

Analysis of budget allocation

Part 1: Overview and Background of Project “Analysis of budget allocation”

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entellgenio

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Part 1:

Overview and Background of Project

“Analysis of budget allocation”

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). For gas or water grids the number of damages is a key quality indicator.

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.

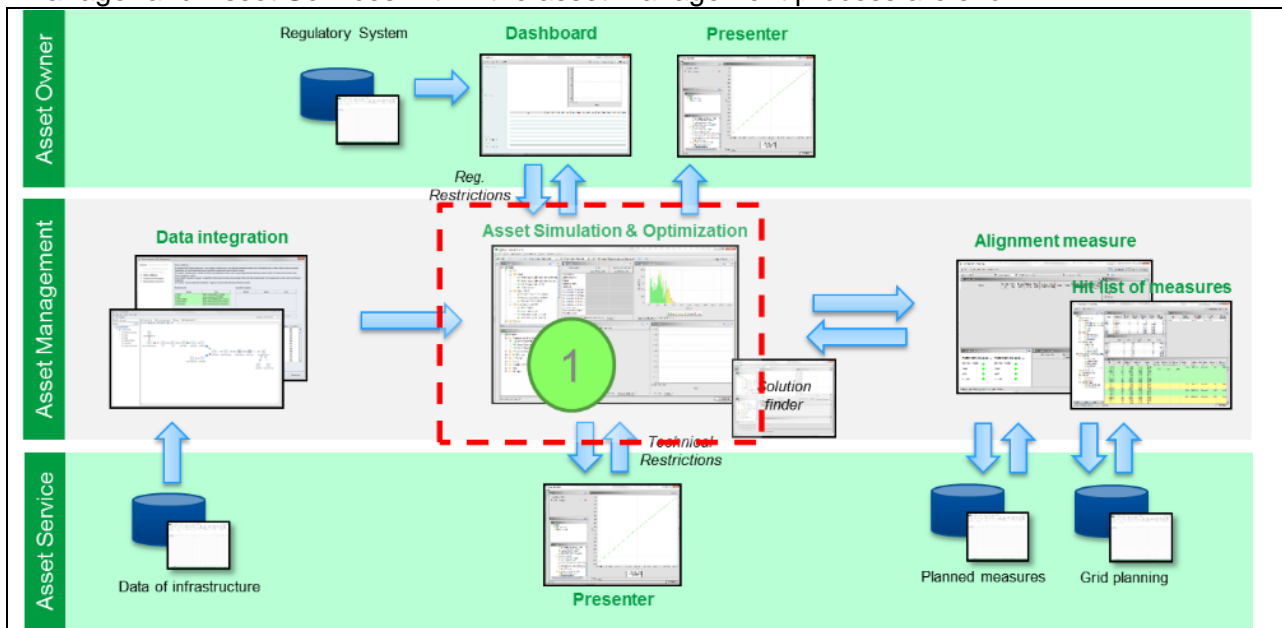


Figure 1: Overview – Complete Asset Management Process

2 Method “Systems 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 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.

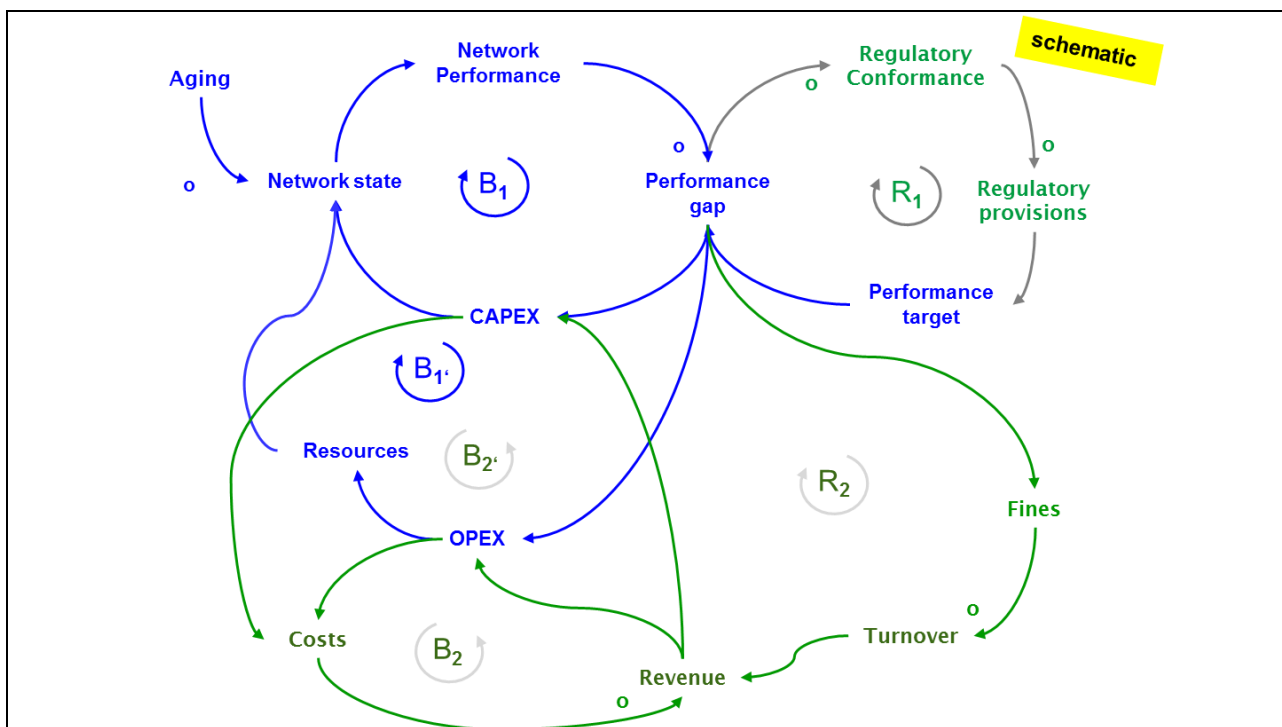


Figure 2: simplified CLD for infrastructure in a regulated market

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.

2.2 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)

2.2.1 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 and flow structure and its hydraulic metaphor

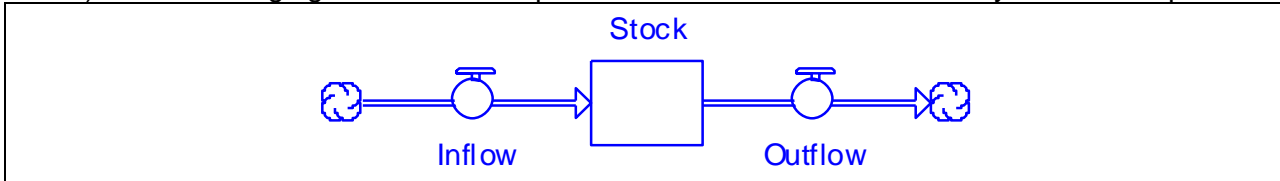


Figure 3: Example of a simple stock and flow structure

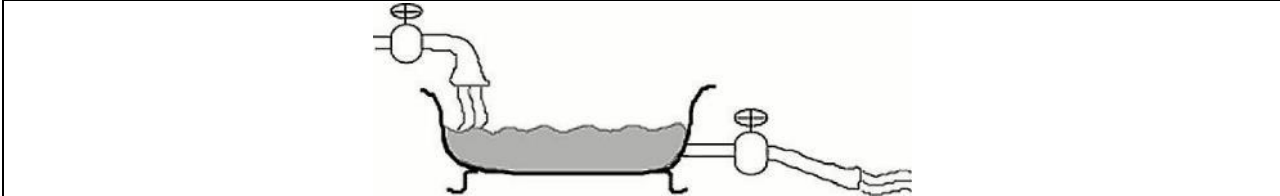


Figure 4: Hydraulic metaphor

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:

$$\frac{d(Stock)}{dt} = Inflow(t) - Outflow(t)$$

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.

2.2.2 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 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.

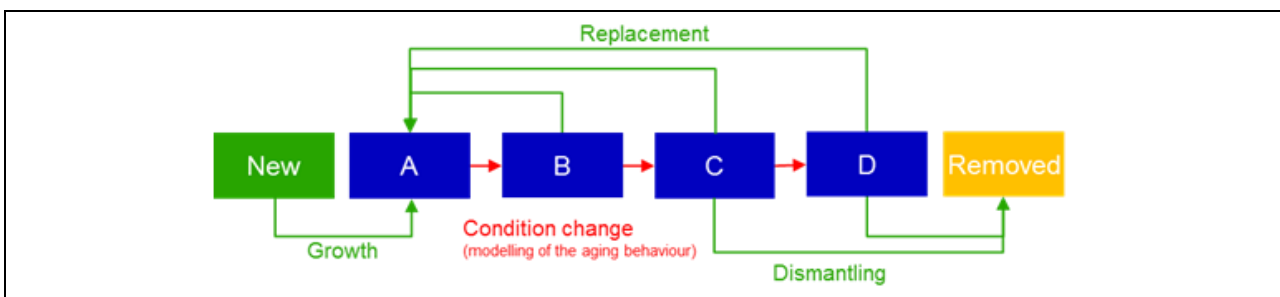


Figure 5: Example of an aging for assets in the utility section

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 conveyor system with slots representing the age of an 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.

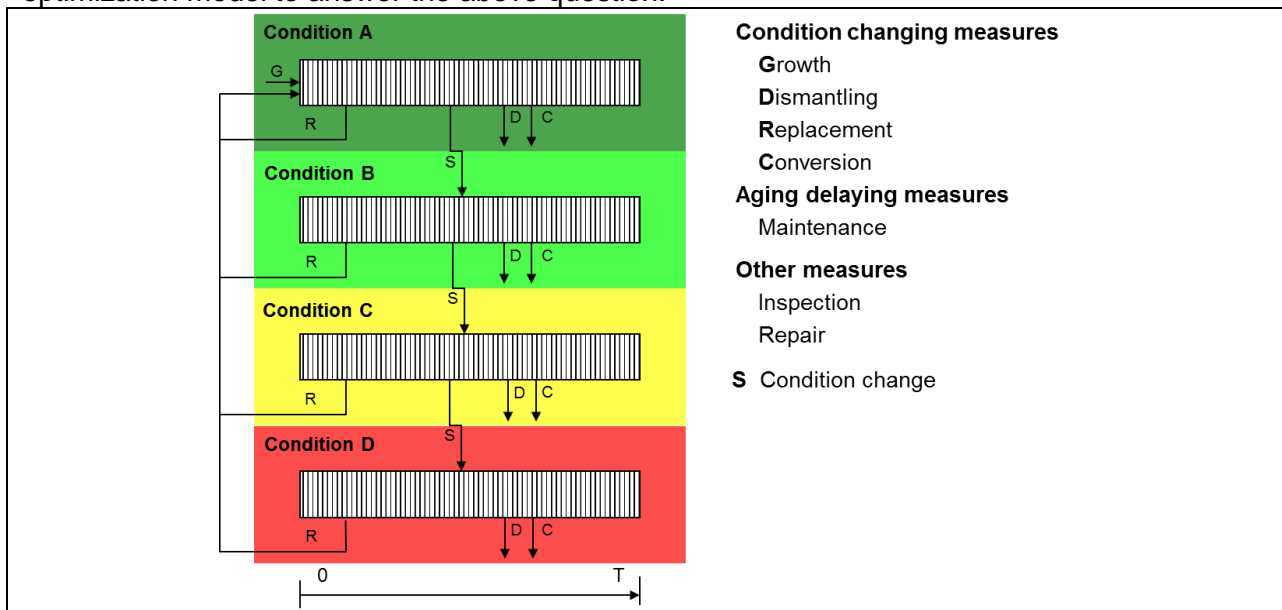


Figure 6: Aging chain based on conveyers for asset groups in the utility section

A conveyor is a special type of a stock that represents the age as an additional attribute of an asset. Every tick of the conveyor represents an amount of asset with a 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.

2.2.3 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

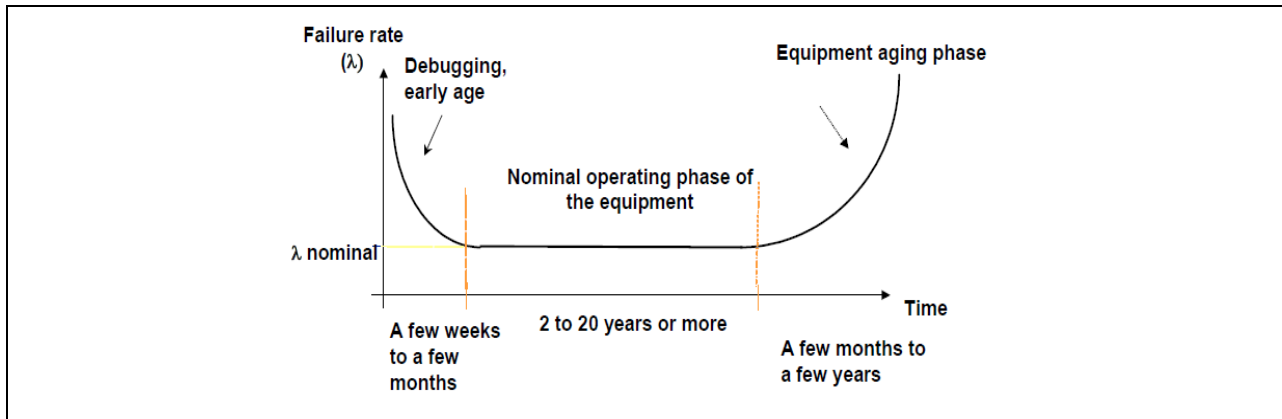


Figure 7: Bathtub curve

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 lifetime¹. In this condition an asset has to be replaced within the next years. The transition from condition B to C is defined by a distinct increase of failures (see Figure 8).

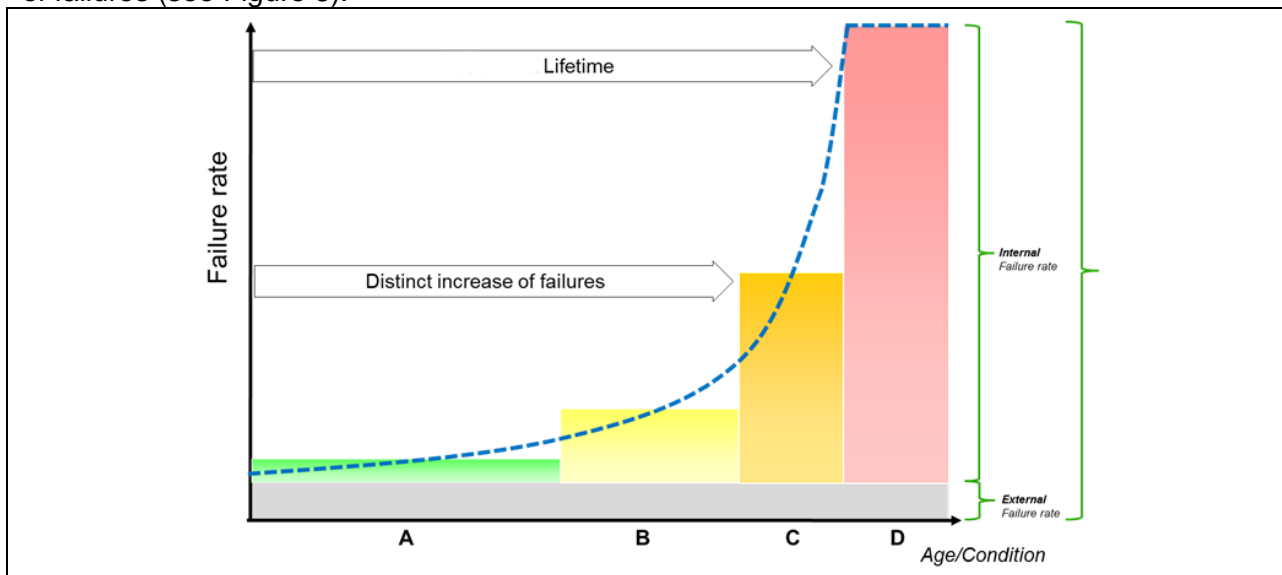


Figure 8: Definition of condition transitions

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 2.2.2 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

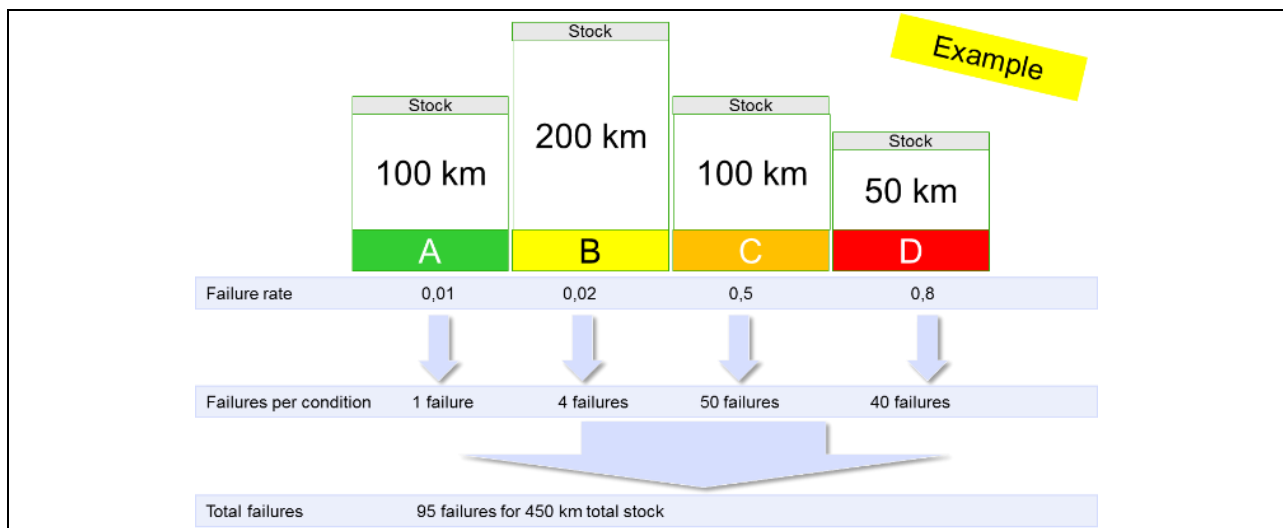


Figure 9: Example how to calculate the number of failures of an asset type according to its condition distribution

2.2.4 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.

2.3 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 defined 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

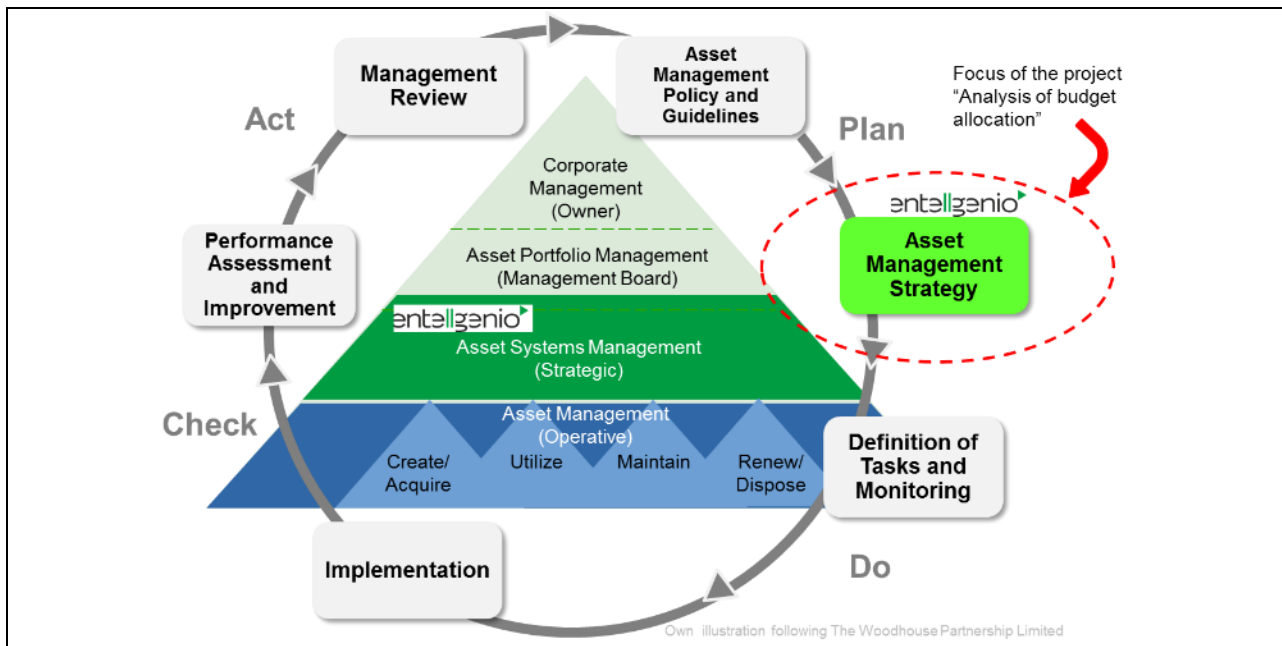


Figure 11: ISO55000 defines the elements of asset management as a cycle of activities

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

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

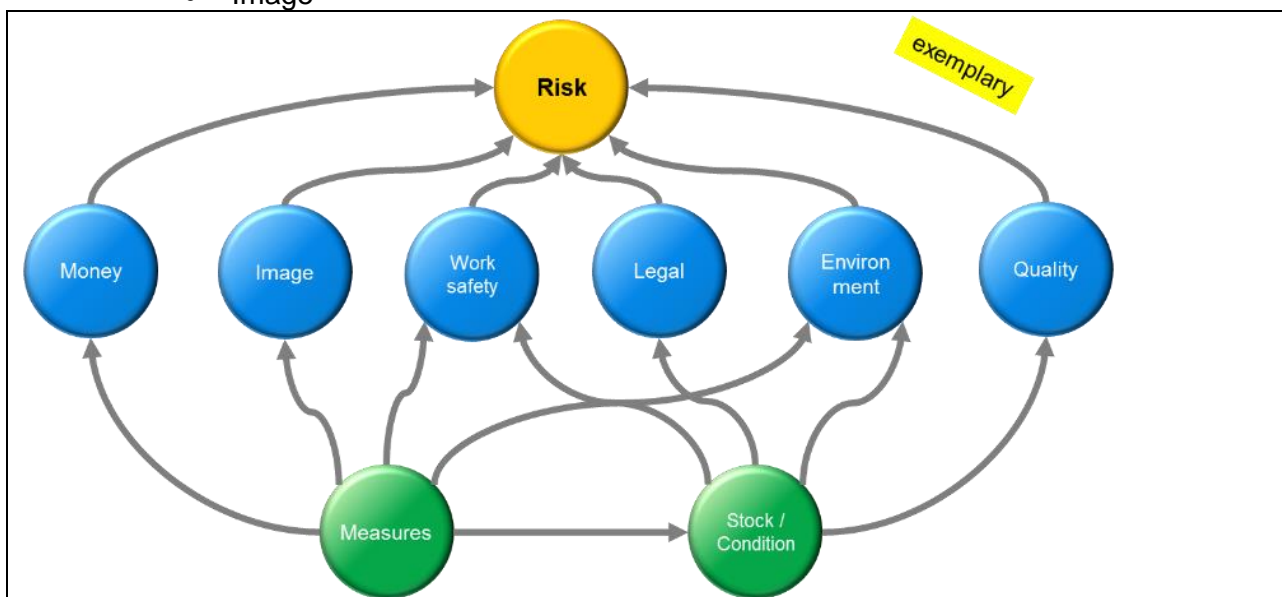


Figure 12: Extension of the Causal-Loop-Diagram (simplified representation) to integrate the PAS 55 approach

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 the targets customer and owner risk examined in the current project.

3 Synopsis (incl. targets) of project “Analysis of budget allocation”

The objective of the current project is to answer the following question for Elektrilevi:

Based on the assumptions between the relation of age and condition for existing asset groups: Is current budget allocation for to existing asset groups for 2017 done right? Are there any areas where current budget should be allocated differently?

Additionally to the base question the following issues have to be answered:

1. Calculate 2017 budget allocation between asset groups of Elektrilevi based on the assumptions between the relation of age and condition for existing asset groups
2. Calculate risks levels of asset groups at the end of 2017, if using 2017 budget allocation
3. Analyze with simulation calculated and planed 2017 budget allocation differences
4. Give 2017 renewing amount of asset groups, if implement budget allocation with simulation calculated
5. Give risks levels of asset groups in Elektrilevi at moment
6. Give list of risks components by asset groups what was used in calculations)
7. Give levels of risks by risks components in every asset group

Basis to answer the above question is entellgenio's Asset Management Service which is certified according to IDW PS 951.

The project was implemented during the period from February 2016 to November 2016 with the project phases:

- Specification of the simulation model and supply of required data
 - Discuss required stock/parameter data and data formats
 - Agree on assumptions about relation of age and condition
 - Setup of the specific simulation model for Elektrilevi
 - Supply the required stock and parameter data
- Data processing and validation
 - Validation (including calibration) and preparation of supplied stock data files
 - Data processing according to the technical concept
 - Data validation with the specific simulation model
- Analysis and results
 - Analysis of the current investment and maintenance budget
 - Answer question „Is current budget allocation to existing asset groups done right? Are there any areas where current budget should be allocated differently?
 - Draw insights/ make recommendations

To answer the mentioned question for Elektrilevi a specific simulation model was created. The asset tree is split into the voltage levels medium voltage (MV), medium/low voltage (MV/LV) and low voltage (LV). Every voltage level is then divided further into asset groups like stations and cables. The elements at the bottom of the tree are the asset types like 35 kV cable. These asset types all carry 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. To better reflect cost and aging differences in the regional structure of the grid of Elektrilevi some asset types like non-insulated overhead lines were added to the tree twice: one asset type for rural assets and one for other regions (urban, urban core and suburban). Figure 13 shows the complete asset tree of Elektrilevi that was used to build the simulation model. Data of the assets of Elektrilevi is then used to fill the model. During the process of data import every actual asset is assigned to exactly one asset type in the tree.

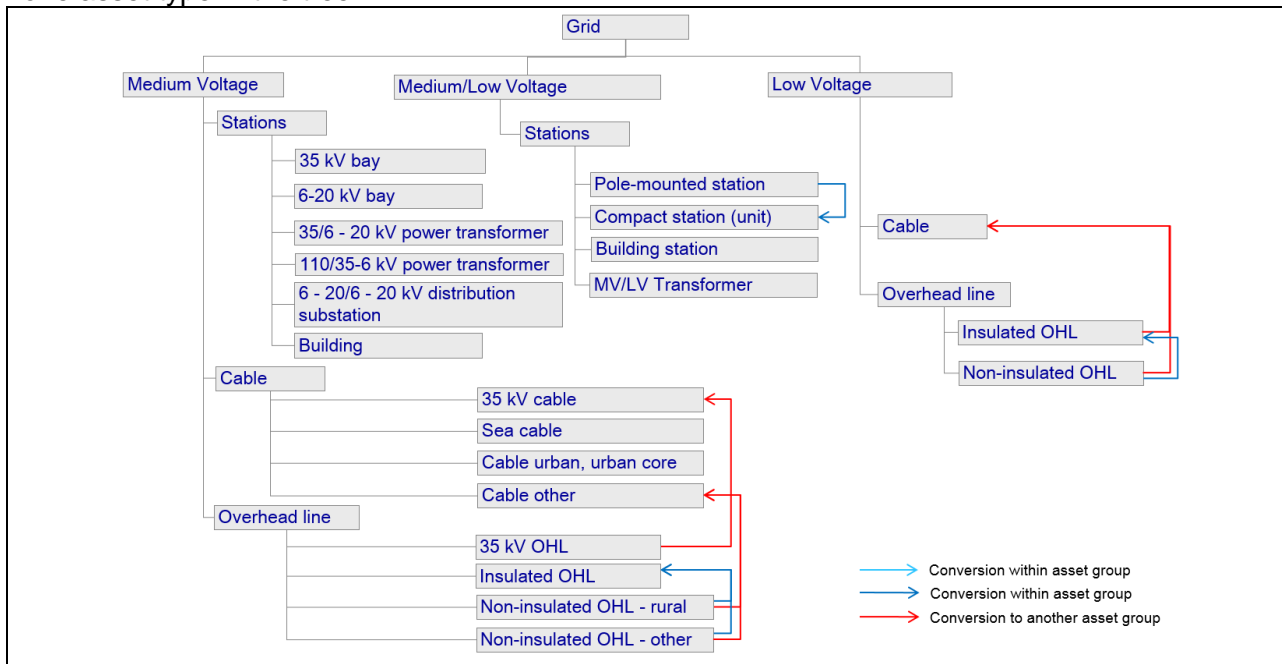


Figure 13: Elektrilevi asset tree

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: Average age at the end of condition C (AC_C) is the bookkeeping lifetime

Assumption 2: Average age at the end of condition B (AC_B) is defined as:

$$AC_B = AC_C - 10 \text{ years}$$

Assumption 3: As Assets in condition A and B are at the bottom of the bathtub curve it is usual 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 14 and Table 3.

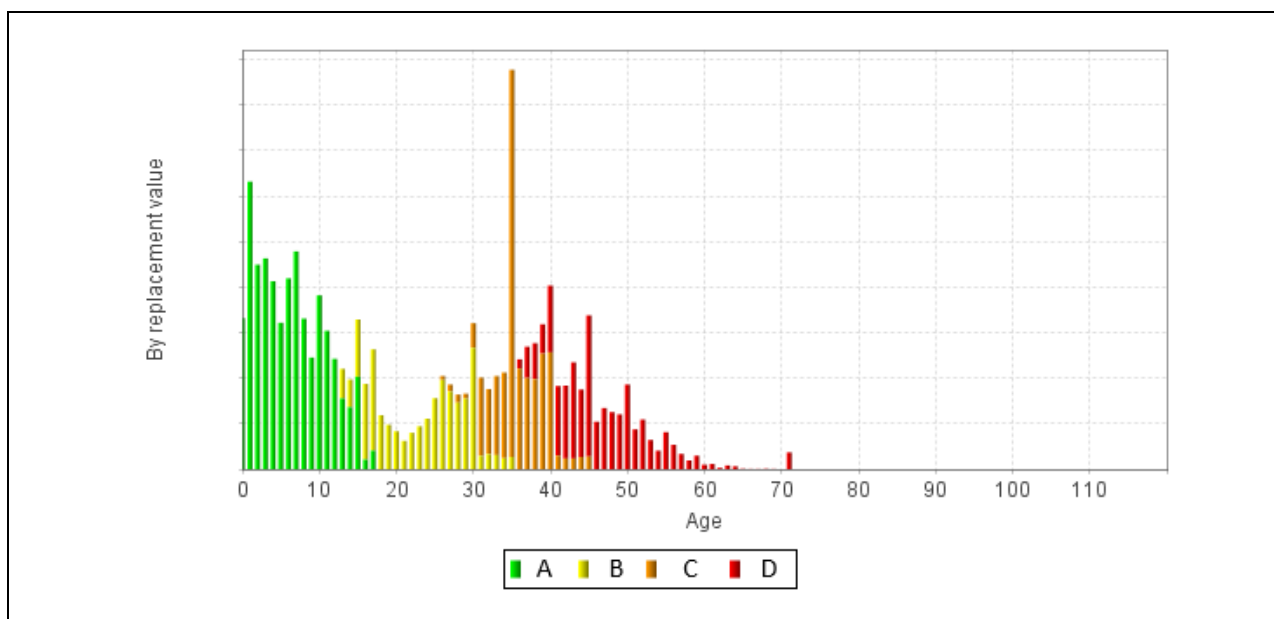


Figure 14: Age distribution of Elektrilevi

Assets	Condition				Total
	A	B	C	D	
35 kV bay	279	101	134	337	851
6-20 kV bay	1900	870	949	861	4580
35/6 -20 kV power transformer	79	33	58	48	218
110/35-6 kV power transformer	10	2	1	3	16
6 -20/6 -20 kV distribution substation	55	49	72	63	239
Building	42	48	58	94	242
35 kV cable	39	23	32	13	106
Sea cable	31	2	2	0	35
Cable urban, urban core	784	640	387	342	2153
Cable other	4441	592	326	142	5500
35 kV OHL	98	423	599	1003	2123
Insulated OHL	1168	193	0	0	1361
Non-insulated OHL -rural	980	2493	6164	2542	12179
Non-insulated OHL -other	247	632	2075	787	3741
Pole-mounted station	4987	3145	112	248	8492
Compact station	5490	3723	2859	2364	14436
Building station	90	216	187	191	684
MV/LV Transformer	14463	6143	2965	3508	27079
Cable (LV)	6638	1210	922	616	9386
Insulated OHL (LV)	11854	2552	16	26	14448
Non-insulated OHL (LV)	46	537	3399	5500	9483

Table 3: Elektrilevi assets divided into condition classes (unit: pcs/km)

We assume that the probability of a damage (= damage rate) increases with the age of an asset according to the bathtub curve described in fig.7. The following damage factors are used to calculate the damage rate for every asset and condition: 1 (A), 2 (B), 4 (C) and 10 (D). Combined with data from the Elektrilevi fault statistics 2015 the damages rates in Table 4 are calculated.

Assets	Damage Rate			
	A	B	C	D
35 kV bay	0.0023	0.0046	0.0091	0.0228
6-20 kV bay	0.0016	0.0031	0.0062	0.0156
35/6 -20 kV power transformer	0.0012	0.0023	0.0047	0.0117
110/35-6 kV power transformer	0.0208	0.0417	0.0833	0.2083
6 -20/6 -20 kV distribution substation	0.0075	0.0149	0.0299	0.0747
Building	0.0008	0.0015	0.0031	0.0076
35 kV cable	0.0030	0.0059	0.0119	0.0297
Sea cable	0.0230	0.0460	0.0921	0.2302
Cable urban, urban core	0.0242	0.0483	0.0967	0.2417
Cable other	0.0175	0.0350	0.0700	0.1749
35 kV OHL	0.0014	0.0028	0.0057	0.0142
Insulated OHL	0.0373	0.0746	0.1493	0.3732
Non-insulated OHL -rural	0.0288	0.0576	0.1153	0.2882
Non-insulated OHL -other	0.1223	0.2446	0.4893	1.2232
Pole-mounted station	0.0045	0.0090	0.0180	0.0451
Compact station	0.0087	0.0175	0.0350	0.0875
Building station	0.0003	0.0006	0.0013	0.0031
MV/LV Transformer	0.0018	0.0035	0.0070	0.0175
Cable	0.0258	0.0516	0.1033	0.2581
Insulated OHL	0.1509	0.3018	0.6036	1.5090
Non-insulated OHL	0.1651	0.3302	0.6603	1.6508

Table 4: Damage rate per asset and condition

In addition to the adaptation of the asset tree the target tree was also extended with three additional risk targets that reflects the customer and cost side of a potential damage. Figure 15 shows a standard Causal-Loop-Diagram.

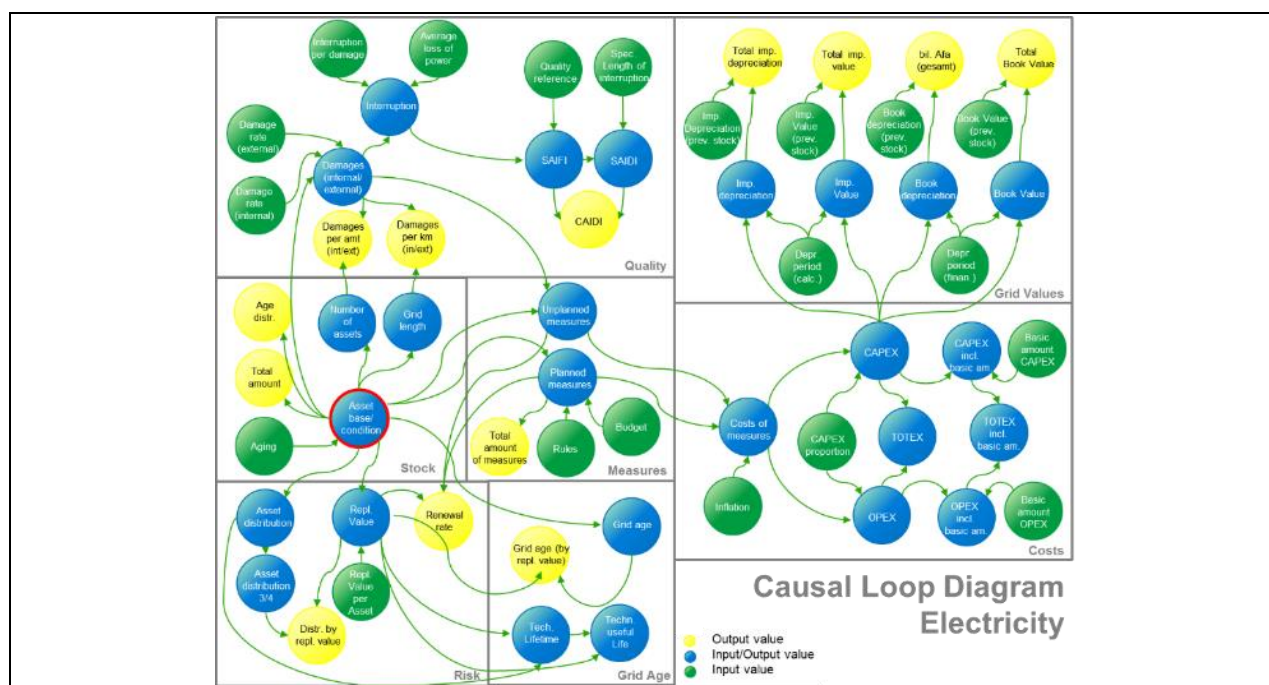


Figure 15: Standard Causal-Loop-Diagram

Three new target values were added to the model to calculate the budget allocation: risk based on affected customers, risk based on repair costs and risk based on replacement and repair costs. All risk values use the number of damages per asset:

Number of damages =

$$\sum_{A,B,C,D} (\text{Number of assets in condition}_{A,B,C,D} \times \text{damage rate per condition}_{A,B,C,D})$$

The risk based on affected customers combines this information with the average value of affected customers per damage to calculate the risk level:

Risk of Elektrilevi based on affected customers =

$$\text{Number of damages} \times \text{customers affected by damage (average value)}$$

The risk values based on replacement and/or repair costs on the other hand give a monetary estimation of the risk:

Risk of Elektrilevi based on repair costs =

$$\text{Number of damages} \times \text{repair cost per damage (average value)}$$

Risk of Elektrilevi based on repair costs for lines and replacement costs for plants =

$$\text{Number of damages} \times \text{repair cost per damage (average value) if line else replacement costs per damage (average value)}$$

These target values are calculated on an asset level and are added up for all higher levels of the asset tree. The given CAPEX budget for 2016 to 2021 is used to calculate measure amounts for renewal and conversion: the 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 OPEX budget is divided into the following categories: inspection cost, defects and maintenance cost, interruption elimination cost, planned maintenance for stations, line corridor maintenance for Overhead Lines.

During conversion of non-insulated overhead lines in rural areas is a reduction of total overhead line length in the grid of Elektrilevi.

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