Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Manufacturing and Civil Engineering

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A move towards smart water infrastructure

An evaluation of utilizing Multi-Criteria Decision Making methodologies to determining Internet-of-Things and Digital Twin requirements

Master's thesis in TØL4902
Supervisor: Niels Peter Østbø
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Preface

The following thesis concludes a two-year study program in sustainable manufacturing. The original course of study was from 2013-2015, but due to unforeseen events the writing of the thesis was put on hold.

The thesis is written while balancing school, family life and working as a municipal employee. While writing the thesis it has proven difficult to distinguish between the roles, as a student and an employee, especially given my role in the municipality; Involved in IT solutions, Water and infrastructure, civil engineering, and planning. Additionally, If I was to start writing the thesis now there are several changes I would have made based on the acquired knowledge.

I want to express my gratitude to Vevelstad Municipality who allowed me to use some of my time at work to write the thesis, and to allow me to use my office during evenings and late nights for personal reasons. Furthermore, I would like to thank NTNU to allow me to submit a thesis even though it is seven years since it was supposed to be done.

I also want to express my gratitude towards Niels Peter Østbø for his guidance, discussions, and supervision throughout the process. Even though we haven't had the pleasure to physically meet and discuss the thesis, his suggestions were immensely helpful.

Furthermore, I would give a thank you to all those who were able to lend a hand to help us through our everyday life. Most of all, I would like to thank my girlfriend and our two children for their patience throughout the entire process during the completion of the thesis.

Abstract

In the recent year the focus on sustainability has increased, and in 2015 the United Nation presented the concept Sustainable Development Goals. Additionally, the focus on the water infrastructure has increased due to the cost related to future maintenance and the reported leak percentage.

The industry related to water infrastructure and the research performed on the topic agrees that the notion of automating the process is a good idea. However, there are no descriptions on how to make the transition from having no automation to a fully automated system. The description of the automated process is also ambiguous regarding the content, but it relies on Internet-of-Things (IoT) technology.

The approach to use Multi-Criteria Decision making (MCDM) as a means to make decisions regarding the different IoT solutions requires a clear project description. The premises behind the project could potentially make different MCDM approaches more suitable than others. The reason is that different MCDM techniques can handle different types of data, and the premise of the project could increase the amount of data needed to make an evaluation.

The decision to implement IoT in water infrastructure is affected by the determined end-product, which is decided by one or several decision makers. The final product and the applied MCDM – methodology depend on the boundaries of the project. It is also possible to use MCDM to decide the technological level of implementation in cases where the Decision Maker is unable to determine the project boundary.

Aside from defining the goal and scope of the project, the next key factor is the internal data-mapping required to determine the current available technology. When all the data is gathered and organized the process of determining how to implement a smarter water infrastructure can begin.

Sammendrag

I de senere år har det vært økt fokus på bærekraftighet, og i 2015 presenterte FN konseptet de bærekraftsmålene. I tillegg har fokuset på vannledningsnettet økt på grunn av kostnader knyttet til fremtidig investeringsbehov og de rapporterte lekkasjetallene.

Industrien knyttet til vannledningsnettet og forskning utført på området er samstemte på tanken på økt automatisering av prosessene er en god idé. Men, det er ingen beskrivelse på hvordan man skal gjennomføre overgangen fra å ha liten, eller ingen automatisering, til et helautomatisert system. Beskrivelsen av det automatiserte systemet er uklar, men det bygger på Internet-of-Things (IoT) teknologi.

Tilnærmingen til bruken av Multi-Criteria Decision Making (MCDM) som et verktøy til å ta beslutninger angående de forskjellige IoT løsningene krever en klar prosjektbeskrivelse. Forutsetningene bak prosjektet kan potensielt gjøre forskjellige MCDM metoder bedre egnet enn andre. Årsaken er at forskjellige MCDM teknikker kan behandle forskjellige typer data, og forutsetningene til prosjektet kan øke den nødvendige datamengden for å kunne ta en beslutning.

Beslutningen om å implementere IoT i vannledningsnettet er påvirket av beslutningen om type sluttprodukt, som er avgjort av en eller flere beslutningstakere. Sluttproduktet og den anvendte MCDM metoden avhenger rammegrensene til prosjektet. Det er også mulig å bruke MCDM til å avgjøre det teknologiske nivået på implementering i tilfeller hvor beslutningstaker ikke er i stand til sette rammegrensene.

Sett bort fra å definere mål og omfang på prosjektet, så er den neste nøkkelfaktoren den nødvendige interne datakartleggingen for å kartlegge nåværende teknologi i vannledningsnettet. Når all informasjon er samlet og organisert så kan prosessen om hvordan man kan implementere smart vannledningsnett snart begynne.

Content

List of figures

List of tables

List of abbreviations

BIM	Building Information Modelling
CBS	Case-based Reasoning
CPP	Cost/price principle
DM	Decision maker
DQR	Data Quality Requirement
DT	Digital twin
FM	Facility management
KOSTRA	KOmmune-STat-RApportering
KPI	Key performance index
KS	The Norwegian Association of local and regional Authorities
MAUT	Multi - Attribute Utility Theory
MCDM	Multi - Criteria Decision Making
SAW	Simple Additive Weighting
SDG	Sustainable Development Goals
SMART	Simple Multi Attribute Rating Techniqeu
SSB	Statistisk Sentralbyrå
UN	United Nations

1. Introduction

Beginning with a survey the British medical journal did in 2006 (Ferriman, 2007), the readers was asked to choose from a certain number of topics and select the topic which they considered the "greatest medical advance since 1840". According to the readers the greatest advance was the access to clean water and sewage system, or the sanitary revolution, and this is still important today.

In September 2010 the UN's human rights council decided that access to sanitary and water is a human right. Today there are about 2.2 billion people with no access to clean drinking water, and about 297.000 children under the age of five dies from diarrhea-related diseases because of their sanitary conditions (United Nations, 2022). The United Nations additionally decided in 2015 to implement the Sustainable Development Goals (SDG), further known as the global goals. In total there are 17 SDGs that are meant to end poverty and ensure peace and prosperity by 2030. Each nation can choose to work towards these goals, and a key aspect is the ability to measure improvement.

Norway decided to develop an action plan for the SDG regarding Norway's contribution. The action plan (Meld. St. 40 (2020–2021), 2021) describes how everyone must contribute, and it is a document that presents the 17 different SDG and how it is interpreted from a Norwegian perspective. They break down the global indicators into "possible Norwegian measurement indicators" which is a subset of key performance indicators (KPI) that Norway must follow.

Figure 1: Overview of the 17 SDG's

From a municipal standpoint there are implementations that could be done regarding short-term and long-term improvement. In a long-term perspective the SDG could be included in the municipal area- and regulation-plans, to ensure sustainable development on sea and land. This is mainly laying the groundwork for implementation in the future because each plan is required to be on open hearings, verified by other governmental institutions, and be accepted by the local community. The governmental institutions also follow the SDG to ensure nationwide implementation and is a main concern when objecting to plans on open hearing.

When it comes to smaller municipalities there is no reason to not implement or adjust to the SDG. A more common phenomena is the lack of resources and knowledge on the area. For those who are unable to do this work themselves are using tenders to acquire external aid. Another dilemma is the ability to perform multiple similar tasks simultaneously, which could make the time span for these processes to last several years; it is a question relating to available resources. This has led to the municipalities implementing the SDG in tenders, often related to more short-term results.

Typical terms municipalities are familiar with:

- Green building
- Green transportation
- Green industry
- Green management
- Green economy
- Clean water

To increase awareness of climate change and environmental questions the Miljødirektoratet(2019) has developed a guide for climate- and energy planning. It does not raise awareness towards the SDG, but it does focus on environmental awareness, and it lists benefits regarding having a separate climate- and energy-plan contrary to having it integrated in the municipality plan.

1.1 Background

For Norway to achieve the different SDG's it stands to reason that the different Norwegian municipalities also must work towards the national KPI's. To achieve this the municipality must create an environment whereas it is possible to work towards the KPI's and the SDG. Depending on the different regional challenges the solutions may vary, be it out-of-the-box thinking, land management, local infrastructure, industrial benefits, or through economic incentives from the state.

The most relevant goals that yield most short-term effect in smaller municipalities is assumed to be:

- 6th Clean water and sanitation.
- 7th Clean energy
- 9th Industry, innovation, and infrastructure.
- 11th Sustainable cities.
- 14th Marine life.

Based on the most relevant SDG it is natural to question how this is achievable in the municipalities, and how to determine the requirements for improving. According to The Norwegian Association of local and regional Authorities (KS)(2022) every municipality is required to produce a variety of plans. The plans are divided into main plans and theme plans, whereas the thematic plans are a subset of the main plans. The duration of these plans varies, but an Action plan should be revised every four years. Another example is the Economic plan which undergo a yearly revision for a four-year timeframe.

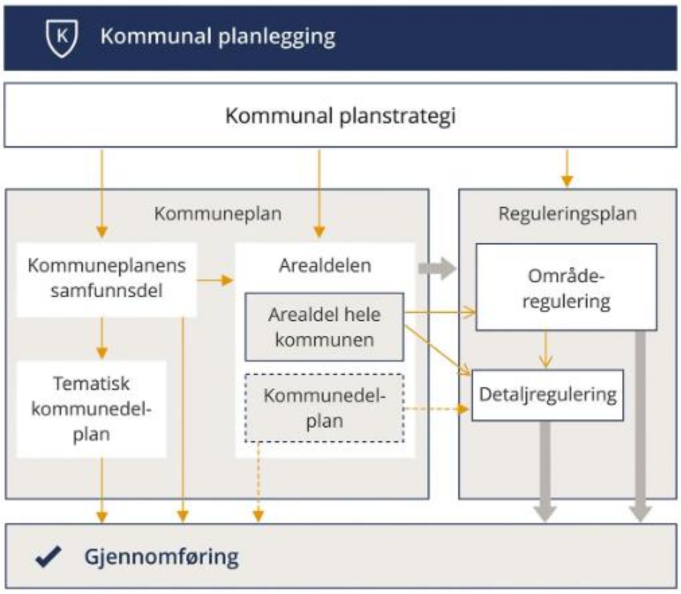

Figure 2: Municipal plan process (Regjeringen.no, 2022)

To implement the SDG's in the municipalities it is necessary to be included into the municipal plan work. Furthermore, the different plans have different laws they need to consider. The duration of work to revise, or produce, required for each plan is also dependent on the laws. It is requirements, such as open hearing and political anchoring. The different processes have different timeframes, and there could be several hearings for one plan. Considering the timeframe, it could be concluded that this process takes months, and if it includes more than one plan it could take years depending on the resources available.

According to KS (2022) the municipal action and social plan includes all of the municipal tasks and goals, making it natural to describe how the municipality implements the SDG's. The underlaying thematic plans then describes in more detail how the SDG are implemented in their area. Those plans will function as a framework for the departments, especially for Facility management (FM) and Technical department and their tenders. In the tenders the requirements for the end-product and the entrepreneur are specified. The departments could demand energy efficient buildings and systems, as an end-product, but it is also possible to demand a green construction process. The biggest challenge in that aspect is the dependencies regarding the economic perspective. Another challenge is the capacity of the local electrical grid to support zero-emission vehicles.

Example:

Electric tools, green transportation, zero emission groundwork, zero emission transportation are examples of sustainable construction processes. Regarding transportation it requires that the different entrepreneurs have zero emission vehicles, and it also requires the possibility of charging the vehicle on the way during deliveries. For zero emission groundwork there are battery solutions, is it possible to use the amount of electricity needed to support a sustainable construction process?

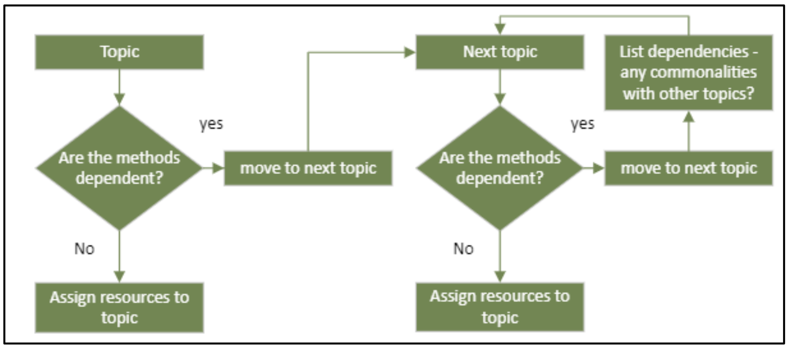

Figure 3: Simplified thought process for identifying conditional requirements.

The example is based on figure 3. A precondition is that we have listed different tasks, orders, and assignments. All the different topics and events are either listed or sorted into subsets. The purpose is to find topics which is intertwined with each other due to common dependencies. The figure also assumes that the municipality have sufficient resources to assign to the different topics.

In 2021 Miljødirektoratet arranged a climate convention in Bodø, Nordland County. During the convention different topics were discussed. The one physical topic that was common for the whole county was infrastructure. Aside from the physical topic there was also 2 human factors that were common. 1. Resources, and 2. Knowledge. To solve the human factors regarding sustainability the concept of work sharing was discussed to not perform overlapping work in several municipalities.

Recent challenges:

Today we have to face new challenges. The price for electricity has been rapidly rising, and at the same time the water reserves are running low in several municipalities. It is expected that the cost for electricity will rise, as way to urge the community to use less electricity. In addition, Norway is one of the countries in Europe with the highest water leak percentage. In certain areas about 40% of the treated drinking water is lost due to leaks in the water pipeline infrastructure, and in some local cases even more. (Norsk vann, 2022a)

Since Norway, historically, has never had any lack of accessible drinking water the leak percentage has not been addressed as an issue. Combined with the lack of maintenance on the different pipelines this has even become an important topic.

1.2 Problem statement

The main purpose of the thesis is to investigate a method for decision-making in relation to municipal water infrastructure. The concept of smart delivery systems, automation, surveillance, and technology is to a degree commonly used today. Furthermore, studies show that it is highly recommended to use such systems due to efficiency and data gathering properties(Shinwari, Youssef and Hamouda, 2012), but there are little to no information regarding how to prepare for such a system.

Additionally, on a nationwide scale the water infrastructure is behind on upgrades and maintenance(Sintef, 2021), and drinking water is one of the SDG's. Furthermore, fresh water is a valuable resource for marine life industry in Nordland County. Based on the different challenges in the area an evaluation-method for making the right decisions at the right time is valuable and is worth investigating.

This thesis is going to investigate the requirements for long term planning for water infrastructure. The goal is to investigate which information is needed to take the right decisions at the right time. The municipalities want industry development, enough water for emergency situations, drinking water, and it stands to reason that we need a model for how to make the right decisions and where future investments need to be made. To have proper FM, the infrastructure needs to be able to transmit information. For operation and maintenance, the grid could be equipped with measuring units connected to Internet-of-things (IoT) transmitters, displayed in a Digital Twin (DT). On a long term basis, the system itself could be prepared to support Building Information Modelling (BIM) in simulation scenarios, and if needed simulations on the network for further improvement.

Research Problem:

Is it possible to apply a MCDM technique to determine best course of action to achieve an IoT or DT solution?

1.3 Objectives & scope

The main objective of the thesis is to explore and identify common traits in a common water pipeline in a municipality. The different municipalities will have different geographical challenges, but the main objective is the same: To deliver clean water to the inhabitants and companies in the municipality. Henceforth, the thesis will not investigate the water source itself as a criterion, the process to purify drinking water, or the sewage system.

Secondary objective is to identify requirements for various types of technology, systems, and criteria that can provide the municipalities with the required information needed to make the right decisions at the right time.

The tertiary objective is to investigate if different decision makers (DM) require different approaches for choosing methodology for the infrastructure evaluation.

1.4 Thesis structure

This thesis is a compilation of six chapters, and the thesis is structured as follows:

1. **Introduction**

Presents the background of the thesis, problem statement, including the scope and research topic.

2. **Methodology**

Describes the theoretic background behind the research, and how the research problem presented in the introduction was solved.

3. **Theory**

Presents relevant theory and information on the topic required for understanding the premises of the thesis.

4. **Results**

A presentation of findings and results from the conducted research

5. **Discussions**

Discusses the results as they relate to the research problem.

6. **Conclusion**

Contains the final observations as they interact with the research problem.

2 Methodology

2.1 Design of the study

As described by Leedy and Ormrod (2010), the research process is a methodical process of collecting, analyzing and data interpretation. The different methodologies have their own strengths and weaknesses and choosing the correct method for solving the problem stated in 1.2 and 1.3 is important. Based on the research problem, and the objectives, this thesis is focusing on methodology. Randolph (2009) states that the goal of literature review is to integrate, generalize, conflict resolution, and linguistic bridge building. Furthermore, use the information to analyze previous research, its central issues, and clarify a line of arguments within a certain field.

The outline of the methodology is:

- Literature review
- Combination of qualitative and quantitative research

The method while conducting research is the common approach researchers take. In a way the method determines the tools the researcher selects, and the design of the research must be clear (Leedy and Ormrod, 2010). Normally the research methods are described as either quantitative or qualitative but Bryman (2016) states a question if a quantitative and qualitative boundary could be regarded as hard and fast one. Bryman states the difference lay in the emphasis of presentation, where qualitative focus on words, and quantitative focus collection and analyzing data.

The quantitative approach is the evaluation of quantities of one or more variables. The standard approach of quantitative research is breaking down components into empirical data to support their claim. It could be done by standardized equipment, or a method of their own design; it is typically in form of tests, questionnaires, and scales. Thus, a good example of such quantification is the measurement of sadness, happiness, and depression. (Leedy and Ormrod, 2010)

As described above the focus on qualitative research is text, which is considered soft data. Hence, soft data is information, or characteristics, that are not easily broken down into empirical values. The study of the human perspective towards complex circumstances is such a case. Bryman (2016) describes qualitative research as research concerning a group of theories contrary to the testing of theories.

This thesis is investigating how it is possible to quantitatively determine the best approach to reach a goal determined by a DM. However, the task performing a quantification, or the methodology, of criteria is not a part of the thesis. The literature review will go through methodologies capable of performing that task, and the thesis is qualitative in nature given that the computations are based on human perceptions and evaluations. The thesis itself will not present new hard data, but present how to produce new hard data based on previous quantitative research. The Theory is built up with tables and equations as examples to serve as a guide for future application.

2.2 Literature review

The benefits of performing a literature review are it can give an overview of a field of research which was previously unfamiliar. The method can serve as inspiration for new topics, increase awareness towards previous research completed in the field, and it can be helpful to determine if there are any pre-existent flaws in the area. Furthermore, it can serve as a part of a bigger study for further research (Knopf, 2006).

The topic was originally based on the different SDG's and how the municipality could approach the different KPI's that were set at a national level. While analyzing what the municipality could do that could yield an immediate effect to achieve those goals the decision was made that infrastructure was a relevant topic. Improving the infrastructure yields an improved KPI as a side-effect.

Norsk Vann (2022b) is an important organization providing the members, about 320 municipalities and about 96% of the Norwegian population, with vital information. Given the need for maintenance and upgrades on the water infrastructure in the municipalities of Norway, a methodology for the work is needed.

Using Norsk Vann as a source of inspiration it was identified topics as:

- Sustainable water delivery systems
- Development of water pipelines
- Sustainable calculations of leaking percentages
- Quality assurance on pipelines
- Smart water distribution

Norsk Vann sort the reports in A, B and C quality. Some of the reports are older than 8 years, and the reports mainly discuss the physical aspect of this industry. Furthermore, Norsk vann does not describe how to take on a project on how to digitalize the delivery system, but only describes that it is beneficial.

As a control the researcher went through information provided by The Norwegian Association of local and regional Authorities (KS). KS have information about the SDG's, digitalization, and smart technology. Furthermore, KS had no information about how to develop a smart water infrastructure, but KS is a potential partner for developing a project. On the other hand, Digitaliseringsdirektoratet has some information regarding some technological aspects the decision maker needs to be aware of, such as:

- framework
- rules
- semantics
- technological operability
- Network security

As mentioned, it is not described how to approach the digital era in water infrastructure. This led to the investigation of different IoT solutions, Digital twin, and if MCDM could be used as a tool to decide how and where to start. Furthermore, it led to a more practical approach where it was investigated what kind of information an entrepreneur, or the municipality itself, could provide when working on the municipal water infrastructure. A common challenge today is that a lot of the older workforce has a lot of information which is undocumented for the future generations. Regarding Vevelstad municipality it is beneficial to avoid the following situation:

> *"We had to get a retired man from the nursing home last week to pinpoint where the leak was"*

Henceforth, it was put emphasis on securing undocumented data. Internally in Vevelstad municipality this led to group discussion where it was discussed which common questions could be expected if the municipality has insufficient data. The conclusion was five points:

- When the pipes were laid
- Type of materials
- Exact position
- Dimension
- Are there any other private waterpipes connected to that pipe

The abovementioned was the core basis to perform a literature search to locate material for review.

2.3 Literature search

Searching method – Boolean “AND, OR & NOT”

Boolean Operation	Search modifiers	Purpose
AND	+ & AND: Infrastructure and water	Inclusion
OR	Internet or IoT	Multiple hits combining either word
NOT	- and NOT: Infrastructure NOT road	Exclusion
Term specification	Quotation marks: “IoT”, “Internet of things”,	Avoids search hits with AND/OR priorities. Finds only the term specified in quotation
Parentheses/Grouping	Parentheses: (IoT or Internet of things)	Combining relevant topics

Table 1: Boolean searches - examples

Relevance and Reliability evaluation of publications

Technology is a field with rapid changes, making papers and publications from a newer date more relevant. Searches on digital twin and IoT were limited to 3-5 years ago.

Topics regarding management, MCDM, and methodology are ideas or publications which are considered more unlikely to be outdated if the search reaches further back, i.e. 10-25 years.

Facts and statistics related to the water infrastructure in Norway are mostly based on KOSTRA numbers and is based on tables combined in the statistics central bureau (SSB). In addition, Norsk Vann is an active and leading participant in the sector.

This leads to three different methods to apprehend information on the different topics:

Technological	
Example - Search term	Age/Date
“IoT” or “Internet of things”	*1-3y*
“Digital twin”	*1-3y*
“Digital twin” + “IoT”	*1-3y*
“Digital twin” + “IoT” + “water”	*1-3y*
Management and methodology	
“multi-criteria decision making”	*1-25y*
“Mcdm”	*1-25y*
“mcdm”+methodologies	*1-25y*
“mcdm”+”literature review”	*1-25y*
Facts and statistics	
“Norsk vann og rapporter”	*1-3y*
“SSB”	*1-3y*
“KOSTRA”	*1-3y*
“Sintef”+”Vann”	*1-3y*

Table 1: Search patterns and result

Search hit assessment

Technological:

For IoT and digital twin there were a lot of different papers and journals published. A commonality is that the information presented the benefits and uncertainties of such a system. A presentation of smart grid water supply presents why it should be done, but there was no information on how to implement such a system. It determines that the study in the thesis is very case specific.

Management and methodology:

The process involved in finding information about MCDM as a concept, and sorting through different MCDM techniques. To determine potential MCDM techniques a range of MCDM techniques literary reviews was studied. A few MCDM-techniques was selected for further investigation, based on the properties of each techniques, and the process described in table 1 was a repetitive cycle for each technique.

Such as:

"MCDM"+"AHP", "MCDM"+"Fuzzy Theory", "MCDM + MAUT"

In addition to the traditional theories, a more modern approach is the combination of two or more MCDM techniques. In the process of writing the thesis the method of combining the techniques is not considered as a separate technique. It is based on the review by Velasquez and Hester (2013) where a review on eleven different techniques was performed. If each method of combining consisted of two of the techniques, there would be 110 different approaches, and is in this thesis therefore considered be case specific.

Facts and statistics:

Using SSB as a source of information requires awareness regarding:

Age of data

The use of relevant filters

Understanding where the data comes from

Without that information it makes it more difficult to interpret the statistics, and the wrong conclusion could be drawn from faulty data, or incorrect use of filters.

3 Theory

3.1 Multi-criteria decision making (MCDM)

The field of multi-criteria decision making (MCDM) could be described as both old and new. It could be described as old since people historically had to choose between a certain set of possibilities. The modern approach to MCDM were developed in the 1950s and the 1960s where the method to explain this process is studied. (Koksalan, Wallenius and Zionts, 2011). Furthermore, the topic of MCDM covers multi-objective decision making (MODM), and multi-attribute decision making (MADM), as it describes the same type of models (Triantaphyllou, 2000). MCDM is a method developed to deal with common management problems. Additionally, management must deal with several objectives, and the objectives are often conflicting with each other. It is meant to cope with economics, finance, resources, time management, and more.

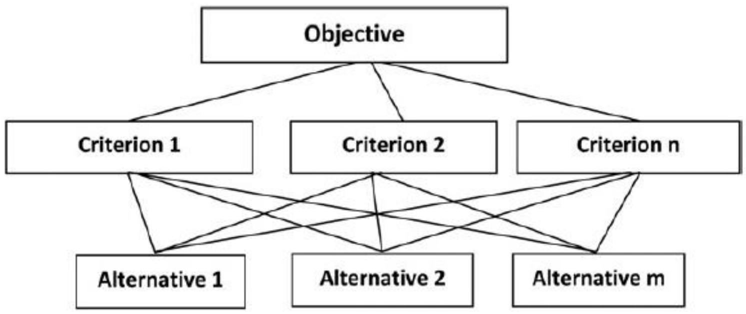

Figure 4: MCDM - Objective illustration (Chourabi et al., 2018)

Figure 4. illustrates the process of defining one objective with n-criteria and m-alternatives. Furthermore, the process of achieving a goal could be a compilation of multiple objectives.

As mentioned above, the concept of MCDM refers to making decisions based on a certain set of criteria, and it’s not only related to business problem. MCDM is also applicable in everyday life, like choosing a school, a new car, buy a house, rent a house, and criteria for each objective could be ranked according relatable for the DM. The criteria could consist of: Cost, size, comfort, accessibility, quality and more. These are relatively simple cases to use as an example for illustrating the capabilities of MCDM, but in business context the problems are far more complex and larger in scale. Lots of companies in Europe are performing an organization wide self-assessment. The self-assessment is based on hundreds of criteria and sub-criteria determined by the European Foundation for Quality Management (EFQM) business excellence model (Daniel, Naderpour and Lin, 2018). Furthermore, some departments are needed to be able to break down their less tangible services into criteria, such as: sale service, quality management, and economic stability. Xu and Yang (2001) explained that the development of computer technology has benefitted the study of MCDM, thus making it possible to accumulate and manage larger amounts of data. Henceforth, this made MCDM more vital and useful in the process of business decision making.

Based on the increased amount of data collected and published over the years the research area of MCDM has increased, resulting in different types of methodologies. Henceforth, the methodologies have underwent refining and testing throughout the last couple of decades, and Velasquez and Hester(2013) did a study on MCDM methodologies. In the study they sorted the different methods and highlight the different advantages and disadvantages. The use of the different methodologies could be sorted into areas of application and the various advantages and disadvantages. The awareness towards the advantages and disadvantages of the different methodologies has resulted in various ways of utilizing MCDM. A way to weigh up for the different disadvantages is to create hybrid MCDM methodologies, which is a method of combining two or more methodologies to create a new approach (Velasquez and Hester, 2013).

Xu and Yang (2001) explains that in general there is 2 specific types of MCDM problems and it is based on the difference in problem settings. One of the types has a limited amount of solution, while to other type has an infinite number of solutions. Furthermore, generally the alternative solutions are limited in selection and assessment of problems. On the other hand, problems related to a field such as design may have properties that can take any value in range, and the potential number of solutions is thus infinite. In such cases the problem is called a multiple objective optimization problem, and not a multi attribute decision problem.

Let $A = \{ A_i$, for $i = 1, 2, 3, \ldots, n\}$ be a (finite) set of decision alternatives and $G = \{g_j$, for $j = 1, 2, 3, \ldots, m\}$ a (finite) set of goals according to which the desirability of an action is judged. Determine the optimal alternative A^* with the highest degree of desirability with respect to all relevant goals g_j.

	Criteria				
	C_1	C_2	C_3	…	C_n
Alts.	(w_1	w_2	w_3	…	w_n)
A_1	a_{11}	a_{12}	a_{13}	…	a_{1n}
A_2	a_{21}	a_{22}	a_{23}	…	a_{2n}
.	.	.	.	.	.
A_m	a_{m1}	a_{m2}	a_{m3}	…	a_{mn}

Figure 5: Standard decision matrix (Triantaphyllou, 2000)

MCDM problems could be described by using a decision matrix, which is illustrated in figure 5. Consider there are m-number of alternatives and c-number of criteria, where the decision matrix is (m x n)-matrix. Each attribute value could be presented as a_{ij} as an element being the j^{th} value of the i^{th} alternative. Additionally, even though the different MCDM methodologies have circumstantial variations, they share the following features and phases (Youssef):

- Defining the situation, the alternatives to be prioritized and the decision criteria
- Assigning weights to the different criteria
- Ranking the different alternatives

The MCDM area of study has several different ways to approach the subject, and according to Triantaphyllou (2000) the commonality for all different approaches are:

Alternatives:

Traditionally the alternatives are represented by the choices of action available to one or more decision makers.

Multiple attributes:

Every single MCDM problem is connected to multiple attributes, and they are defined as goals and/or decision criteria. In a matrix the attributes are a representation of dimensions from how the alternatives can be considered in relation the different criteria. In cases where the different criteria are numerous it can be organized in a hierarchical manner. Criteria could in certain cases be divided into main criteria and several underlaying sub-criteria. Similarly, depending on the complexity of the problem, sub-criteria could be divided into sub-sub-criteria, and so on. Depending on the MCDM methods, where some method may favor the hierarchical structure, it is normal to assume single-level criteria.

Conflicting criteria:

Based on the criteria and the dimensions of alternatives the alternative may conflict, such as relations like cost/profit, quality/profit, and cost/quality. It is best to assume criteria confliction, unless investigation show otherwise.

Units - Lacking basis of comparison:

Criteria could relate to different units of measure, for example buying a house. As an example, when buying a house, the cost-criteria is measured in currency, the age-criteria is measured in years, and the location-criteria in relation to school could be measured in meters. It is specifically this nature in MCDM problems that makes them inherently hard to solve.

Decision weights:

The MCDM methodology normally requires that the criteria is given a weights of importance. The weights are thus normalized for adding.

Decision matrix:

As described in the beginning in 3.1 a MCDM problem could be expressed in a matrix setup. In addition to the matrix it is also assumed that the decision maker, or decision makers, has decided the weights of relative performance.
(represented as w_j for J=1, 2,…,n)

Classification of MCDM methods

As previously mentioned, there are different MCDM methodologies available in the literature, and each methodology has its own characteristics. There are different ways of differentiating the different methodologies, such as Xu and Yang's (2001) solution by dividing the methods in finite and infinite number of solutions. Another way of classification is to divide by the type of information they use, such as deterministic, stochastic, or fuzzy MCDM methodologies. Furthermore, they could also be divided into single and multiple decision makers categories (Chen and Hwang, 1992).

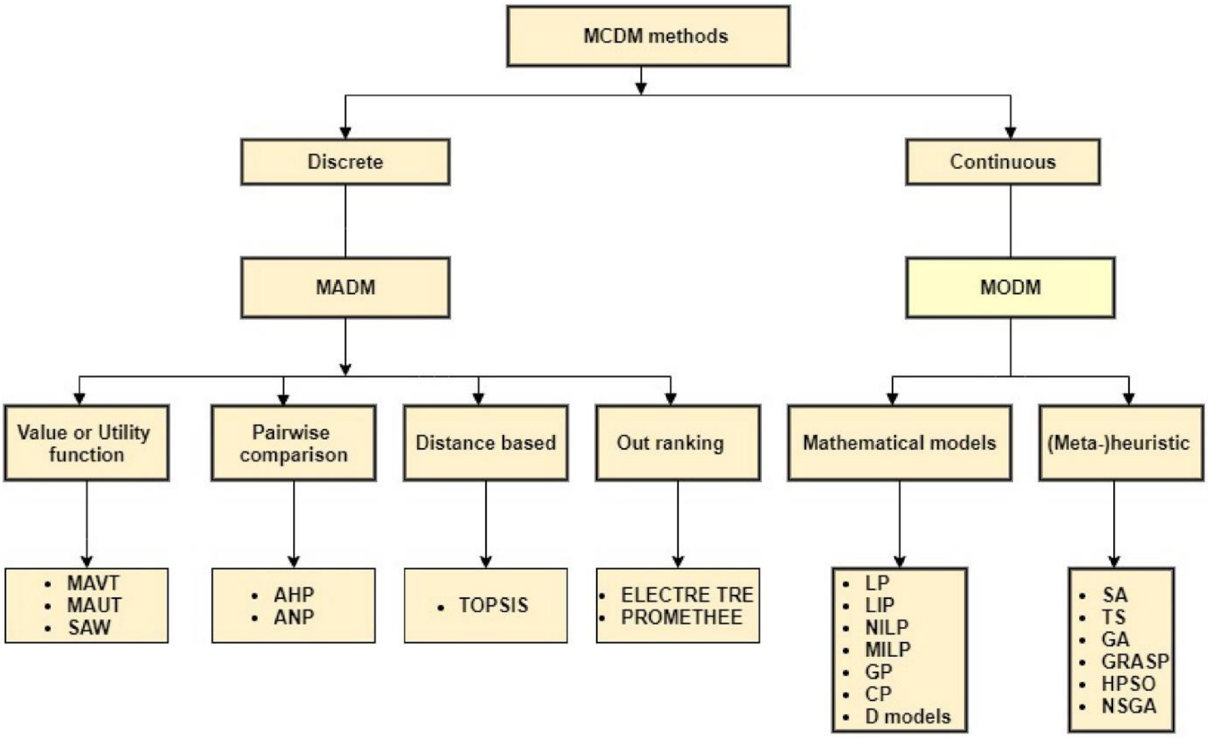

Figure 6: MCDM - methods, an overview (Gebre et al., 2021)

Combining methods

As mentioned in the classification of MCDM methods the characteristics could group the methodologies in different ways. This is more challenging when using combined/hybrid methodologies, combining 2 or more approaches. The approach of combining MCDM methodologies could be considered a classification (Mardani *et al.*, 2015). Mardani also carried out a survey on the application of different MCDM methodologies and the frequency each method was used. Here Mardani determined the combination of MCDM methodology a separate technique.

DM techniques	Frequency of application	Percentage
AHP	128	32.57
ELECTRE	34	8.65
DEMATEL	7	1.78
PROMETHEE	26	6.62
TOPSIS	45	11.4
ANP	29	7.38
Aggregation DM methods	46	11.70
Hybrid MCDM	64	16.28
VIKOR	14	3.56
Total	393	100.00

Figure 7: Frequency of MCDM techniques and corresponding methods (Mardani et al., 2015)

In addition to mapping out the different methodologies and the frequency of application, Mardani (2015) also checked the accumulation of MCDM papers from 2000 to 2014. The number of publications increased in the period from 2006 and 2007, and 2014 was the year with most publications.

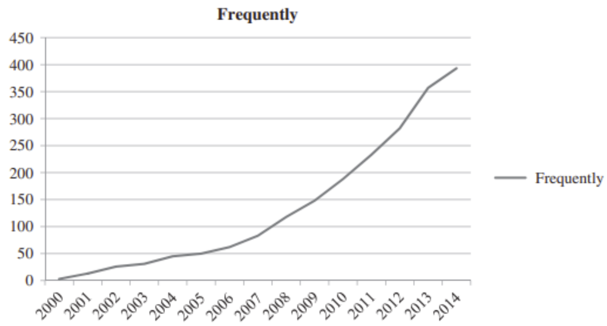

Figure 8: Accumulation of MCDM publications (Mardani et al., 2015)

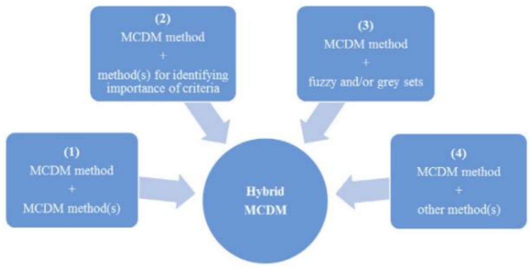

Figure 9: Illustration for combining methods (Zavadskas et al., 2016)

Mardini further concluded that the MCDM-model being employed more frequently, and deciding an appropriate approach is determined by factors such as: number of DM, Goal, time, and available information. Mardini further emphasizes the importance of selecting a model, or models, based on the DM. Furthermore, Mardini concludes the paper with the importance of reviewing papers and journals where the methodologies where a combination of two or more MCDM are applied.

3.1.1 Multi-Attribute Utility Theory (MAUT)

Traditionally, arguments are made the DM do not always follow the foundational truisms of decision theory. It may be a true descriptive statement for the individual decision-making process, but it is far more difficult to identify important implications for other parties where these norms are not followed. On the other hand, multi-attribute utility theory could be based on a different set of foundational truisms that are appropriate to be used in different contexts. The MCDM approach MAUT is a method of assigning utility value for every single action. The utility is an empirical description for preferability towards the different set of actions, and the theory itself is considered as a classical approach (Dyer, 2005).

Ralph Schäfer (2001) applies MAUT to determine a User's Interests, and at the same time using different layers of complexity to determine compatibility across the techniques between the results. The method itself aims to ensure to achieve a value of satisfactory level for the DM (de Freitas *et al.*, 2013). While Schäfer's study does not include axioms regarding risky choice, the study of Paul Kailiponi (2010) regarding evacuation decision does. Thus, this illustrates that the foundational truisms for risky choice do not have to be satisfied in order to apply MAUT for cases that do or do not involve risk (Dyer, 2005).

James Dyer claims there are no versions MAUT that are relevant to Multi Criteria Decision Analysis. Instead, there are three theories of multi-attribute preference functions that may be used to determine the DM's preferences.

The ordinal additive multi-attribute preference model is built on the prerequisite of mutual preference and independence. Multi-criteria decision analysis is applicable in cases of certainty. Furthermore, the applications and methods are in the perspective of certainty, and it is thus a tempting theory for framing the different approaches. However, the ordinal multi-attribute preference models requires specific assessment techniques, hence forcing the DM's to compromise between the different criteria (Saaty and Vargas, 2001).

Dyer (2005) also describes the process to be able to measure the different value functions is also under the pretext of mutual preference independence. In addition, next to the strong assumptions of weak difference independence or difference independence to achieve sub-components of the model that are easy to evaluate. Assessing different preference models is relatively easy. They could be interpreted intuitively by applying strength preference.

According to Dyer (2005) the MAUT model is a useful when applying risky choice. Furthermore, the work done by Keeney, Raiffa and Meyer (1993) made the theory synonymous to academics within the MCDM community. As a result of their work the theories regarding ordinal and measurable theories are often overlooked and/or ignored. The latter approaches may in fact provide attractive and appropriate theories for multi-criteria decision analysis.

MAUT – Preference theory

Preference theory is a binary set of properties preference relation. The properties could be decision alternatives, functionalities, and more, and these options could be a subset of X. A set of alternatives could be presented as $x,y,z \in X$. If x, y and z are different means of transportation, like walking, driving, commuting, and X is all means of transportation. In this case the symbol < is used to indicate preference. If a certain set of individuals was asked to rank the different options, it could be shown as:

Example	Description
$x<y$	Indicating strict preference towards x
$y\leq z$	Indicating weak preference towards y
$x\sim z = z\sim x$	Indicating indifference
$x<z$, $z<y$	Indicating strict preference to x over z, and strict preference to z over y

Table 2: Example of preference i MAUT (Dyer, 2005)

The use of preference scaling could be performed by comparing the Y-number of alternatives, where each subset of Y is compared in pairwise criteria. The information itself could be collected through questionnaires, or a similar approach.

Delivery system	Cost (C_1)	Quality (C_2)	Delivery time (C_3)
Method A	10.000	Good	Average
Method B	11.000	Acceptable	Good
Method C	8.000	Very good	Bad

Table 3: Example of problem structure (de Freitas et al., 2013)

The score from the method according to table 3 should be noted and inserted into table 4. For determining the utility values the Uv_{ij} is describe by the value score from the method in a range [0,1]. Using C_3 as an example the Bad = 0, Good = 1, Average = 0,5

Alternative	C_1	C_2	C_3
A	i_{11}	i_{12}	i_{13}
B	i_{21}	i_{22}	i_{23}
C	i_{31}	i_{32}	i_{33}

Table 4: Direct assignment values according to i.e. questionnaire (Dyer, 2005)

By determining the assignment values and utility values, the final step is determining the relative weight vector. Saaty and Vargas (2001) defined the formula as:

$$C \times w = \lambda \times w$$

Equation (i)

Where:
C=Pairwise comparison matrix of the presented criteria
w=is the weight vector
λ=maximum eigenvalue λ_{max}

CI = (λ_{max} – n)/(n-1),

Equation (ii)

n= number of factors or criteria in the matrix

CR = CI/RI,

Equation (iii)

Where:
CR=Consistency ratio
CI=Consistency index
RI= Random consistency index

Alternative	C_1	C_2	C_3
A	Uv_{11}	Uv_{12}	Uv_{13}
B	Uv_{21}	Uv_{22}	Uv_{23}
C	Uv_{31}	Uv_{32}	Uv_{33}

Table 5: Utility values

Criterion	Relative weight	Normalized weight
C_1		Relative weight / $\sum R_{w1}$
C_2		Relative weight / $\sum R_{w2}$
C_3		Relative weight / $\sum R_{w3}$
Sum of relative weight = $\sum R_w$		

Table 6: Vector weight of criteria

The calculation of D is performed according to the formula below.

D=Mw

D=decision vector, M=Decision matrix, w=Weight vector criteria

$$D=\begin{bmatrix} Uv_{11} & Uv_{12} & Uv_{13} \\ Uv_{21} & Uv_{22} & Uv_{23} \\ Uv_{31} & Uv_{23} & Uv_{33} \end{bmatrix} \times \begin{bmatrix} R_{w1} \\ R_{w2} \\ R_{w3} \end{bmatrix}$$

Equation (iv)

By calculating the decision vector an alternative is determined based on the preference of the DM. Velasquez and Hester (2013) determined, based on their literature review, that the advantage of MAUT is the incorporate uncertainty and handle preferences. They also estimated the disadvantages as the need to be very precise and the method needs a lot of input.

3.1.2 Case-Based Reasoning (CBR)

Kolonder (1993) performed research on case-based reasoning in the early 90's, and describes the Case-Based Reasoning (CBR) as the reasoner. It was argued that the reasoner remembering previous situations and to apply that knowledge to the current situation. By developing a database the CBR methodology applies previously learned knowledge and attempts to apply knowledge by creating suggestions for solving the new problem. Furthermore, CBR recommend a model based on reasoning that integrates problem solving. Aamodt and Plaza (1994) describes the paradigm in CBR to cover several different methods of organizing, utilizing and indexing information based on past cases. Dependent on how the database is built the applicability could change, depending on the solution, like keeping: concrete experiences, a set of resembling cases, and broken down in units or sub-units. In addition, Kolonder (1993) describes the premise of CBR as:

- References to old cases is beneficial in repetitive situations. The process of referencing to historical data is often a necessity to solve the problems complexity in new situations.
- Description of problems are normally incomplete, and it is necessary to further investigate and interpret the problem. Additionally, over time when the methodology has enough data to compile a sufficient database, less information is needed to understand the problem.
- No old problems are the same as the new cases, making it necessary to adapt an old solution, or solutions, to fit the new situation. The adaptation is a process to compensate for the differences between the old cases and the new one.
- Learning occurs naturally as a result of reasoning. If the solution to an old case is applicable to a new case, the difference between the cases results in a new and more evolved method. If the solution fails the method is revised and adapted to the new situation, thus resulting in a new method.
- Follow-up procedures to receive feedback and the analysis of feedback is a vital part of the process which is a continuous process of reasoning and learning.

Aamodt and Plaza (1994) describes the cycle and premise of CBR as:

1. Retrieve – the gathering of similar cases
2. Reuse – the information method used to solve the problem
3. Revise – the suggested solution
4. Retain – the data most likely to be useful in future cases

Armaghan and Renaud (2012) describes CBR as a problem-solving paradigm within Artificial Intelligence, and it has been used within many different domains. This includes areas such as: manufacturing, design, law, diagnosis, planning and knowledge acquisition. In a string of cases the new problem is describes as a target case, and the case providing the solution is called a source case (Kolonder, 1993).

CBR is recommended for developers who aim to reduce the challenges related to knowledge acquisition. The methodology is capable of avoiding past mistakes, perform reasoning in domains that are not understood, and to reason based on imprecise and incomplete data (Pal, Dillon and Yeung, 2012).

CBR has different processes for retrieving information, such as the similarity assumption, which is a step to sort through older cases with features common with the target case. According to Armaghan and Renaud (2012) the most investigated techniques are:

- k-Nearest Neighbours (k – NNs)
- Inductive approaches
- Knowledge guided approaches
- Templet retrieval

Furthermore, the findings in the retrieval phase could be ranked according to the degree of adaptation; the lower degree is the better match for the target case. More specifically, the retrieval process involves evaluation and calculation of similarity and thus selecting the most suitable source case.

In 2006 there was a CBR model developed to manage the challenges in international market selection. The purpose of the model was to predict potential profitability and competitiveness in projects, based on a company under a certain extent of conditions. The model showed how companies learn from their competitors, in larger international projects, thus resulting in better decision making (Ozorhon, Dikmen and Birgonul, 2006). The method utilizes concrete knowledge from past experience to build a tender evaluation system, and it can store the performance evaluation of past suppliers, which could be retrieved and selected based on the company's predefined specifications (Choy and Lee, 2002; Bhattacharya and Karnam, 2003). This approach selects the past suppliers who fulfills a certain predetermined set of conditions, but the method does not necessarily pinpoint the most optimal decision. Hence, the method is not capable of enhancing the accuracy and it necessary to integrate CBR with other MCDM techniques. (Alptekin and Büyüközkan, 2011; Grieves and Vickers, 2017)

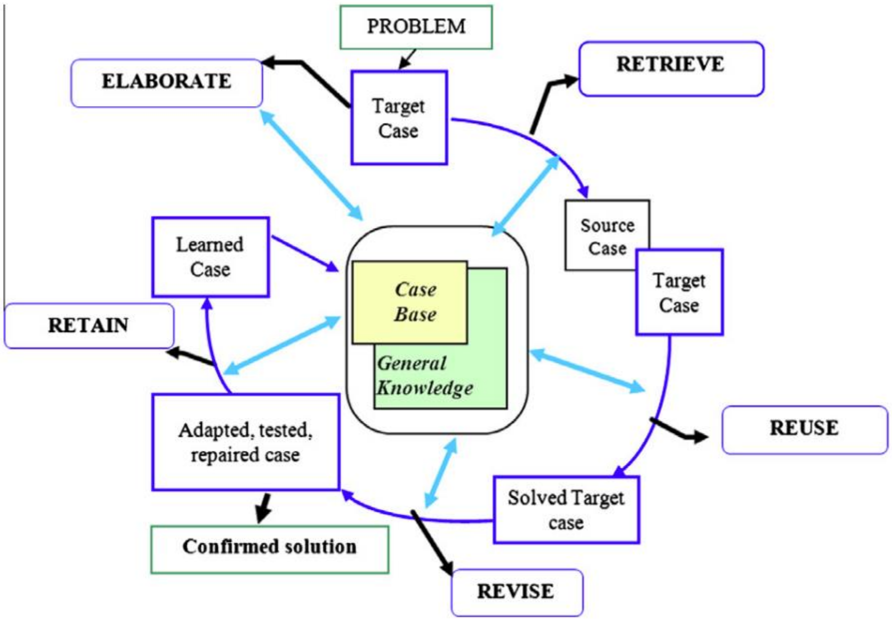

Figure 10: CBR learning process (Armaghan and Renaud, 2012)

Investigation techniques

When the target case is determined the target case undergo a matching process, which is a two-by-two comparison. The process of determining a source case is an assessment of the different properties of each case, and each case is determined by a similarity score, where the properties is a compilation of attributes and values. The process of selecting one or more cases for comparison is based on this approach. As previously mentioned, one of the most frequently used techniques is the (k – NNs) – Technique. The process involves the search for k nearest case in relation to the target case by using a distance measure. The weighting w_j then describes the importance of a DM relative to another DM, which is a value determined within the interval [0,1]. Furthermore, the weighting process evaluates the similarity between: The case source in the case base, and the target case. The process of weighting with $w_j=1$ is considered w_{j-max} and a $w_j=0$ is negligible and can function to filter out potential source cases (Chuang, 2013).

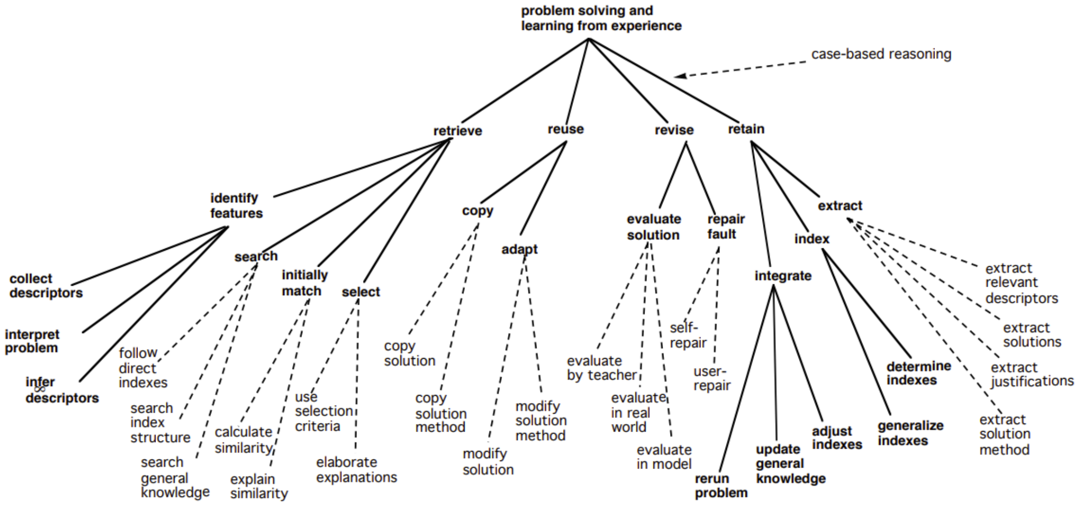

Table 7: Task-method decomposition of CBR (Aamodt and Plaza, 1994)

As described by Armaghan and Renaud (2012) the CBR cycle is a loop of representation, retrieval and adaptation. Furthermore, it is put emphasis on the importance of indexing cases and to retrieve the most relevant ones to ensure effectiveness in the CBR system. In general, use of the nearest neighbor method leads to a retrieval time increasing linearly with the number of cases. A typical algorithm for calculating nearest neighbor matching is defined by Kolonder (1993):

$$Similarity\ Score = \frac{\sum_{i=1}^{n} w_i \times sim(f_i^I, f_i^R)}{\sum_{i=1}^{n} w_i} = 1 - \sqrt{\sum_{i=1}^{n} w_i^2 D^2(f_i^I, f_i^R)}$$

where w_i is the weight for attribute i, n is the number of attributes in each case, $sim(f_i^I, f_i^R) \in [0, 1]$ is the similarity function, f_i^I and f_i^R are the values for attribute i in the input and retrieved cases, respectively. $D(f_i^I, f_i^R)$, a function used to compute the difference between the input case and a retrieved case on attribute i, is defined as in the following equation:

Equation (v)

As depicted in Eq. (i) some assumptions are common, such as:

1. 0 ≤ sim (x,y) ≤ 1
2. Sim (x,x) = 1

The intent of the assumptions is for 1. Normalization, and 2. An implication of a case compared to itself yields a result of being its closest neighbour (Finnie and Sun, 2002). Furthermore, according to Velasquez and Hester (2013) the use of fuzzy logic to verify the results og CBS. CBS in itself could be computated on terms of (k – NNs) like:

```
from sklearn.neighbors import KNeighborsClassifier
model_name = 'K-Nearest Neighbor Classifier'
knnClassifier = KNeighborsClassifier(n_neighbors = 5, metric = 'minkowski', p=2)
knn_model = Pipeline(steps=[('preprocessor', preprocessorForFeatures), ('classifier'
knnClassifier)])
knn_model.fit(X_train, y_train)
y_pred = knn_model.predict(X_test)
```

Table 8: CBS computation (Kolonder, 1993)

Velasquez and Hester (2013) concluded in their review of different MCDM-methodologies that CBS has advantages: Not data sensitive, maintenance requirements are low, the methodology improvs over time, and it can change according to the environment. Contrary to the advantages the method is sensitive to inconsistent data, and it requires many cases to establish a database to be used for comparison. Furthermore, they concluded that it is suitable for environments handling large amounts of data, such as business, vehicle insurance, medicine, and engineering.

3.1.3 Simple Multi-Attribute Rating Technique (SMART)

The MCDM methodology Simple Multi-Attribute Rating Technique was developed by Edward in 1977 (Risawandi and Rahim, 2016). The theory behind this MCDM technique is based in the assumption that each alternative consists of some criteria that have values, Additionally, each criteria have different weights that describes the importance of a criteria in relation to other criteria. The weighting is used for evaluation of criteria to select the best option.

Valiris, Chytas and Glykas (2005) describes the SMART process to consist of a series of stages, which involves:

1. Determining work to be completed
2. Providing and deciding necessary inputs
3. Assessing which outcomes to be generated

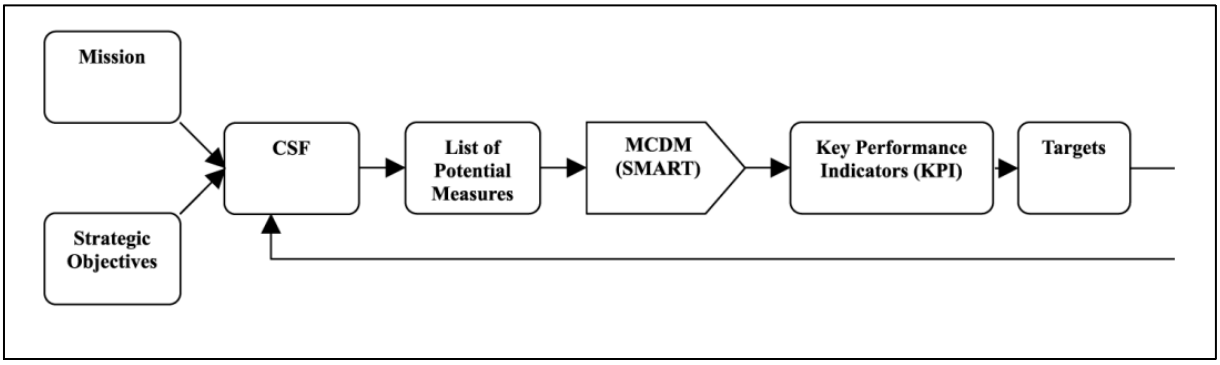

Figure 11: SMART MCDM-process (Valiris, Chytas and Glykas, 2005)

Stage		Input	Outcome
1	Determining the mission, objective and critical success factors (CSF)	Interviews with management – gathering and compiling internal data	Mission Strategic objectives CSF
2	Identification of possibilities	CSF	All possible measures for each perspective
3	Determine KPI through SMART methodology	All possible procedures	KPI in each perspective
4	Establishing goals	KPI	Target each KPI

Table 9: Process in accordance to figure 11

The SMART method is an additive MCDM to predict the value of each option, and it is useful due to its responsiveness towards the DM. Decent examples is the article by Borissova and Keremedchiev (2019) regarding ranking of students based on a set of criteria, or the study Fahlepi (2020) completed for determining the employee discipline at the workplace. The function model, used by SMART, is described as: (Siregar *et al.*, 2017)

$$\sum_{j=1}^{k} W_j * U_{ij}$$

Equation (vi)

Description:

1. W_j is the criteria weighted value to j of k criteria.

2. U_{ij} is a utility value of i on criterion j.

3. The decision selection is to identify which of the n alternatives have the greatest practical value.

The value of this function can also be used to rank alternatives.

No.	Criteria	Weight
1	C1	50
2	C2	10
3	C3	20
j		$\sum$ = 80

Table 10: weight selection table(Valiris, Chytas and Glykas, 2005; Siregar et al., 2017)

Fahlepi (2020) used the table 10 template to insert criteria such as: performance, attendance, obedience and compliance. The weight itself is predefined by the DM or DM's.

No.	Criteria	Weight	Relative Weight
1	C1	50/80	0,625
2	C2	10/80	0,125
3	C3	20/80	0,25

Table 11: Relative weight table(Valiris, Chytas and Glykas, 2005; Siregar et al., 2017)

The weight of each criteria is divided by the sum of all criteria to achieve a Relative weight k = [0,1]

Alternative value factor determination

$$\left(\frac{Maximum\ C1 - A1\ value}{Max - Min}\right), \quad C_n = \text{Criteria}, \qquad A_m = \text{Alternative}$$

Equation (vii)

	Criteria		
Alternative	C1	C2	C_i
A1			
A_m			

Table 12: Alternative and weight value (Valiris, Chytas and Glykas, 2005; Siregar et al., 2017)

Fahlepi (2020) carried out a survey to have data to insert in table 12, with sub criteria and their corresponding values. The DM ranks the employees according to the predefined values related to each criterion.

Criteria	Alternative	
	A1	A_m
C1		
C2		
C_I		

Table 13: Evaluation factor (Valiris, Chytas and Glykas, 2005; Siregar et al., 2017)

Criteria	Evaluation factor A1	Factor weight	Weight evaluation
C1		0,625	= Evaluation x factor weight
C2		0,125	
C3		0,25	
Total			

Table 14: Evaluation factor for each alternative (Valiris, Chytas and Glykas, 2005; Siregar et al., 2017)

The process in table 8 needs to be repeated for all alternatives.

Criteria	A1	A_m
C1		
W_{C1}	0,625	
C2		
W_{C2}	0,125	
C3		
W_{C3}	0,25	
Total	$=C1 * W_{C1} +...+ C_n * W_{Cn}$	

Table 15: Alternative value factor evaluation (Valiris, Chytas and Glykas, 2005; Siregar et al., 2017)

Velasquez and Hester (2013) summarized the benefits of the SMART methodologies as: simplicity, low effort on the DM, and it allows for any type of weighting technique. The biggest disadvantage of the method is it may not be convenient depending on the framework. Furthermore, it is considered applicable in the area of environmental studies, construction, transportation, manufacturing and assembly problems.

3.1.4 ELECTRE-MOr

In the literature review performed by Govindan and Jepsen (2016) the background of the ELECTRE methodology stems from the consulting company SEMA, in 1966, and its attempt to solve real world problems. From the ELECTRE method was introduced it has undergone a series of changes, resulting in other methodologies named: ELECTRE I, ELECTRE II, ELECTRE III, ELECTRE IV, ELECTRE TRI, and it is still carried out research in the field.

Each of the ELECTRE methodologies have different operability, but they also differ regarding the problems they are capable of handling. As an example, ELECTRE I is appropriate for the "choice problematic", where the main objective is to select the best choice from a set of "best alternatives". On the other hand, ELECTRE II, ELECTRE III, and ELECTRE IV, is appropriate for the "ranking problematic" which is the task of ranking the alternatives from best to worst (Govindan and Jepsen, 2016).

The ELECTRE-MOr method is an ELECTRE technique that is suitable for mapping potential future outcomes, to identify trends and uncertainties, and to anticipate opportunities and threats. The ELECTRE-MOr method was used in the study of choosing flying hospitals during the COVID-19 pandemic (Costa *et al.*, 2021), and Mellem *et al.* (2022) used the methodology regarding problem solving in prospective scenarios in portfolio management. Therefore, the method is very useful in the context of decision-making because it considers the judgements of DM and not only the issues (Drumond *et al.*, 2021).

For applying the method to problem solving requires defining the system and the variables of the system. The next step is then the process of establishing outranking relationships.

Acronym#	Criteria	Criterion type	Monotonicity
Acronym1	Type A	Numerical	Increasing value
Acronym2	Type B	Qualitative	
Acronym3	Type C	Numerical	Decreasing value

Table 16: Uncertainty and variable identification (Drumond et al., 2021)

After the criteria and alternatives is chosen the DM's are responsible for determining the value of each alternative in a cross impact matrix (table 18) and the values in the cross impact matrix are determined by the values in table 18.

<<	Much worse and/or much less important	-2
<	Worse and/or less important	-1
=	Equal to and/or important as	0
>	Better and/or more important	1
>>	Much better and/or much more important	2

Table 17: Decision maker evaluation criteria(Mellem et al., 2022)

$$\text{Normalized score v} = \frac{a_{ij} - min\ a_{ij}}{max\ a_{ij} - min\ a_{ij}}$$

Equation (viii)

Decision maker$_n$	Type A	Type B	Type C		Normalized score	weight
Type A	0	1	0	1	0,8	0,8
Type B	-1	0	-2	-3	0	0,008
Type C	0	2	0	2	1	1

Table 18: Decision maker Cross - impact matrix with example values and weight criteria (Mellem et al., 2022)

When a normalized score reach a value of 0 it is by ELECTRE-MOr web software determined to be 1% of the subsequent minor. Which, in this case, is 0,8/100=0,008. The process of inserting data in the Cross – impact matrix is performed for every decision maker, for every single criteria, and the result is inserted into table 19 to determine preference among the DM's.

	DM$_1$	DM$_2$	DM$_n$	$\sum$DM
Type A				
Type B				
Type C				

Table 19: Decision maker – preference aggregation

Selection of relevant variables

In a more complex situation the decision maker(s) will have to evaluate N-number of criteria with m-number of alternatives. As shown in table 18 type B has an impact of 0,008 which means it has little to no impact in the final decision. Therefore, in a larger complex situation there will be a need to remover criteria that will not impact the final decision. This could be done by plotting the weight into a graph with quadrants to determine the importance. (Mellem *et al.*, 2022)

Mellem et al. proposed to divide the graph in 4 quadrants:

A – Influential variables: Very influential and not very dependent

B – Support variables: Very influential and very dependent

C- Dependent variables: not very influential and very dependent

D – Independent variables: uninfluential and little dependent

Calculating Bh value:

$h = \frac{a_{ij} - min\ a_{ij}}{Number\ of\ classes}$, $bh_l = min\ a_{ij} + l * h$

Equation (ix)

Calculating Bn value:

$k = \frac{n^o\ of\ alternatives}{n^o\ of\ classes}$, bn = k – th best alternative score

Equation (x)

Criteria & alternatives		C1	C2	C3
Criteria Alternatives	A1C1			
	A2C1			
	A1C2			
	A2C2			
	A1C3			
	A2C3			
Distribution classification	Bh3			
	Bh2			
	Bh1			
	Bn3			
	Bn2			
	Bn1			
q (weak preference)				
p (strict preference)				
v (Veto)				
w (weights of criteria)				
λ – cutoff-level is determined by specialists based on the given result				

Table 20: Performance matrix (Drumond et al., 2021)

After plotting the results in the performance matrix the alternatives can be evaluated and distributed in n-classes.

Bh_{max}> $Criteria_{score}$ > Bh_3 => Classification A

Bh_3> $Criteria_{score}$ > Bh_2 => Classification B

Bh_2> $Criteria_{score}$ > Bh_1 => Classification C

Bn_{max}> $Criteria_{score}$ > Bn_3 => Classification A

Bn_3> $Criteria_{score}$ > Bn_2 => Classification B

Bn_2> $Criteria_{score}$ > Bn_1 => Classification C

λ = cutoff level	bh		Bn	
Alternative	Pessimist	optimist	Pessimist	Optimist
Type A	C	D	A	B
Type B	A	A	A	A
Type C	B	B	B	A

Table 21: Result-matrix for plotting in scores

As mentioned in the beginning in 3.1.4 some of the benefits of the method is its ability to take uncertainty and vagueness into account. Additionally, the method has been used in research areas such as: energy, economics, environmental, water management and transportation. However, the disadvantages of the method is the difficulty of explaining the process to non-professionals, and the outranking process is not able to determine strength and weaknesses of alternatives (Xu and Yang, 2001; Velasquez and Hester, 2013).

3.1.5 Simple Additive Weighting (SAW)

The MCDM – methodology known as Simple Additive Weighting (SAW) is a weighted linear combination method. SAW is a method often used as a MCDM as a multi-attribute decision technique, and the method is based on a weighted average. The next step is an evaluation score, which is calculated for every alternative by multiplying the scaled value with a weighted value with relative importance. The determination of weighting and relative importance is calculated by the DM. The process is carried out by three steps:

Step 1

To perform the SAW method, you need a process for normalizing the decision matrix in order to compare ratings of existing choices. The process itself is like process carried out in 3.1.4, and the data is inserted into a (n x n) comparison matrix:

<<	Much worse and/or much less important	-2
<	Worse and/or less important	-1
=	Equal to and/or important as	0
>	Better and/or more important	1
>>	Much better and/or much more important	2

Table 22: table for pairwise comparison (Saaty and Vargas, 2001; Afshari, Mojahed and Yusuff, 2010)

The information required in the weight value could be a value determined by pairwise comparison, according to table 22, or it could be weights according to DM preference.

Criteria	Information	Weight value
C_1	$Description_1$	X
C_2	$Description_2$	X
C_n	$Description_n$	X

Table 23: Inserting criteria, information and assigning weight value

An example could be a way to determining which construction project to choose, as the option, and Information is the criteria which the project is selected by. It could be criteria such as: Cost, size, function, etc. The alternatives will then provide information for comparison, and it inserted into:

Alternative	Result value		
	Weight value C_1	Weight value C_2	Weight value C_n
A_1			
A_m			

Table 24: Alternative-rating for each criteria

Step 2

Construct a decision matrix (m x n) that includes all personnel(m) and all criteria(n), in accordance to the following equations:

$$r_{ij} = \begin{Bmatrix} \dfrac{X_{ij}}{Max\, X_{ij}} \\ \\ \dfrac{Min\, X_{ij}}{X_{ij}} \end{Bmatrix}$$

r_{ij} =Performance rating value, normalized

X_{ij} =Attribute value, pr criteria

Max X_{ij} =Largest value of each criterion

Min X_{ij} = Smallest value of each criterion

Equation (xi)

The result from each r_{ij} then inserted into:

$$R=\begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ r_{31} & r_{32} & r_{33} & r_{34} \\ r_{41} & r_{42} & r_{43} & r_{44} \end{bmatrix}$$

Equation (xii)

$$V_i = \sum_{j=1}^{n} w_j r_{ij}$$

V_i =Ranking of the alternatives

w_j =value weight of each criterion

r_{ij} = Performance rating value, normalized

Equation (xiii)

Equation (xiii) is used to calculate preference. The V_i with the highest value indicates the best alternative (Nurmalini and Rahim, 2017).

The advantages of SAW is its ability to compensate among criteria, it is intuitive to decision makers, and the calculation does not require computer programs. However, the downside of SAW are the viability of the results, which might not reflect the real situation and/or is not logical (Velasquez and Hester, 2013).

3.2 Digital Twin

In the more recent years the amount of information about the digital twin has increased. There are more publications, descriptions, and different types of processes in both industry and academia relating the subject. The origin of digital twin stems from NASA, Michael Grieves and John Vickers(2014), and their work on virtual representations of a physical product. Furthermore, a vital component is the link between the physical product and the virtual representation which opens for an exchange of data. The concept is built upon the notion that the virtual model is mirroring the physical product.

Given the width and the depth of the recent research done on digital twin it can be said that the only thing missing is a consistent view on what at digital twin actually is (Jones et al., 2020) They argue that this inconsistency could dilute the concept, and at the same time be a risk to lose the benefits the digital twin was intended to yield.

Early definitions:

The university of Michigan had a presentation titled "Conceptual Ideal for Product Life Cycle(PLC) Management" in 2002, where the concept of Digital Twin(DT) was brought up (Grieves and Vickers, 2017). Even though the concept presented discussed PLC, the concept had the basic traits of Digital twin, which has not changed much since then.

"a "real space" and a "virtual space" connected via data and information exchange"
(Grieves and Vickers, 2017).

NASA redefined the concept of DT in 2010, where DT is described as:

"Integrated multi-physics, multiscale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin."

(Shafto *et al.*, 2012)

More recently the term used in manufacturing as a representation of an active product, or product service system, that contains the selected properties, behavior, and characteristics. It is represented by models, information, and data within single or multiple phases of life cycles (Stark and Damerau, 2019).

Scope of digital twins:

Among the different definitions of DT a lot synonymic terms arose. In reference to NASA's definition, among the different characteristics the most important feature is the ability to create an accurate virtual model of the real product. Publications tends to stick to this definition, targeting the convergence points of real and virtual space (Grieves and Vickers, 2017; Boschert, Heinrich and Rosen, 2018; Stark and Damerau, 2019).

According the review by Trauer *et al.* (2020) it is stated that most publications agrees on the concept of virtual space, but opinions differ on the concept of real space. The work done by Stark and Damerau (2019) consider company assets as real space, whereas Boureanu (2017) consider machines and products as real space. Some extends the concept and include whole systems (Trauer *et al.*, 2020). Furthermore, Trauer et al. also considers the possibility to be a non-physical object to have a twin, based on the work of (Kuhn, 2017; VanDerHorn and Mahadevan, 2021).

Regardless of the object, being physical or non-physical, the object needs to be defined with aspects of the real space and should be transferred to a virtual space. The method of modelling the behavior is varying depending on the type of corresponding literature. The discord in literature regarding behavior-modelling is dependent on the field of study (Trauer *et al.*, 2020).

Methods of presenting data:

- Representation of product related data
- Copying physical behavior, properties, and situations
- Thorough representation of all knowledge and information from physical twin to the DT.
- The inclusion of data generated from fusion, integration and data analysis from both digital and physical space.
- The concept of limiting information relating to case-specific applications
- Limiting the data representation to condition and other physical related properties.

Riesener *et al.* (2019) describes an approach for determining the relevance of data. Furthermore, the selected information must consider all sides of the product, such as: customers, product structure, function, requirements, technology, and finances. To make the model scalable Schleich *et al.* (2017) describes a method for implementation of a more abstract and conceptual model and a virtual representation.

The work done by Kuhn (2017) and Boschert, Heinrich and Rosen (2018) states that the DT is not only defined by the inclusion of data, but also algorithms and simulations. Henceforth, DT is normally described at the next level simulation based on the ability use real phase data.

Definition and types of digital twin:

The different terminologies connected to the topic of DT are concepts like digital shadow (Riesener *et al.*, 2019), digital twin (Kuhn, 2017), digital model (Schleich *et al.*, 2017; Trauer *et al.*, 2020). There is also a common understanding that these terminologies are not interchangeable. The digital model is a digital representation of a physical object, but there is no flow of information between the physical and virtual space. On the other hand, the term Shadow has been determined unsuitable as it is an image of reality simple and limited properties. Additionally, a shadow cannot give feedback to the physical system, and it is thus not a method with two-way flow of information, and the method is considered to be a partial implementation of DT (Trauer *et al.*, 2020).

The term Digital Thread has been described as "a digital connection of all relevant information within the product lifecycle". Contrary to the digital shadow it can function with the Twin. Furthermore, the functionality of a Digital Thread is more beneficial with a Twin. The differences between the DT and a Digital Thread lies in the DT ability to realistically and to automatically interact with its physical twin in a bidirectional way (Kritzinger *et al.*, 2018).

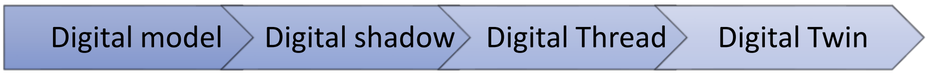

Figure 12: Hierarchy of the digital terms

Therefore, based on the work by Kritzinger *et al.* (2018) the ranking of the mentioned terminologies could be performed, se figure 12. For each step the reliability and automation of information flow increases. Furthermore, the flow of information changes from one-directional to two-directional. Henceforth, Trauer *et al.* (2020) concludes there are three more characteristics of DT that should be included in the definition:

- The Digital Twin is a virtual dynamic interpretation of a physical object or system
- Data is automated with a two-way information exchange between the DT and the object.
- The twin contains data for all phases of an object in the entire lifecycle and is connected to all of them.

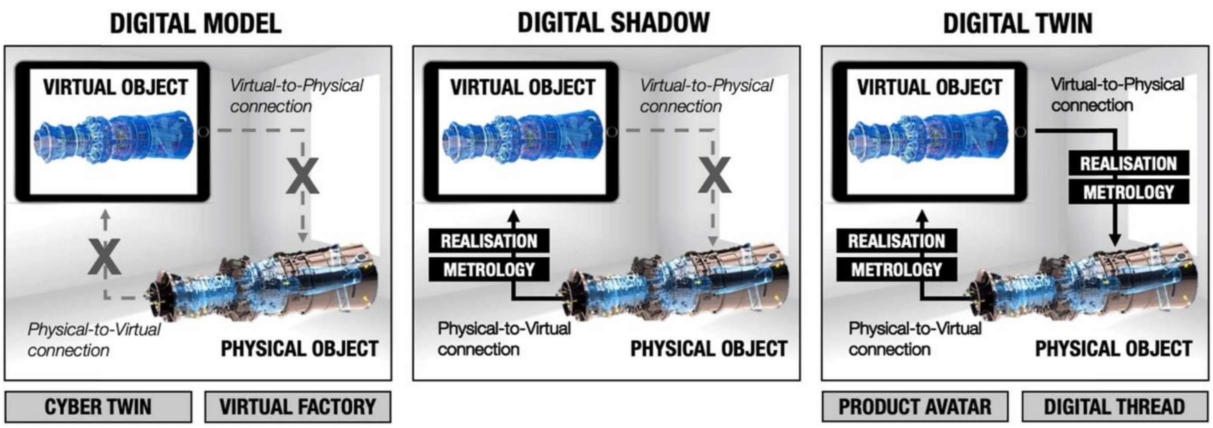

Figure 13: Presentation of Digital model, shadow and twin (Bertoni and Bertoni, 2022)

"A digital twin is a cirtual dynamic representaiotn of a physical system, which is connected to it over the entire lifecycle for bidirectional data exchange."
(Trauer et al., 2020) p. 761

The definition presented by Trauer et al. is a unification and a highlight of the previously mentioned aspects of the DT. Even if the definition itself is broad and generic it consequentially removes the need for further details as it allows for subdimensions. Trauer et al. further defines three different sub-types of the DT: Production twin, Engineering Twin, Operation Twin.

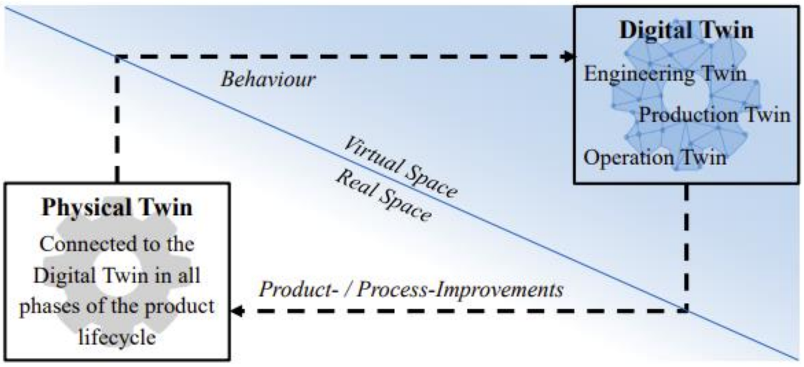

Figure 14: Concept of DT with sub-types (Trauer et al., 2020)

There is no specific example for DT when defining DT, where the Twin itself is defined as a collection of cases contributing to a main strategy. Therefore, a digital twin is always a compilation of use-case situations.

Digital Twin challenges

IT infrastructure:

A frequently growing and evolving AI needs to be supported with a properly developed IT infrastructure. The requirements involving the AI needs proper hardware and software to execute the algorithms. One of the biggest challenges is the initial start-up cost for installation, and another challenge is running the different system (Fuller *et al.*, 2020). As an example, a high quality high performing graphics processing unit (GPU) capable of performing the machine and deep learning algorithm has a cost [10.000,90.000]Nok; The cost is an estimation per unit based on what's commercially available august 2022.

To overcome the challenge Fuller *et al.* (2020) propose to use the GPU on a "as-a-service" (-aaS) solution, like SaaS-solutions (Software-as-a-Service) where a program is accessed through a browser. The -aaS solution circumvents the need for a local infrastructure and hardware, as it removes the need for a start-up cost. Additionally, the -aaS solution present other challenges like information security. This is also the case for Internet-of-Things (IoT) devices transmitting information. Fuller et al. further states that without a proper connection the DT will eventually fail to effectively achieve the determined goals.

Data

Collecting and organizing data is important the ensure a high quality, and it needs to be sorted and stripped to vital parts before being fed into the AI algorithms.

When it comes to the process of providing data for the DT the requirements are:

- Noise-free data
- High data quality
- Constant data stream
- Uninterrupted DataStream

If the above-mentioned points are not followed it will cause the DT to underperform. Thus, the quality and quantity of IoT signals is important in DT data. Analyzing and planning the device, and the intent, is a determining factor for the collected data and efficient use of a DT. (Fuller *et al.*, 2020)

Privacy and security

A relatively new regulation, The General Data Protection Regulation (GDPR), is a regulation meant to ensure privacy and security of personal data throughout Europe. Fuller et al. describes the regulations as one way of protecting the, and another method is associated learning; a decentralized structure with the intent of training models. The method allows user data to stay localized without the need for data sharing. Hence, the method is the addressing the privacy and security issues in the process of data implementation within a DT. The to reduce the trust issues related to DT is ensured by taking considerations towards the security and privacy issue.

Trust

A different challenge in the field of AI is trust, which is closely related to internet security. One of the reasons for low trustworthiness is the relatively new technology, and to and, from a developer's perspective, the use of AI can seem overwhelming. Normally the description and portrayal of AI focuses on the negative effects that may occur, which affects the trust barrier. However, positive stories and articles in the media is becoming frequently more common, and the increased positive exposure could help remove the trust barrier.

The concept of trust issues could be identified from both an organizational and user-oriented point of view. To raise awareness and increase the knowledge of the user is a step towards overcoming the challenge. The key component for ensuring trust is a DT performing as intended.

Standardized modelling

There is no model for standardization for how to approach the modelling of a DT. According to Fuller *et al.* (2020) there is a need for a standardized approach, from the initial design to a simulation of a DT. The approach could be physics based or design-based, and it aids in ensuring the domain and user understanding. Numerous types of technologies, from data collecting, insight, and decision making are areas with a need for standardization. Furthermore, the development process for making standards is traditionally slow, causing a slow wide-scale adoption of DT. (VanDerHorn and Mahadevan, 2021)

Domain modelling

The method for ensuring the information related to the use of the domain, should be determined in the development and functional stages of the DT modelling. Such an approach ensures that compatibility with other domains, like IoT and data analytics. With such an approach it ensures compatibility with these domains, making it possible to successfully use the DT in the future. Thus, to ensure applicability and implementation it is a need for standardization towards to the approach regarding domains (Fuller *et al.*, 2020).

3.3 Internet of Things

In the recent years the term digitalization has become more prominent in the municipalities of Norway. The term itself covers welfare technology to janitorial alert-systems. The increasing focus on digitalization is also intertwined with efficiency and effectiveness. With more investment in modern technology, it is possible to either reduce the workforce, or to be able to cover more with the staff at hand.

In accordance with digitalization the awareness of IoT has become more prominent. Not necessarily the term IoT itself, but a quick in-house survey showed that employees are aware of:

- Machine to machine communication (M2M)
- Cyber-physical systems (CPS)

Although the term Internet of Things, or IoT, has consensus about what it means, the definition of IoT might be unclear; given the uncertain nature of the IoT definition this has led to several companies writing their own definitions (Firouzi, Chakrabarty and Nassif, 2020). Hassan (2019) further describes the IoT architecture as a 3-tier system, consisting of a hardware/perception layer, communication and messaging protocols, and interfaces/services.

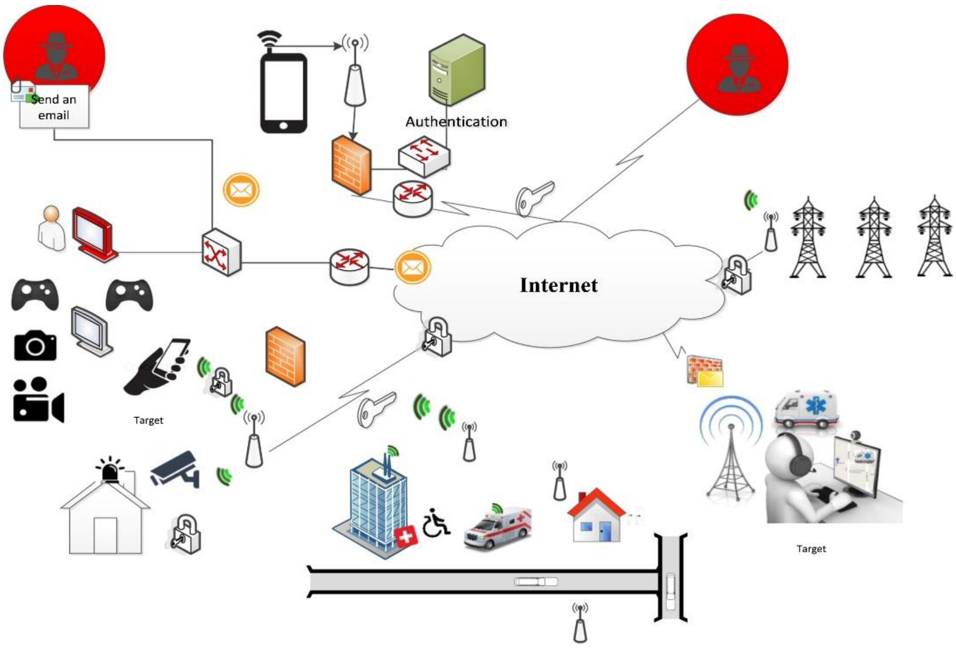

Figure 15: IoT – Illustration (Alaba et al., 2017)

Internet of Things, Industrial Internet of Things and Industrie 4.0 are modern topics undergoing immense research. The understanding of the different terminologies have a generally accepted meaning, but the definition itself is vague (Firouzi, Chakrabarty and Nassif, 2020). The result is a series of interpretations of the term, where companies has described IoT, IIoT and Industrie 4.0 according to their own understanding.

Some interpretations of the IoT domain

Gazis (2021) describes IoT as the enabling of the Industrie 4.0, and the purpose is the connection between humans with machines and smart technologies. Furthermore, IoT is a reference to the vast network of computers & devices, with a large amount of information exchanged at high speed. The communication between the devices is through Machine-to-Machine (M2M), much like a sensory device transmitting data to a surveillance system. In addition, as described by Firouzi, Chakrabarty and Nassif (2020) there are several different interpretations of IoT.

According to Prasad (2020) and Firouzi, Chakrabarty and Nassif (2020) a few organizations has defined IoT as:

"IoT is the next generation of the Internet. It is a global system of IP-connected computer networks, sensors, machines, and devices"

Bosch corporation 2014

"In what's called Internet of Things, sensor, and actuators embedded in physical objects – From roadways to pacemakers – are linked through wired and wireless networks, often using the same Internet Protocol (IP) that connects the Internet"

McKinsey & Company, 2010

"a proposed development of the internet in which everyday objects have network connectivity, allowing them to send and receive data"

Oxford Dictionary (2022)

"In the most general of terms, the Internet of Things includes any object – or "thing" – that can be wirelessly connected to an Internet network. But today, IoT has more specifically come to mean connected things that are equipped with sensors, software, and other technologies that allow them to transmit and receive data – for the purpose of informing users or automating an action."

(SAP, 2022)

As described, the description of IoT stems from the common understanding of the concept. Due to the uniqueness of technology development, partly due to rapid growth and evolving technology, the IoT is quickly evolving. Henceforth, there is no single definition available that can incorporate all properties of technology to satisfy every single user; the characteristics of IoT and the common understanding of the concept remain the same Firouzi, Chakrabarty and Nassif (2020).

The foundational principles - IoT

Things/Devices/M2M:

Objects in the IoT domain are connected to a network, whereas the objects are "smart" or simply sensors connected to a network. Depending on the purpose of the device are either have a wired or a wireless connection. The minimum requirement to be referred as an IoT device is: Processing unit, power source, sensor, network connection with a unique identifier. (Prasad, 2020; Firouzi, Chakrabarty and Nassif, 2020; Gazis, 2021)

Connectivity:

Connectivity is important for an IoT solution. Without connectivity the devices are incapable of transmitting and receiving information. (Amodu and Othman, 2018)

Data:

The product of IoT devices are mainly a compilation of data, such as sensory data, location, diagnostics, status, or other relevant input related to the task. (Amodu and Othman, 2018)

Intelligence and execution ability:

Example of intelligent use of IoT includes: AI, Deep learning, and Data analysis. Having a setup with such properties could result in better experience for users, predicting maintenance, perform risk analysis based on data, and increase efficiency. (Amodu and Othman, 2018; Firouzi, Chakrabarty and Nassif, 2020)

Execution ability is the resulting action because of intelligence, either automatic, prompted, or as a result of being affected by other IoT devices.

Ecosystem:

The ecosystem is a cluster of IoT devices, working according to protocols, different platforms, and the diversity of devices which is simultaneously working on networks. It also includes the users and the stakeholders interest in the data (Firouzi, Chakrabarty and Nassif, 2020).

Background

As mentioned in the foundational principles of IoT and the interpretations in the IoT domain, there is a common understanding of IoT, and it requires some foundational principles to function properly. Furthermore, how a task is solved is related to the problem, and there are situational variations. The IoT design may vary even if there are similarities between problems. An example is welfare technology in hospitals or nursing homes. The problem could be the same on several locations, but the design and requirements will be different. The IoT solution is affected by layout, geographical locations, the internet access in the area and other factors like information security (Hassan, 2019).

The developers of IoT should also include security hardware. A solution could be adding a cryptographic code processor and/or a security chip. Regarding the hardware of IoT devices, it is normally using a Real Time Operating Systems, which includes(Amodu and Othman, 2018; Hassan, 2019):

- Microkernel
- Hardware abstraction layer
- Communication drivers
- Process isolation
- Secure boots
- Application sandbox

For the layer of software application there are (Hassan, 2019):

- Custom applications
- Cryptographic protocols
- Third party libraries
- Drivers

The main concerns about the selection of hardware are properties like authentication capabilities, end-to-end encryption, and secure boot loading process. Furthermore, it needs to evaluate the implementation of digital signatures during firmware updates, and transparent interfaces. Another important component that allows interaction with the cloud through a gateway is the messaging protocols. Accessing cloud services such as Microsoft Azure has its own benefits.

By implementing Wireless Sensor Network (WSN) the built-in protocols in WSN allows device -to-device communication with a gateway at the endpoints. Additionally, the WSN solution supports dynamic communication, and one of the benefits of the WSN protocol is the scalability and its low operating cost. Deciding on the needs other communication protocols could be more suited, such as: WiFi, Bluetooth, 4G and 5G. By adding a component like an aggregator makes it possible to function as a gateway for IoT architecture, such as a WiFi-router.

As mentioned in 3.2. regarding the importance of infrastructure, a cloud-based solution could provide services making it less difficult to implement. The threshold towards IoT solutions is lower than a fully developed DT, as a network of IoT devices is a prerequisite to be able to fully utilize a DT. Especially IoT devices that only transmits sensory data do not require much from the infrastructure. A Cloud Service Providers (CSP) provides services for IoT solution, such as messaging, storage, data processing and analytics. Additionally, the CSPs also supports features used in M2M communication, such as Messaging Queuing Telemetry Transport and Representational State Transfer communication protocols.

IoT security:

The topic of security is, as previously described in chapter 3.2, increasingly more relevant. The use of smart-technology is increasing and the GDPR regulation, which is a regulation meant to shield personal and private data, is therefore also applicable to IoT solutions. The large variety of IoT devices, and various communication protocols, in an IoT system it is not suitable to apply security mitigation based on the framework of traditional IT network solution. The traditional framework for network solutions does not encompass the three different layers of IoT devices, making it vulnerable to attack vectors, and a network solution should include all IoT layers. Due to the insufficient authentication and authorization procedures, there are popular attack vectors used to gain access to such IoT devices (Amodu and Othman, 2018; Hassan, 2019).

Presently, the most widely used security method to gain secure communication in the network layer is authentication. Still, there are some issues regarding the impracticality due to device constraints. To solve the impracticality there is ongoing research in the field of lightweight authentication centered around public key management. Another cause for inadequate security is the hardcoded credentials which is normally used in the IoT devices. The weakness in the methodology are credentials used to access many different devices, and the lacking physical security is prone to vector attacks due to vulnerability in the hardware. The process of encrypting the devices, such as basic appliances such as sensors, are considered the main obstacles.

Layer	Security challenges	Mitigation
Perception	Detection of the abnormal sensor node The choice cryptography algorithms and key management mechanism to be used Data and sender anonymity Device vulnerabilities	fault detection algorithm, decentralized intrusion detection system public key encryption due to the large scale network slot reservation protocol Access control, mitigation of resource depletion attacks
Network	Enabling IPSec communication with IPv6 nodes	Research in the suitability of IPv6 and IPSec for secure communication.
Application	Configurable embedded computer systems.	No suggestion is available from this paper

Table 25: Challenges and countermeasures in IoT security (Hassan, 2019)

3.4 The cost/price – principle: Vannforskriften

The funding of infrastructure development in Norway is regulated by Vannforskriften (2006). The funding is secured by the cost/price – principle. The methodology itself allows to detail the actual cost of expenditures, and it is not difficult to maintain through different periods. One weakness of the method is the inability accurately reflect the current value of assets. However, it makes it easier to identify, verify expenses over time.

The method enables a tracking process of expenses, and to observe how the cost of products and services changes over time. Furthermore, the budgeting process can consider historical data and correct for rising cost trends to determine the cost for the next few years.

When it comes to securing funding in the different municipalities one of the biggest benefits of the cost/price principle is that water infrastructure does not need to compete with other service area to secure funding. Additionally, according to Vannforskriften (2006) it is illegal to pursue profit, however there is a 5 year buffer where the municipality can end up with a miniscule positive result in the accounting. There are separate rules regarding those assets, and it is illegal to use those assets for investment projects. The disadvantage with this law is that there will continuously be a recurring need to get new loans to complete smaller investments, resulting in fee variations for the inhabitants in the municipality.

One of the challenges with the method is that the assets for maintenance and development stems from within the municipality; meaning the funding is highly affected by population density. Since there is no correlation between population density and the size of the water infrastructure, it might be challenging to execute larger necessary projects to ensure water quality. The budget available for FM varies greatly between the different municipalities.

Larger investments might be dependent on factors outside of the company/municipality’s control. It might lead to delayed larger investment projects or putting projects on hold. Another factor is changes in the estimation of interest rates. These factors destabilize the development of the yearly fees to the inhabitants.

4 Results

4.1 Defining project goal and scope

As described in the introduction the end goal of this work is to create a more efficient water distribution infrastructure in the municipalities. Through that work we can reduce the amount of wasted water, and at the same time make it possible for companies to establish their business in the area. Furthermore, there are several ways to move forward depending on which goal is chosen. There is also a difference in efficiency now, and efficiency in the future. It is possible to create a system that tell us the bare minimum amount of information needed to have an efficient infrastructure, but that system isn't necessarily suited for identifying problems on the infrastructure, and it might also not be able to tell where the problem is located. The final product therefore relies on the goal, which in turn has separate data quality requirements (DQR). As described in chapter 3.1. there is put a lot of emphasis on the end goal. The idea is that DQR is a score the DM or DM's must settle. The municipality must also determine who the DM is. Depending on the scale the DM could change. If the process of upgrading the infrastructure is handled locally the resulting complexity is low, making it possible to use MCDM techniques like SMART, ELECTRE-MOr, and SAW. If the project is a result of intermunicipal cooperation the applied techniques could lean towards MAUT or CBR as a result of the larger database. The methods of performing weighting according to the different methodologies are described in chapter 3.1.1 – 3.1.5. and the following result is an attempt to determine which criteria should be used in the decision-making process. If DM is unable to determine the final product the table could be used to assign weights in a MCDM model.

DQR	IoT	Digital modell	Digital Twin
Low	-	-	-
Middle	X	-	-
High	X	X	-
SOA	X	X	X

Table 26: Result - Data quality requirement

As shown in the table above is an attempt to raise awareness towards the final product. If the goal is an IoT solution with a system receiving sensory data from the infrastructure the different evaluations will change contrary to a digital model or a DT. A DT would have more alternatives affecting the cost, and population density would function as a variable affecting the duration of the project. As described in 3.4. the funding for the projects is secured through the cost/price principle, but the implementation of and investment in a complete system at once may result in unreasonably high fees for the inhabitants of the municipality.

Table 23 is a table with the intent of aiding the DM in deciding the DQR and MCDM approach to evaluate certain measures.

Goal	Description	How/Why
Increasing automation	Reducing the need to manually read data from water meters, pumps, and the use of sound equipment to detect leaks. It will increase efficiency and reduce the need for some manpower through the reduced time consumption.	Firstly, if private households have mechanic water-meters, they could be replaced with smart water meters that can relay information through an IoT solution. If there is no water-meter it could be installed one. Similar installations could be made all over the infrastructure to track consumption and leaks.
Decreasing response time	When facing problems in the infrastructure, be it cracked or collapsed pipes, the problem area is more easily found. The problem could be resolved faster, and the inhabitants can get their water back more quickly	Installing water meters on main lines on strategic points. Water consumption above average could indicate a leak. What a strategic point is will be determined by DM or workers in the field.
Future Prognosis accuracy	The municipality and politicians want to make the right decision for future establishments, both private and company.	Requires information on current capacity, and to use that information in correlation with the municipal area-plan.
High Infrastructure data	Information about: - Pipe locations - Pipe type; I.e. Emergency/Fire - Pipe age - Pipe material - Age manhole	Using GNSS equipment to map and allocate parameters before measuring the pipes. Measured on the pipes when it is possible.
Facility Management	Type of solution, Outsourcing, inhouse, software,	Investing in a third-party to provide information security and i.e. VPN solutions for information security.
Data evaluation	Requires an evaluation on current data.	Determining the amount of information currently available. - needs to determine accuracy from old measurements. - Are certain areas not measured with GNSS equipment. - if the information is lacking the area needs to be measured.
Water loss	Measuring the leak percentage	Measuring the amount of produced/cleansed water against the amount of billable water. The difference indicates a leak in the pipeline.

Table 27: Data quality matrix

Table 24 is a collection of questions to determine the extent of equipment currently available. It serves to determine the investment areas in addition to estimate the size of the needed investment. When the final product is determined by the DM the answers to each question could determine the criteria in a MCDM model. Furthermore, the answers could serve to list alternatives to the described criteria.

Questions	
How many households and businesses are paying for water?	
Are they receiving invoice based on square meters?	
How many m^3 of water do you produce each year?	
How many m^3 of water do you bill each year?	
Do they have water-meters?	
How many water meters does the municipality own?	
Are there parts of the infrastructure not covered with the meters?	
Do these water-meters support an IoT solution?	
Are any maintenance projects planned?	
Are any development projects planned?	
Is the current cost price accounting updated according to these projects	
+	
+	

Table 28: Current available information evaluation

4.2 Water infrastructure

As previously mentioned, the complexity of the area of interest, in combination with the goal and scope set by the municipality, will determine the different criteria. An evaluation of complexity will help determine the weights of different criteria. Additionally, the laws regarding cost/price principle will determine a different set of cost-criteria. A municipality with large area boundaries and low population density will have a cost-criteria with higher weight than a municipality with high population density. Additionally, the cost-criteria should be included in the municipal water plan.

If a project is specified in the municipal water plan it is possible to get external funding from the county, or other sources, depending on the scope of the project. The physical aspect with creating new infrastructure, groundwork, laying pipes, could get external funding from the county if the project fulfills the application criteria. If the scope of the project also includes digitalization, external funding can be given regarding the process with digitalizing and making it communicating with existent digital infrastructure.

There is a need for creating GIS data, where each line is allocated a set of properties. If the municipality later decides to use IoT solutions, the information could be used to create a model.

4.2.1 IoT & Digital Twin related Criteria

As presented in 3.2 and 3.3 the biggest issues are regarding internet security. Depending on the technological level the requirements will change, like specified regarding the protection of devices and a more inclusive framework for network solutions to cover all layers of IoT devices (Amodu and Othman, 2018; Hassan, 2019).

The properties of the water infrastructure are the large area it covers, which contains a set of "unchangeable" data, as it is the description of physical properties. The digitalization of such a network will contain a large amount of IoT devices which transmits the same type of data. At some point it must be determined how many of these devices are sufficient to receive sufficient data regarding the status of the infrastructure. The task of determining where to strategically put the IoT devices to ensure the highest amount of coverage, is suitable for DM or someone with sufficient knowledge.

Another challenge is to determine how to handle the data. Traditionally, in the region, this is a task outsourced to a third party. As an example from the Vevelstad municipality water treatment plant, the data regarding pressure, purification of water and pH is transmitted via 3G/4G to the service-provider. The municipality gains access to the data through a secure VPN connection. This could also be the solution for a fully developed DT.

The concept of running simulations is also an important variable as it serves to determine where we need to upgrade the infrastructure in certain scenarios. An example could be a local housing project, and it need to be determined if enough water is available in case of emergencies, like a house fire. The combination of data from the DT and the housing project model could be used to simulate accessible water and water pressure.

4.3 Method evaluation criteria

A vital part is the available workforce in the municipality, and another is the decision maker. The available workforce requires sufficient knowledge in the area to be able perform the right evaluations. The DM doesn’t need to be the municipality, but it could be a cooperation between several municipalities, the county, or even nationwide. Depending on the scale of the project will yield different benefits from different MCDM methods.

If the project is initiated by the county, or the nation, it could be beneficial to combine one or more MCDM methods with Case-based reasoning. As mentioned in 3.1.2 a major disadvantage with CBR alone is its sensitivity to inconsistent data and that it required a large database.

On the other hand, should the DM be a smaller cooperation between municipalities, or if the municipality is acting alone, the use of CBR would be difficult given the lack of a sufficient database.

4.4 Vevelstad Municipality – An example of early-stage data gathering

Figure 16: Vevelstad Municipality

Vevelstad municipality is in a stage of gathering and collecting data. The situation is relatively unique in the case that the water infrastructure is not digitized, and there are no water-meters in either the grid or the households. The whole process started with the idea of securing information before certain key-personnel retires.

The municipality is prioritizing to secure the undocumented knowledge using GNSS equipment with a pre-built set of properties that could be assigned to GIS data, such as: Diameter, material type, quality of measurement, capacity and more.

Secondly there has been an investment to be able do digitally follow the process of cleansing water and tracking the amount m^3 purified and delivered pr day. In this case an external company is responsible for internet security and maintaining the system.

After the whole system is measured and digitally available further means will be evaluated. The next step is to determine the amount of purified water lost due to leaks in the pipeline. In reality it could involve investing in smart water-meters to early be able to determine how much water is lost due to a faulty system.

5 Discussion

The thesis has reviewed the different domains of the MCDM methodology, the concept and requirements of DT and IoT. The core purpose of the study was to determine if the MCDM methodology and the requirements of DT and IoT could be used to decide the best course of action for the municipal water infrastructure. Furthermore, the biproduct of a more efficient water delivery system in the municipality increases the capacity of the delivery system. Additionally, the increased capacity of the delivery facilitates establishing companies relying of fresh water, and it improves according to different KPI in the SDG's presented by the UN.

To answer the research question an extensive review was done on MCDM, DT and IoT, gathering and sorting around 120 different journal and papers, and sorting them by relevance. The field of MCDM is extensive but based on several MCDM literature reviews (Youssef; Velasquez and Hester, 2013; Mardani *et al.*, 2015; Zavadskas *et al.*, 2016) a few methodologies were chosen for further research, and became the baseline for the thesis. The MCDM methodologies were picked based on their ability to handle imprecise data, suitability towards water management, and/or uncertainties. (Velasquez and Hester, 2013; Zavadskas *et al.*, 2016)

In some ways the topic of MCDM was both easier and more difficult than first presumed, and it did in some ways changed the process in the thesis. As the MCDM methodologies was an unfamiliar research area and the different methodologies had emphasis of different subjects it also affected the final result of the thesis. As an example the unawareness towards the importance of the decision maker, and in some cases decision makers, changed the methodology from one method to another depending on the extent of a project(Saaty and Vargas, 2001; Dyer, 2005; Risawandi and Rahim, 2016; Borissova and Keremedchiev, 2019). Given that the thesis was an approach to evaluate the capabilities of MCDM in the setting of DT and IoT within a municipal framework, the premise changes when the extent of a project changes (Triantaphyllou, 2000; Koksalan, Wallenius and Zionts, 2011). When it comes to projects carried out in municipalities it is not unheard-of projects extending across the municipality's borderlines. In turn, this would result in different DM, complexity, need for investment, and perhaps a reduction of alternatives in relation to criteria. The original intent was to carry out a comparison of a MCDM approach within the framework of DT, IoT and geographical location, and then decide if one or more of these methodologies were suitable for application.

Given the change in the thesis and the increased literature review made it difficult to include another relevant topic, such as Building Information Modelling (BIM). The thesis only investigated the Digital Twin and the differentiation between a Digital Twin and a Digital Model. Ideally the topic of introducing a BIM model into the Digital Twin is something worth discussing, and if the concept was introduced the thesis would be unable to investigate the MCDM methodologies in depth.

5.1 Information quality

Choosing the MCDM methodologies:

The selection of MCDM was a result of researching other papers with MCDM literature review, whereas the aim was to find methods that are easy to use, even for those unfamiliar with the field. Additionally, given the importance the decision makers have, and the fact that a project could extend outside the municipal borderline, a couple of MCDM methodologies were chosen to determine if they are applicable or more suited if the size of the project increased (Choy and Lee, 2002; Dyer, 2005). It was under the presumption that a bigger project resulted in a bigger data base and/or more data to handle.

The research field of MCDM is vast, and it is possible to suggest several other methodologies to be investigated in the thesis. Additionally, in the newer sources regarding hybridization it was considered a separate MCDM techniques in line with SAW, CBR, MAUT, ELECTRE, and SAW (Zavadskas *et al.*, 2016).

Data quality matrix and available information evaluation

Each municipalities have different needs related to their water infrastructure, which could be data input in the table. The data quality requirements are purely based on the minimum information requirements needed in IoT, Digital Twin and BIM, and is primarily viewed from the perspective of Vevelstad Municipality. Hence, the concept of reflexivity and bias might occur due to the challenges of separating two roles.

Additionally, the thesis could have carried out a questionnaire to determine problem areas and use the statistics to present the information in table 24 as a concrete result instead of a suggestion. The same process could have been carried out to determine the data quality matrix. Alternatively, a few semi-structured interviews could have been carried out to perform simple mapping of problem areas in the field.

Internet security – IoT&DT solution

The rules regarding the digitalization of Norway are becoming increasingly more strict, especially regarding personal and sensitive information. The security itself is not described as criteria in the thesis, but in reality the topic internet security would become a criteria with a higher DQR level. At the junction point where the selected end product require more infrastructure a new decision maker, or decision makers, would be introduced into the MCDM methodology. The added DM’s would take the role of experts determining the criteria regarding Internet security, and determining new weighting values for cost estimates regarding hardware selection and security issues (Hassan, 2019)

6 Conclusion

Given the adaptable nature of the MCDM methodology it is considered suitable for determining the best course of action. However, there are some requirements that needs to be fulfilled. Firstly, an appropriate MCDM methodology must be selected, but it is advisable to fully describe the project with a goal, scope, and have a clear view of what the final result should be.

1. The geographical area of interest should be predefined
    - Determines the level of decision makers
    - Clear boundary of the area
2. Determining the final product
    - IoT devices based on sensory equipment
    - Digital model/Digital shadow
        - No information exchange between the virtual and physical model
        - Some information exchange between physical and virtual model
    - Digital Twin
3. The decision maker, or decision makers, should be decided
    - Decided by the municipalities
    - Additional decision maker should be recommended by the researcher in case of developing model with information exchange between virtual and physical model.
4. Gathering information on in-house data
    - Mapping of current device in the municipality
    - Investigating if GIS data is available for the whole grid
    - Determining the need for more data
5. Determining the funding limitations, determined by the cost/price principle
    - Depending on the size of the municipality and the population density two new factors could be introduced. The cost limitation criteria, and a function of time which determines the duration of the project.

After fulfilling the requirements an evaluation of an appropriate MCDM – methodology could be chosen. Depending on the requirements in the chosen methodology it might be necessary to gather more information, or to adapt the model to the current case. Additionally, when it comes to funding there is the possibility to apply for funding, which serves to shorten the duration of the project, and reduces the cost limitation. A requirement is often a description of the project in the municipal water plan and in the economy and investment plan. Therefore a pt.6 is introduced.

6. Creating a project description to apply for additional funding to:
    - The County
    - KS and Digitaliseringsdirektoratet

6.1 Further Research

As mentioned in 5.2 it could have been beneficial with a different approach, and as mentioned in chapter 2 a literature review and the chosen approach could serve as a precursor to a bigger project (Knopf, 2006). Additionally, the thesis is written on that basis, and as a result there are some projects and potential case-studies that could be carried out.

Implementing IoT solution in a low developed infrastructure

The proposal is on the premise of selecting a municipal with little to none IoT devices in their water infrastructure. Furthermore, the study could carry out the mapping of available information and determining the final design on the final product. When the stage data gathering is completed, the purpose is to apply a MCDM methodology to determine the best course of action.

Implementing IoT solution in a developed infrastructure

The premise of the project is similar to the implementation of IoT solution in a low developed infrastructure, however the difference lay in the existing IoT solution. The project introduces new variables such as IoT compatibility, and the design of the IoT ecology.

Creating a digital twin model

The idea for this work is the development of a Digital Twin, where the difference mainly lies in the size and complexity of the different infrastructures.

1. Small sized
2. Medium sized
3. Complex

Implementing communication between a digital twin and a BIM model for simulations

The prerequisite for this project is an existing Digital Twin and to introduce BIM models with various levels of complexity to run simulations. The simulations could consider the changes in distribution of water, if it occurs water shortage during droughts, and similar simulations.

1. Simple BIM model
2. Medium BIM model
3. Complex BIM model

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8 Appendix A – MCDM procedures and equations

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