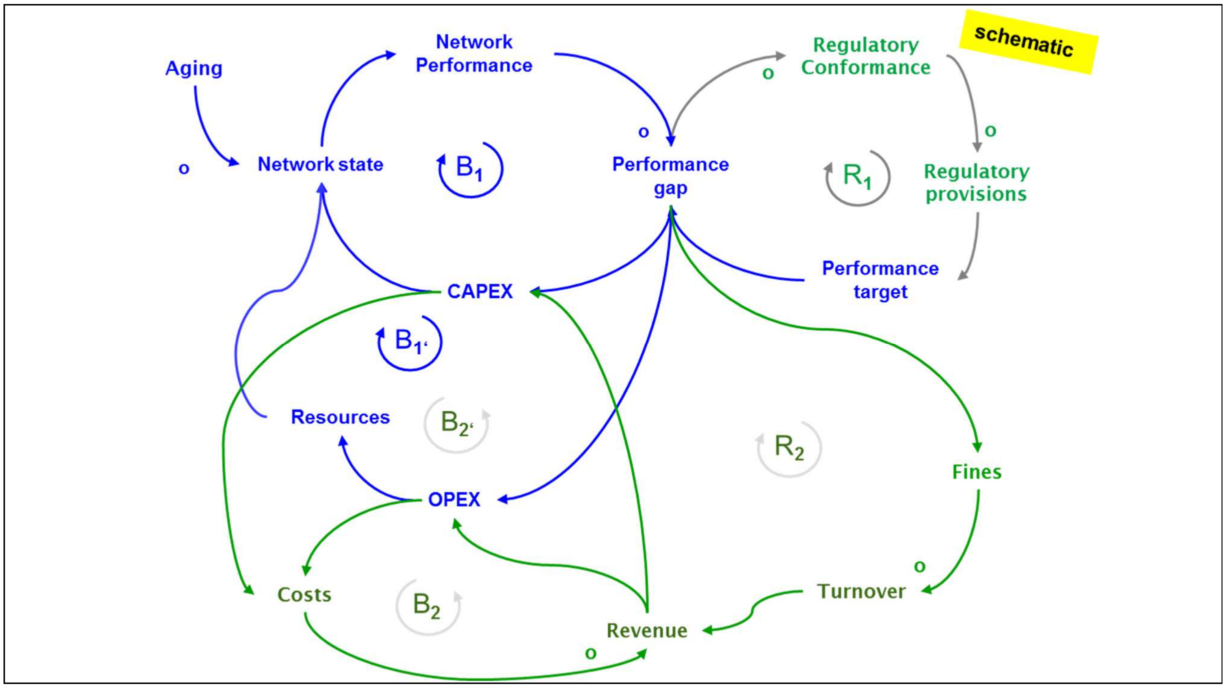

Figure 2: simplified CLD for infrastructure in a regulated market

Figure 2 shows two different types of feedback loops which are the foundational structures of systems thinking:

- A reinforcing loop (R) is one in which an action produces a result which influences more of the same action thus resulting in growth or decline.
- A balancing loop (B) attempts to move some current state to a desired state though some action.

The methodical frame starts with definition of use cases which a simulation model should answer. These use cases are displayed in text or graphics. On the basis of agreed use cases a Causal-Loop-Diagram can be developed.

2.1.2 Stock and Flows

The dynamic behaviour is thought to arise due to the Principle of Accumulation that means, that all dynamic behaviour occurs when flows accumulate in stocks (System Dynamics Society 2016)

2.1.2.1 Stock and flow diagrams

In general flows will be functions of the stock and other state variables and parameters (Sterman 2000). The following figures show a simple stock an flow structure and its hydraulic metaphor

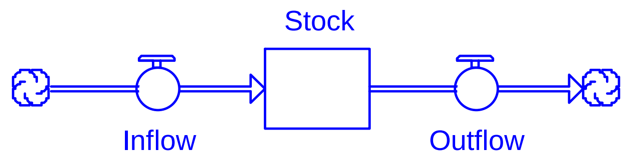

Figure 3:Example of a simple stock and flow structure

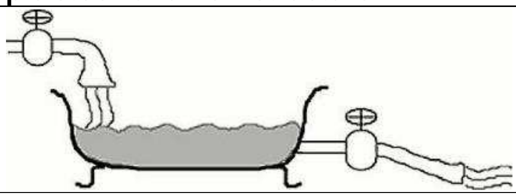

Figure 4: Hydraulic metaphor

The dynamic behaviour of the system arises due to the flows into, and out of, the stock. The change of stock within the time can then be described with the following differential equation:

$$d(Stock)/dt = Inflow(t) - Outflow(t)$$

In a more infrastructure view a stock can be defined as an amount of assets combined with one or more attributes like a type and/or condition.

2.1.2.2 Aging chain

An aging chain can have any number of stocks, and each stock can have any numbers of inflows and outflows. It is used to model the stock and flow structure in situations with additional inflows and outflows to an intermediate stage (Sterman 2000). In the present approach every aging chain represents an object of consideration like cables, overhead lines (OHL) or transformers and the condition of an asset is represented by a stock. As a common industry standard for infrastructure in the utility section aging chains with four stocks (conditions) have been established in the last years. The transition between stocks (inflow and outflow) are on the one hand side measures like replacement or conversion (transition into another aging chain) and on the other hand side the aging behaviour of an asset group. The effect of transitions to the aging chain is described in Figure 5.

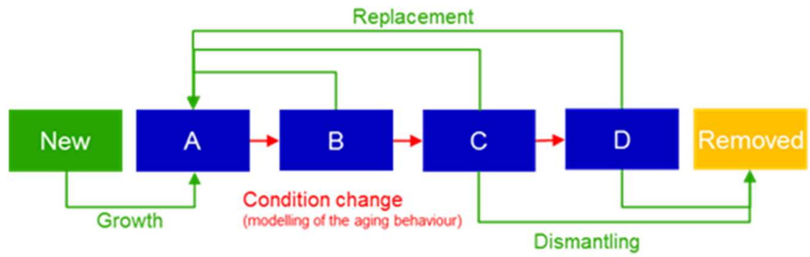

Figure 5: Example of an aging for assets in the utility section

For a more precise description of the age distribution of an asset group during the simulation and its influence on KPIs like the asset book value the approach extends the stocks to a conveyer system with slots representing the age of on asset. So in every simulation step it is possible to keep track of the actual age distribution of an asset group. Figure 6 shows an actual aging chain of asset groups in the utility section based on. It is implemented in the standard simulation and optimization model to answer the above question.

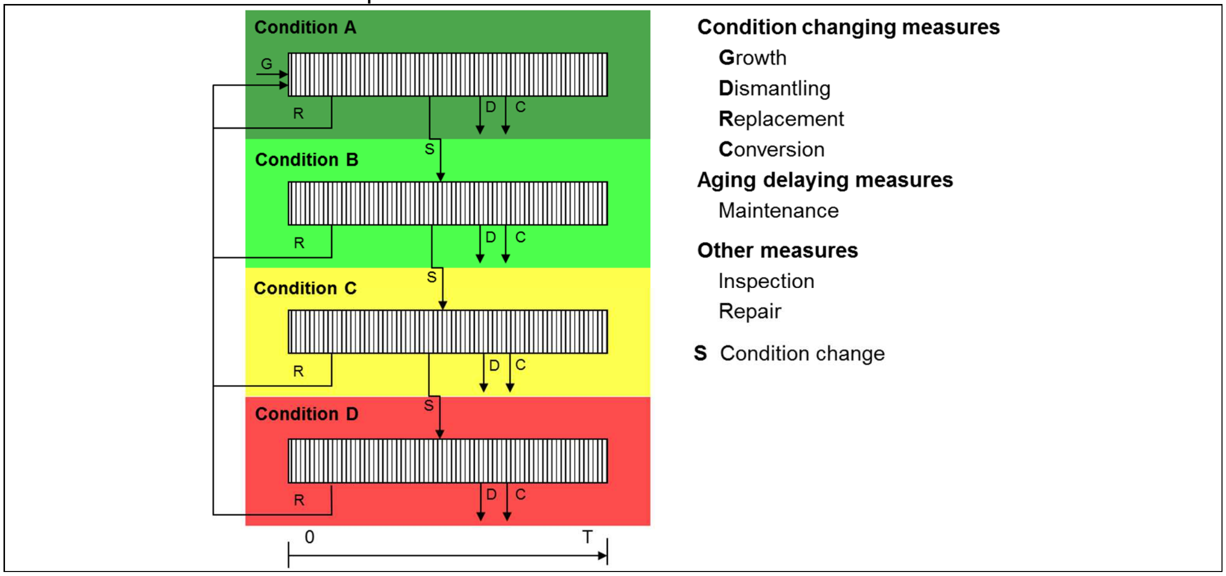

Figure 6: Aging chain based on conveyers for asset groups in the utility section

A conveyer is a special type of a stock that represents the age as an additional attribute of an asset. Every tick of the conveyer represents an amount of asset with an defined age. The first tick contains asset with the age zero and so forth, During one simulation step the assets move from tick n to tick n+1 if they are not operated by a measure like a renewal.

2.1.2.3 Condition of assets

The aging of assets can be described using a bathtub curve (Wilkins 2002). The curve contains three parts (see Figure 7):

1. Debugging, early age:
   - decreasing failure rate
   - infant mortality caused typically by defects and blunders (material defects, design blunders, errors in assembly etc.)
2. Nominal operating phase of the equipment:
   - „normal life“ (useful life)
   - relatively low, constant failure rate,
   - random failures, typically caused by „stress exceeding strength“
3. Equipment aging phase:
   - End of life (wear-out)
   - Increasing failure rates
   - Failures caused by wear-out due to fatigue or depletion of materials

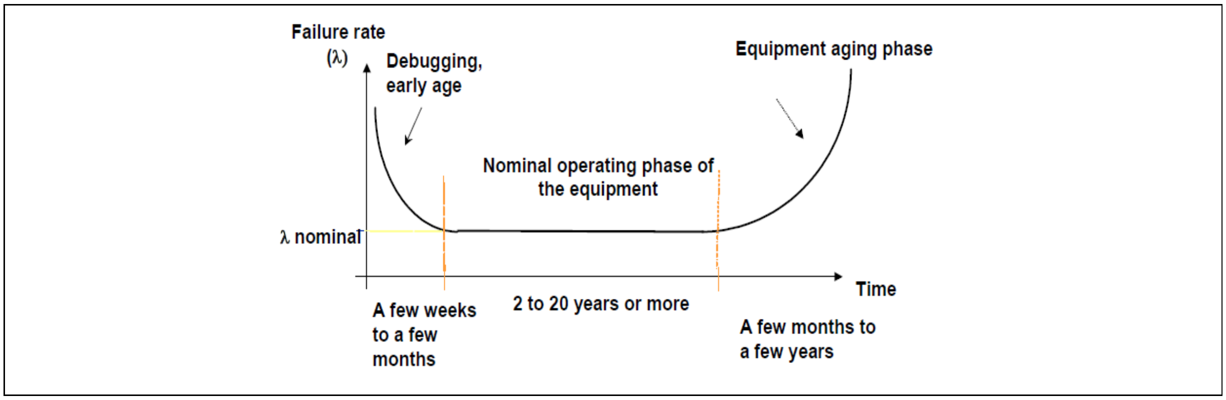

Figure 7: Bathtub curve

In a standard simulation model the bathtub curve defines the classes of condition where the transition from condition C to D describes the end of the lifetime[1]. In this condition an asset hast be replaced within the next years. The transition from condition B to C is defined by a distinct increase of failures (see Figure 8).

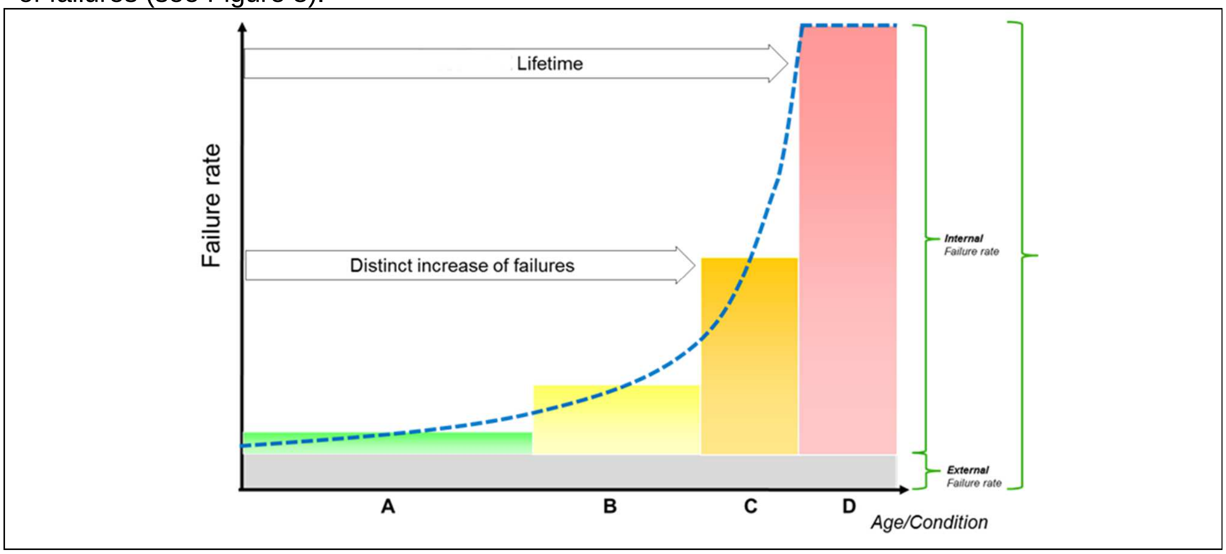

Figure 8: Definition of condition transitions

The definition of conditions used in the standard simulation model are defined in Table 1.

Table 1 Definition of asset conditions

Condition	Definition
A	New or new built assets with no symptoms of aging and wastage
B	Assets which show first symptoms of aging, e.g. rise of damage and failure
C	Assets which are reaching the end of the live cycle and the need for action occurs
D	Assets which have reached the end of their live cycles. Actions have to be done

The generic aging chain defined in Chapter 2.1.2.2 approximates the theoretical “bathtub curve”.

The relation of condition and number of failures is shown in the following figure:

[1] In the current project the bookkeeping time is defined as lifetime

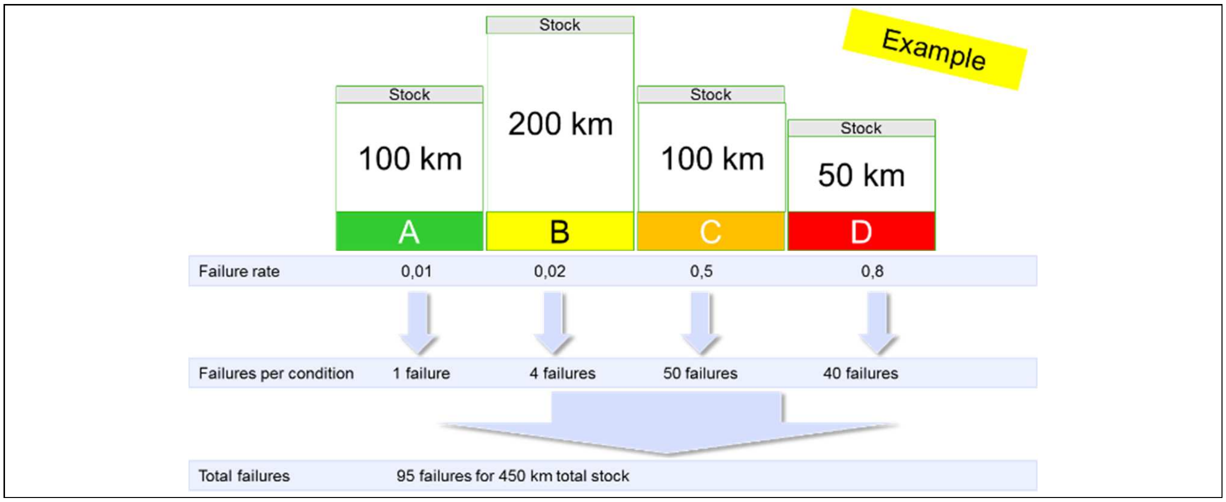

Figure 9: Example how to calculate the number of failures of an asset type according to its condition distribution

2.1.2.4 Transitions

The dynamic of flows is given by transitions in the aging chain. In the infrastructure section the transitions are predefined via measures of replacement, rehabilitation and maintenance. Table 2 gives an overview about definition impact of measures (transitions) to the aging chain.

Table 2: Typical measures and their influence to the aging chain

Measures	Definition	Impact on the aging chain
Inspection	Measure to assess and evaluate the current condition of the unit and determination of the reason of “wastage” and derivation of consequences for future usage	Inspection can be executed in all four conditions and is not changing the condition. More inspection can lead to more condition orientated measures and to less event orientated measures.
Maintenance	Measures to delay the “wastage” of the asset The cyclic measure is driven by law and/or supplier guidelines	Maintenance can be executed in all four conditions and doesn’t change the condition.
Repair	Measure to return the asset in an operating mode. No improvement of condition is done.	Repair is event driven. Repair keeps the asset in the current condition and has no effect on the aging behaviour.
Growth/ Construction	Construction of new assets	Growth can be executed only in condition A
Dismounting	Dismounting of existing asset	Dismounting can be executed in all four conditions
Replacement	The asset is replaced with an asset of the same type.	Replacement can be executed in all four conditions and leads to condition A
Conversion	The asset is replaced with an asset of an **different** asset type.	Dismounting of the source asset type executed in all four conditions and reconstruction of the new asset type in condition A.

2.1.3 How to allocate investment budget

Measures are defined on an asset type level as shown in Table 2. In the standard simulation model these measures are linked to a unit price which either is given per km for length-based or per pcs for quantity-based assets.
Measure costs are defines as:
Measure costs: number of measures x unit price of the measure.
The proportion of capex of measure costs is given in a separate parameter (see Figure 10)
The allocation of cost to capex and opex is defined as:
Capex part of measure costs: number of measures x unit price of the measure x Capex proportion of the measure
Opex part of measure costs: number of measures x unit price of the measure x (1 - Capex proportion of the measure)

Costs

Parameter	Cost per Measure	Capex proportion per Measure
Inspection	9.00 €	0.000 /a
Maintenance	19.00 €	0.000 /a
Repair	246.00 €	0.000 /a
Replacement	5,000.00 €	0.000 /a
Renewal	25,000.00 €	1.000 /a
Conversion 1 (expansion)	0.00 €	0.000 /a
Conversion 2 (expansion)		
Conversion 1 (dismounting)	0.00 €	0.000 /a
Conversion 2 (dismounting)		
Construction	25,000.00 €	1.000 /a
Decommissioning	0.00 €	0.000 /a
Lavation		
Renovation		
Specific costs	0.00 €	0.000 /a

Figure 10: Definition of unit costs and capex proportion per measure

Definition of Infrastructure Risks
The impact of the asset strategy on the grid risk has to be shown. Within the scope of the project two different perspectives of Elektrilevi's risk should be analysed.

1. The first is the customer perspective. The target here is to show how the asset strategy changes the number of customers affected by an outage.
2. From an owner perspective:
    a. The costs caused by an outage based on replacement costs as a result of the current asset strategy should be analysed.
    b. The cost caused by an outage based on replacement costs for plants and repair costs for lines

A detailed insight in the analysis of grid risks and its avoidance is given in the Asset Standards PAS55/ISO55000. The standards require a strategic focus on infrastructure.

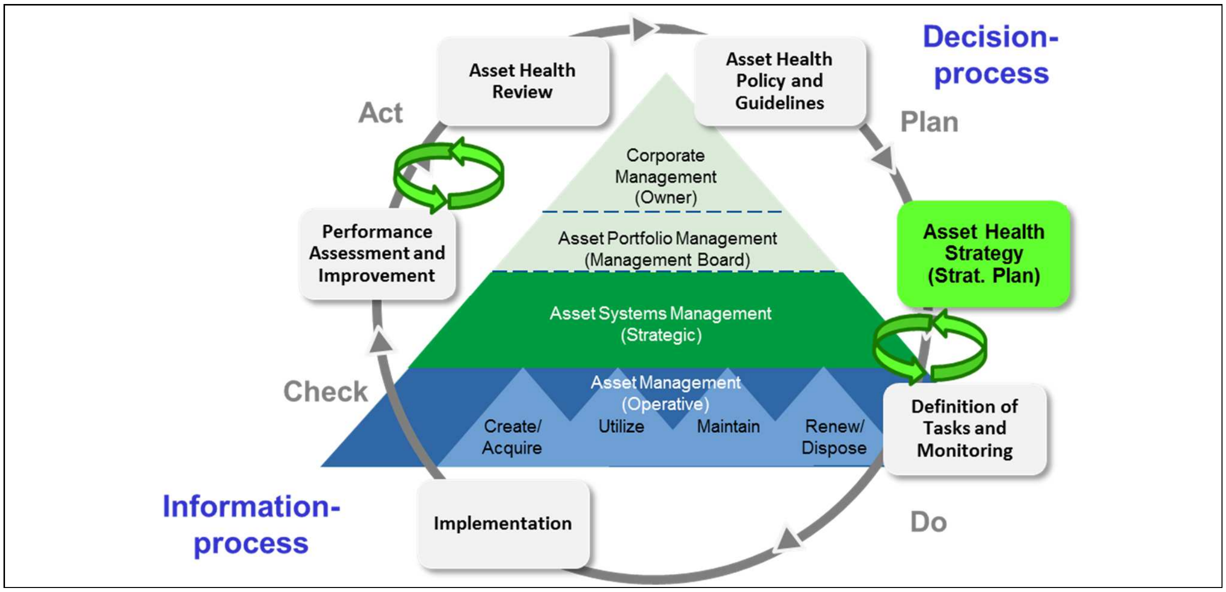

Figure 11: ISO55000 defines the elements of asset management as a cycle of activities

In the PAS 55/ ISO 55000 standard risk is divided into the following components:

- Environment
- Legal
- Work safety
- Quality
- Money
- Image

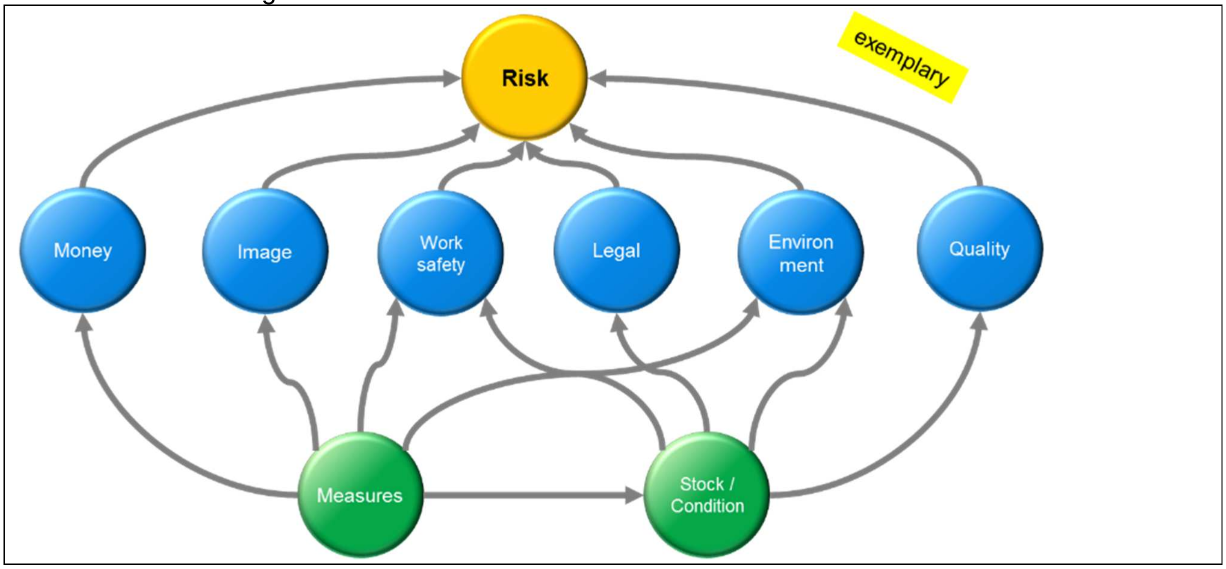

Figure 12: Extension of the Causal-Loop-Diagram (simplified representation) to integrate the PAS 55 approach

In Figure 12 the simplified relation between infrastructure and risk is shown. Further examinations should be done to understand how the risk components like money, image, etc. effect the customer and owner perspective. Then it should be possible to split the target risk from Figure 12 into to the targets customer and owner risk examined in the current project.

2.2 Evolutionary Algorithms

What is the "best" or "optimal" infrastructure strategy concerning business relevant management rules? Typical infrastructure strategies require the adaption of several hundred decision parameters. When choosing a strategy, opposing targets have to be considered. Furthermore, each change of strategy leads to a re-selection of the whole parameter set with regard to the considered time period. That means that over thousands decision-making factors have to be selected optimally. Therefore, so called evolutionary optimization methods are used successfully. The simulation model is extended by the solution finder (see next figure 13).

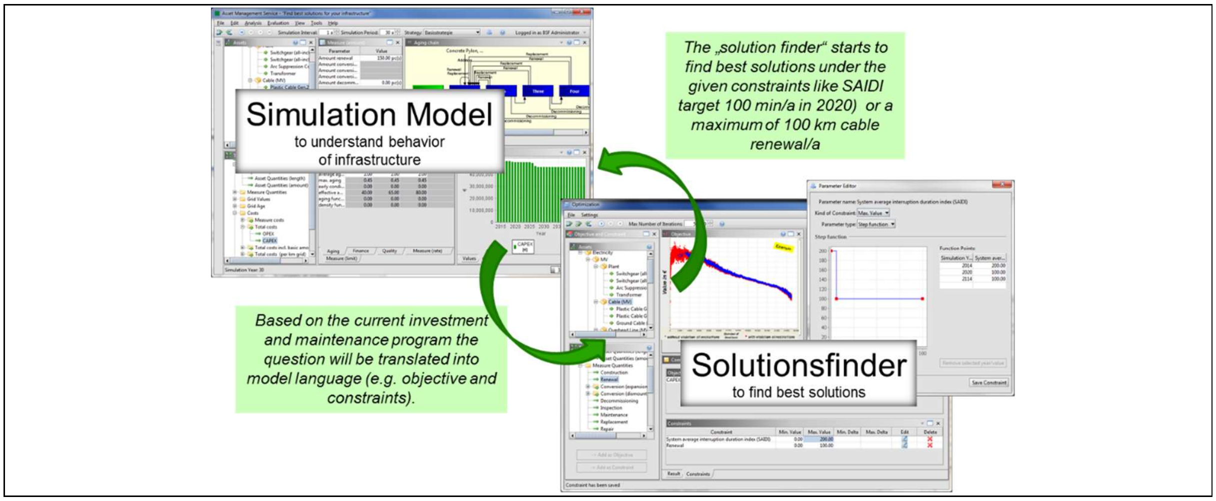

Figure 13: Combination of two methods - business dynamics and evolutionary optimization

The solution finder is based on the methodology of evolution strategies a subdomain of evolutionary algorithms based on ideas of adaptation and evolution. It belongs to the general class of evolutionary computation created by Ingo Rechenberg and Hans-Paul Schwefel. To optimize a given target function the following three evolution-operators are used (see figure 14):

- Mutation: produces a generation of alternatives & variants of genotypes
- Recombination (Crossover): describes the sexual reproduction and random exchange of genetic material
- Selection: describes the survival in an environment (conform to objective function) ant transmission of genetic constitution

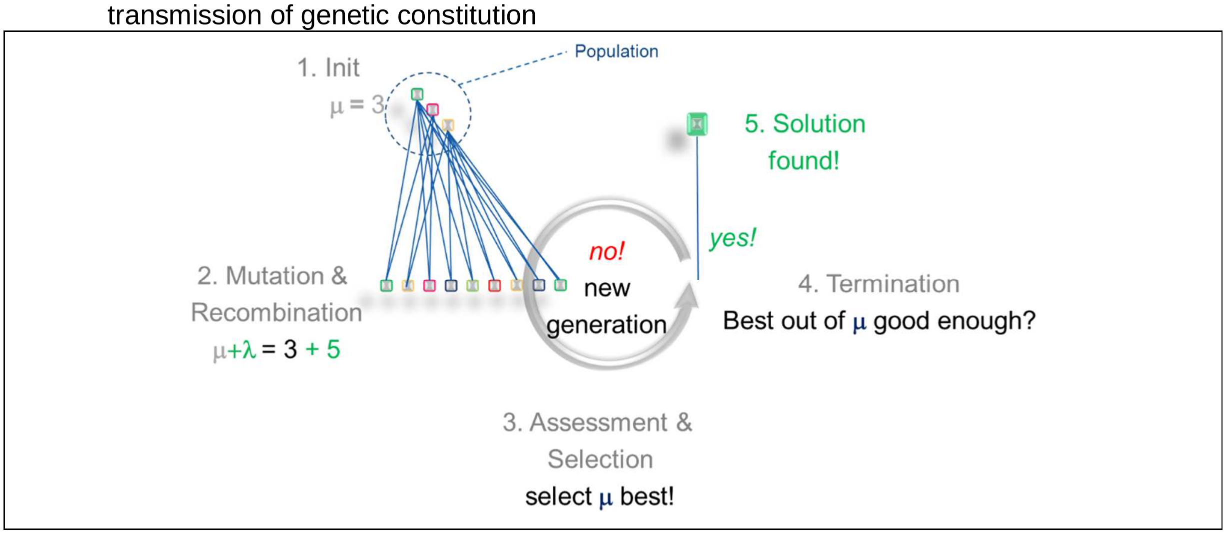

Figure 14: Approach of evolutionary optimization

Evolutionary algorithms are most suitable for optimizing systems including: nonlinear relations, step functions, many influencing variables, many restrictions, fast and dynamical (adaptive optimization) and produce robust results.

The infrastructure manager decides which values should be optimized, e.g. cost, quality and risk. The solution finder then sets different decision parameter combinations and simulates for each of these combinations the assets over the considered period. The best result or a set of best results of the simulation with respect to the objective is returned to the solution finder. Based on this last best result, the solution finder selects a new set of decision parameters with which several simulations can be performed again. The solution finder iterates this run as often until the objective converges i.e. until no further essential changes occur. The infrastructure manager then receives this calculated best result. This is the "best" strategy in form of parameter combinations for decisions.
The optimization of infrastructure strategies requires economic and technical management rules (so called restrictions). An important task is the elaboration of the necessary management rules. The optimization approach described here uses predefined “meaningful” management rules with regard to infrastructure simulation. However, it is of course possible to define “own” management rules as the system configuration is highly flexible.

2.3 Condition, Importance and Priority

Condition, Importance and Priority are calculated as follows:

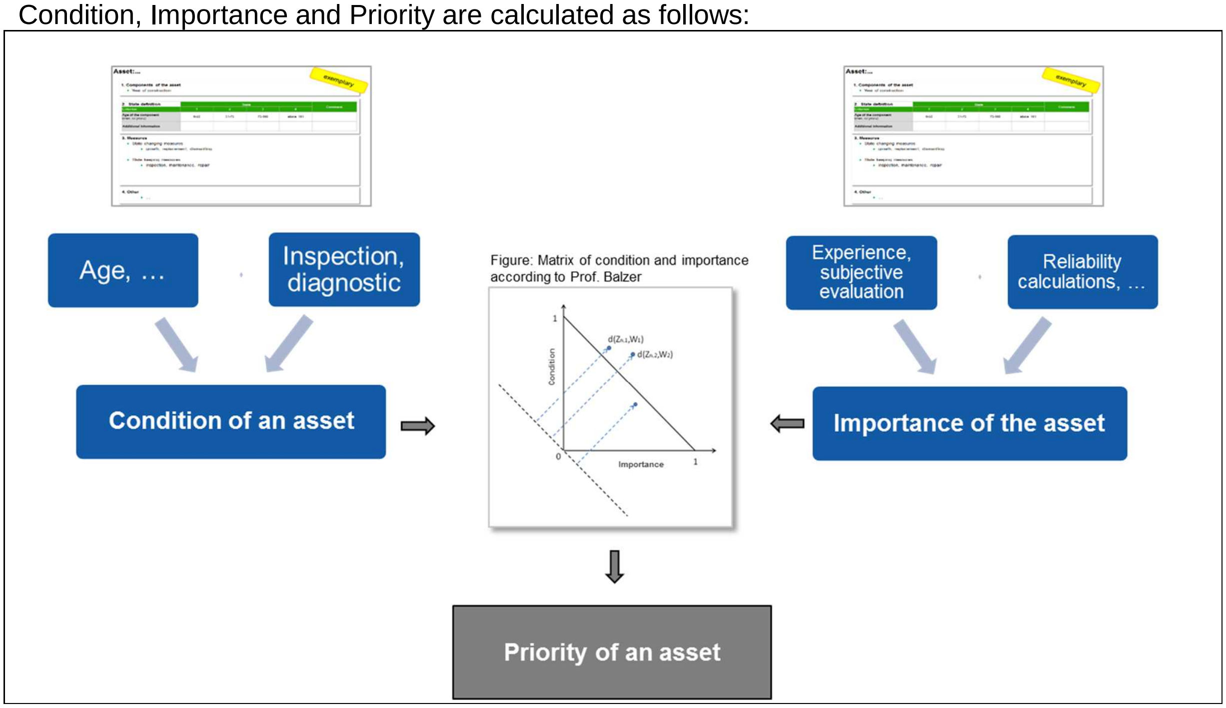

Figure 15: Condition, Importance and Priority

3 Synopsis (incl. targets) of project "Analysis of the investment budget for $SAIDI_{total}$ 90"

According to the Estonian Long-term Power Scenario 2030 (Energiamajanduse Arengukava Aastani 2030) "the average total duration of interruptions in the distribution network in minutes and consumption point per year shall not exceed 90 minutes". The total duration of interruption is also known as the "System Average Interruption Duration Index" (SAIDI). The total SAIDI ($SAIDI_{total}$) is defined as a value consisting of two parts: the planned and the unplanned SAIDI. The unplanned SAIDI is caused by faults in the network that lead to interruptions, whereas the planned SAIDI is caused by planned interruptions, e.g. for construction works on the network.

During this project it was analyzed if Elektrilevi can achieve the goal of a $SAIDI_{total}$ of 90 minutes with current reliability investment budget.

The project was divided into three scenarios:

1) **What $SAIDI_{total}$ can be achieved with the current investment budget?**
2) **What impact does an invetment budget reduction by 10 % have?**
3) **How can the target quality "SAIDI 90_{total}" be achieved?**

3.1 Simulation Model for Elektrilevi´s electricity infrastructure

The Elektrilevi simulation model that was set up during the project "Investment budget Allocation based on risk" was extended to answer the three questions described above.

3.1.1 Asset Segments

The existing asset tree was extended and asset segments were introduced to reflect the regional differences of Elektrilevi's reliability areas.

3.1.1.1 Reliability Areas

Elektrilevi's network can be divided into four reliability areas: rural, suburban, urban and urban core. Because urban core is not significant in size compared to the other areas, it was merged with urban (this will be labeled "urban" in the following). Each reliability area has its own asset tree that allows individual configuration and parameters for each asset group. Therefore it is now possible to model different effects on SAIDI depending on the type and area of each asset as well as different costs and ageing behavior.
On top of the reliability areas another segment was added called "Overall" for all asset groups that behave the same way in these reliability areas, like primary substations or meters. The overall SAIDI is calculated as the sum of the reliability areas and the "Overall" segment.

3.1.1.2 Asset Tree

The asset tree is divided in the asset groups medium voltage (MV), medium/low voltage (MV/LV) and low voltage (LV). Every asset group is divided into further asset groups like stations and cables. The elements at the bottom of the tree are asset types like MV cable. These asset types include their own set of simulation parameters and are the base for all planning activities in relation to business relevant decision criteria (target values) later on. Figure 16 shows the complete asset tree of Elektrilevi that was used to build the simulation model. It is an aggregated version of all segments. The individual asset trees of each segment are a subset of this aggregated tree. Data of the Elektrilevi's assets were used to fill the model. During the process of data import, every actual asset is assigned to exactly one asset type in the tree.

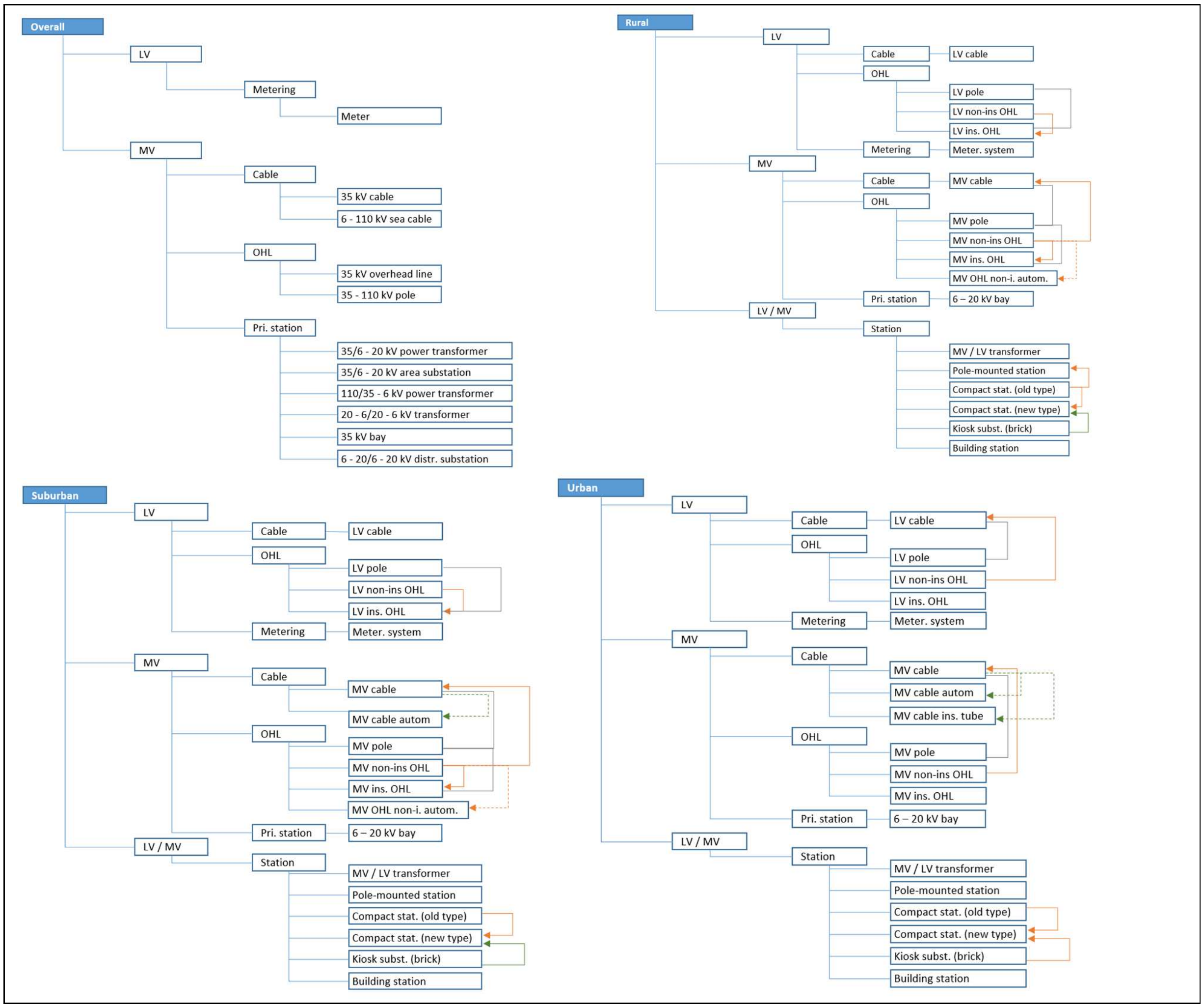

Figure 16: Elektrilevi asset trees for all segments (arrows: possible conversion)

3.1.1.3 Conversions

Conversions in the simulation model allow changes between different asset types, like OHL to cable. Thus, it is possible to not only model the renewal of old assets but also the decommissioning of old assets and the construction of new assets of a different asset type as a replacement. Therefore, it is possible to model improvements in reliability by changing non-insulated OHL to insulated overhead lines or cables.

3.1.2 Data Import from Elektrilevi's Graphical Information System

An interface to Elektrilevi's Graphical Information System (GIS) was set up for non-insulated MV OHL. This allows a direct import of detailed asset data into the model. The simulation is working with aggregated asset data, like the source data for the other asset types. However, a detailed data import from GIS allows a break down of the asset simulation results to measures on asset ID level: during the data import, the condition (based on age) and the importance (based on the feeder level/distance from the substation) are calculated. This information can subsequently be used to calculate a priority value for each overhead line segment that is stored in a database. Thereafter, measure amounts per asset type and year according to the asset strategy are matched. The priority information is used to create a list of measures that is in line with the asset strategy and all the requirements that were set to create it. This list can be visualized in the GIS via an Excel export/import interface to identify the necessary measures in the network.

3.1.3 Aging and Condition of Assets

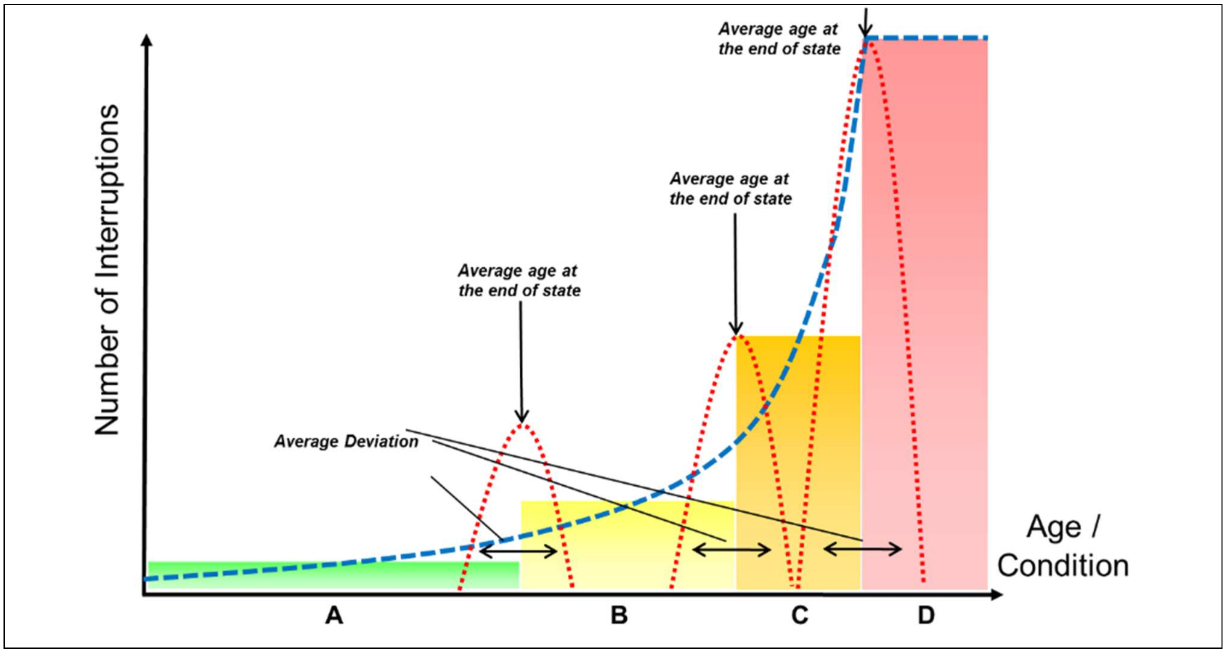

Figure 17: Condition classes based on age

The simulation model is based on the relation between age and condition. The condition of the assets is calculated when they are loaded into the model. It is based on the average age at the end of the conditions. The following assumptions were made to define the average age at the end of every condition class:

Assumption 1: The average age at the end of condition C (AC_C) is the bookkeeping lifetime.

Assumption 2: The average age at the end of condition B (AC_B) is defined as:
AC_B = AC_C – 10 years

This principle is an empirical value. It reflects the situation, that 10 years before the end of the lifetime there is statistically a noticeable increase in maintenance costs. This increase is the definition for the transition into condition 3

Assumption 3: As the assets in condition A and B are at the bottom of the bathtub curve it is common for risk and quality approaches to define a similar statistical lifetime for both conditions: AC_A = AC_B/2

Calculating the condition for every asset and loading it into the simulation model leads to the age distribution shown in Figure 18.

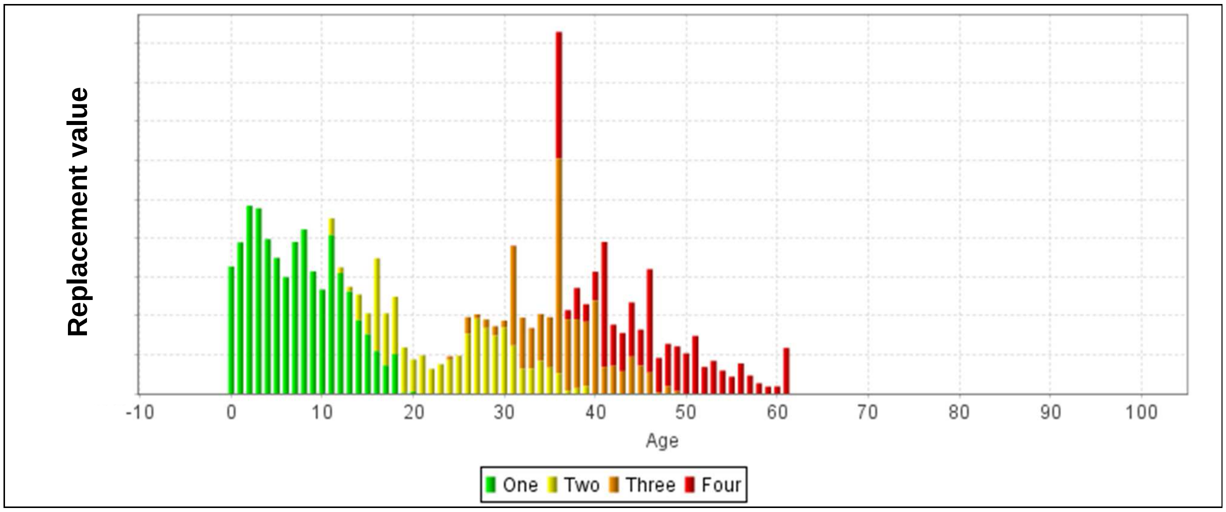

Figure 18: Age distribution of Elektrilevi (as of end of 2016)

3.1.4 Allowed Owner Revenue

A simplified version of the regulated asset value based on age and replacement value was implemented in the model to simulate how the allowed revenue (also known as justified profitability) would develop based on the investment strategies that are analyzed during this project.
The regulated asset value depends on the average age and the replacement value of all assets within the calculatory lifetime:

Replacement Value =

Asset amount within calc. lifetime [km, pcs] x unit price [€]

Regulated Asset Value (RAV) percentage =

max (0, (1 – Average Age / Depreciation Period$_{calculatory}$*) x 100)*

If the average age exceeds the depreciation period, the RAV percentage is 0.

The Regulated Asset Value is then calculated as the product of Replacement Value and RAV Percentage:

Regulated Asset Value =

RAV percentage x Replacement Value

The allowed owner revenue per year is the product of the Regulated Asset Value and the Weighted Average Costs of Capital (WACC, currently at 4.5%):

Allowed Owner Revenue =

WACC x Regulated Asset Value

The calculation of the allowed owner is done on the asset type level and the values are added up for the total value on the grid level.

3.2 Changes to better reflect SAIDI

There are multiple ways for Elektrilevi to improve the SAIDI that have to be reflected in the model as shown in Table 3.

Table 3: Different ways to improve SAIDI

	Description	Representation in the model
Reliability areas	Development of a different strategy for each reliability area to reduce SAIDI	Adding reliability areas as segments to the model
Damage rates	Conversion of asset types to asset types with lower risk of damage	Conversion between asset types, for example from OHL to insulated OHL and from OHL to cable
Effect on SAIDI	Renewal of assets that have a high contribution to SAIDI due to condition and age (assets over lifetime)	The solution finder will identify the assets with the highest impact on SAIDI and renew them
Automation	Usage of automation to reduce the average number of affected customers (rural) or the average interruption duration (urban) per fault	Adding asset types with and without automation that have different quality parameters
Tubes and Tunnels	Usage of tubes to prepare for renewal of MV cables in urban areas	Adding the asset type 'MV cable in tube' that reflects the lower costs of laying cables into existing tubes
Planned SAIDI	Reduction of planned SAIDI	Planned SAIDI is reduced after the installation of smart meters is finished

For the SAIDI targets, individual strategies per reliability area were made (see chapter 3.1.1.2). The investment and maintenance strategy has to consider that the reliability investment investment budget has to be allocated to measures that have a high effect on SAIDI. This could be a conversion to assets with lower failure rate or a renewal of assets that are in a bad condition or have a high failure rate. The solution finder identifies these measures to improve the reliability investment investment budget allocation for a better SAIDI value.

3.2.1 Automation

Automation can be added to the network to improve SAIDI by adding switches that can isolate interruptions after a fault has occurred. It requires two separate supply sources from the area substations. Minimum three switches with short circuit current commutation capability located in the main line are necessary to localize the fault and switch the supply to another substation. Automation is only allowed, if the localizing time with automation is shorter than the localizing time using crews.
Therefore the field of application is limited for automation and it has to be combined with other measures to achieve better SAIDI values and reach the SAIDI 90 goal in 2030.
Automation has been modeled by adding separate asset types to the asset tree that reflect OHL or cables with added automation. They have the same set of parameters than the asset types without automation apart from the quality parameters (average duration of interruption and average affected customers). A transition between OHL (or cables) to OHL (or cables) with automation converts standard assets from condition 1-3 to assets with automation without changing their age or condition. Therefore, the cost of this conversion is the average cost per km to add automation to the network. Assets from condition 4 are not converted to automation assets, because they have to be completely replaced or taken out of the network.

3.2.2 Cable Tubes

Besides the automation, MV cables in tubes were added to the asset tree. The construction of tubes and tunnels are part of Elektrilevi's asset management plan to prepare for the renewal of MV cables in urban areas (starting 2025). This is modeled by adding a new asset type “MV cable in tubes” to the asset tree for urban. The construction costs of this asset type are significantly lower compared to regular MV cables because there are no costs for digging and resurfacing. The amount MV cables and/or MV OHL that can be converted to MV cables in tubes has to be limited by restrictions in the solution finder to reflect the actual availability of these tubes.

3.2.3 Planned SAIDI

Elektrilevi’s planned SAIDI for 2016 was at 78 minutes. Over the last 5 years, the average planned SAIDI was 81 minutes, that were mainly caused by electrical investment works in the network. Most of the investments were made in the sectors reliability, new connections and remote meters. For a weatherproof network and a decrease of faults, much money was invested into the LV network that caused a higher planned SAIDI (no backup supply to clients). During remote metering works, data concentrators to substations were installed, that led to a high planned interruption level as well. In the next years, until 2030, more works in the MV network are planned. Here, it is possible to use network automation and to reduce the planned interruption influence to clients using reserve supplies. Therefore, the planned SAIDI is expected to decrease over the next years. This was modeled using a step function for the planned SAIDI until 2030 as shown in Figure 19.

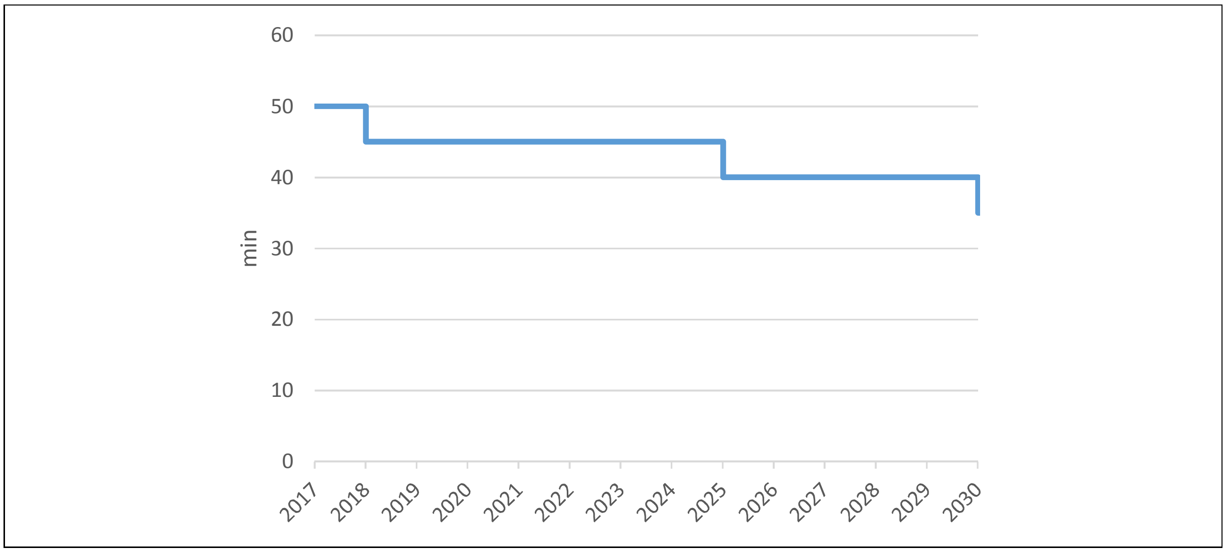

Figure 19: Development of planned SAIDI

3.3 Meters

Smart meters have been installed across Estonia in the past few years. They have a regulatory lifetime of 15 years only. Afterwards, they have to be exchanged. That means that meters do not have the usual 4 conditions, but only 2: new and over lifetime. There is no average age deviation: assets change condition after exactly 15 years and then have to be replaced.

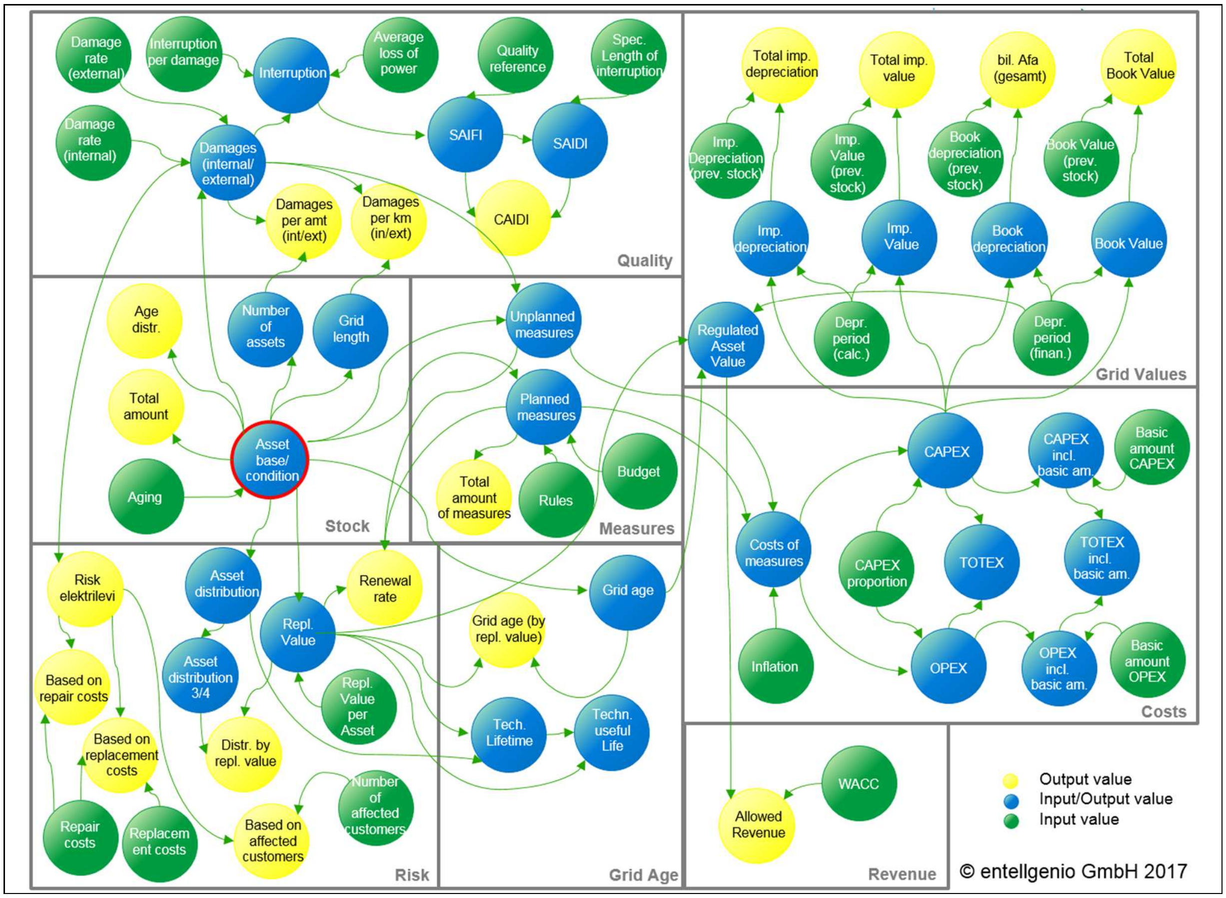

Figure 20: Causal-Loop-Diagram for Elektrilevi

3.4 CAPEX, OPEX and measure costs

The given CAPEX reliability investment budget for 2017 is used to create a starting point for the solution finder and to validate the simulation model. The reliability investment budget is transferred to measure the amounts for renewal and conversion: the reliability investment budget per year and measure is divided by the cost per measure. The costs for renewal and replacement are based on the replacement value per unit given by Elektrilevi.
The conversion costs for OHL are lower than the replacement value. Thus, they have been defined separately.

The OPEX reliability budget is divided into the following categories: inspection costs, defects and maintenance costs, interruption elimination costs, planned maintenance for stations and line corridor maintenance. This information is used to calculate the cost parameters inspection, maintenance and repair:

- Inspection: Inspection costs divided by the number of assets
- Maintenance: sum of defects and maintenance costs, planned maintenance and line corridor maintenance divided by the number of assets
- Repair: Interruption elimination costs divided by the number of faults (with the assumption fault = interruption)

Consequently, these costs are average values based on the costs for one year. Since this project focuses on CAPEX, the OPEX values were not considered in detail.

3.5 Decommissioning

Due to some network redesign and demographic changes it was estimated that the current network will decrease until 2030. This is reflected in the model in decommissioning amounts that are defined for several asset types (mostly OHL MV and LV). The total decommissioning amount in the model is 1 800 km until 2030, which is approximately 3% of the current grid length. The scenarios have been calculated with and without decommissioning to analyze its effect on SAIDI.

3.6 Data validation

The simulation model was validated in 3 steps: meeting target values for amounts of assets, quality and reliability investment budget. The calculated values for every asset group and reliability area were compared to reference values from Elektrilevi. Passing these validation steps proves that the model is a valid representation of the Elektrilevi's grid and can be used for further calculations and analysis.

3.7 Results

Scenario 1: What $SAIDI_{total}$ can be achieved with the current investment budget?

With the current reliability investment budget, reliability measures in the network, it is not possible to reach the set $SAIDI_{total}$ goal of 90 minutes in 2030, even if new technologies like automation, cable tubes and decommissioning are included.

An optimized strategy for the current reliability investment budget was created that can reduce the total SAIDI value by 70 minutes or 35%. However, it has to be noted that a large part of the of the SAIDI improvement is achieved by applying new technologies (mainly automation for MV OHL) and decommissioning (re-design of the network). This shows that a significant share of the investment budget has to be used to keep up with the ageing of the network and to exchange the assets that exceeded their lifetime. This is also reflected in a decrease of the allowed owner revenue (-10%) with the current investment budget scenario: more assets reach the end of their lifetime. Consequently, they cause a high risk of failure and are not considered for the calculation of the regulated asset value. A major shift in distribution of the current investment budget from LV to MV is required. This is due to the fact that the influence of the primary stations is high in this case. A feasibility study "Is it possible to redesign this amount of MV network until 2030?" would be necessary.

Scenario 2: What impact does an investment budget reduction by 10 % have?

A $SAIDI_{total}$ improvement of ~ 60 minutes (30%) seems to be possible until 2030. The effect of automatization and decommissioning is even higher in this case, as the grid quality decreases compared to the case with the current reliability investment budget. A major shift in distribution of current investment budget from LV to MV is still needed. The allowed revenue will decrease even more till 2030 by ~ 13% due to aging of the network. The trend shows that the gap is expected to grow in the following years.

The most effective measure to reduce the SAIDI would be an insulation of the OHL, both, in the low and the medium voltage network. This weatherproofing measure is already extensively done by Elektrilevi on the low voltage network and has to be extended to the medium voltage network within the next years. However, the feasibility of such a shift in Elektrilevi's reliability investment budget allocation over the next years has to be further examined. A more detailed analysis of the required investments in the area substations should also be conducted in the future to find the minimum reliability investment budget for yet to be defined risk targets.

Scenario 3: How can the target quality "SAIDI 90total" be achieved?

The $SAIDI_{total}$ goal until 2030 could be achieved with an average additional annual investment ca 10 Mil. €. The impact of automation and decommissioning is much lower because of higher investments in the MV level and consequently a higher net quality. The additional budget for the MV level is higher than in other scenarios: it is the sum of the shift from LV plus extra the budget. The total allowed revenue will stay more or less the same till 2030.

Not only the possibility to increase the current reliability investment budget has to be checked. Moreover, it has to be verified if there are enough resources to handle the amount of conversions and constructions that are necessary.

The goal of the National Development Plan of the Energy Sector Until 2030 (ENMAK 2030) to reach the average total duration of interruptions in the distribution network of 90 minutes in 2030 without an increase of investments cannot be achieved. A discussion process about the right balancing of the competing targets investment and $SAIDI_{total}$ level for Estonia (incl. timeframes) should be started. The main question is the asset strategy that should be chosen depending on the money that can be spent in the future: if the investments should stay the same or be reduced, the focus has to be set on automation and decommissioning. If more reliability investment budget is available, the asset strategy has its focus on renewal.

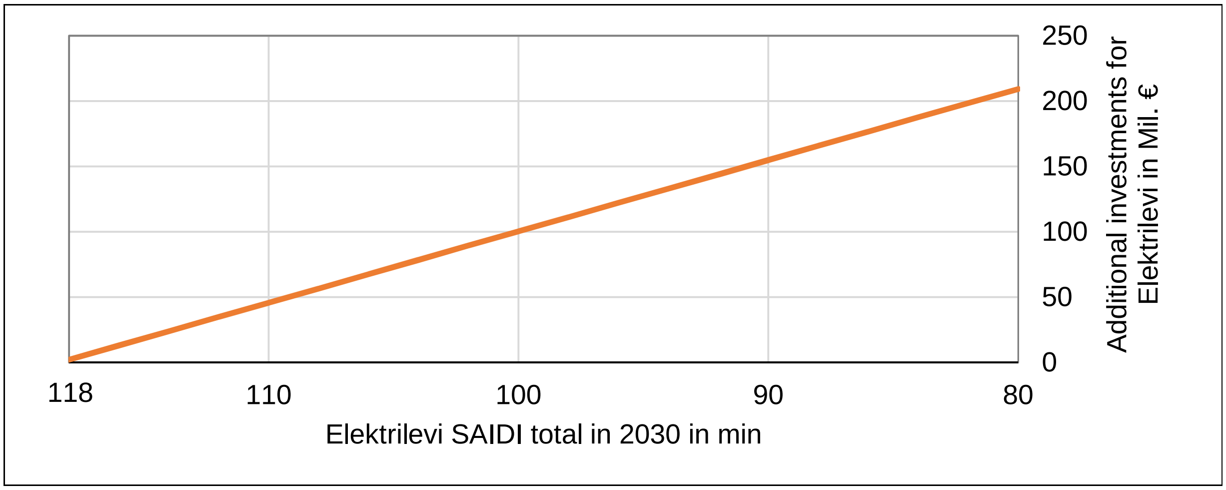

Figure 21: Estimation of additional investment budget for SAIDI goals until 2030 (schematic depiction)

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