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DOI
10.2166/9781789063059_0271

Publication date
2024

Document Version
Final published version

Published in
Asset Management of Urban Drainage Systems: If anything exciting happens, we've done it wrong!

doi: 10.2166/9781789063059_0271

Chapter 7

Decision-making in urban drainage asset management

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ABSTRACT

Decision-making is at the core of urban drainage asset management (UDAM), but its importance is often underestimated, leading to a lack of improvement of decision quality in practice. Therefore, our objective is to present fundamental concepts and theories of decision-making from literature and compare them with real-world experiences of observing, supporting, and participating in UDAM decisions in the Netherlands. The observations are contrasted against selected observations from other nations to illustrate the potential impact of key factors on decision-making processes and outcomes. From this, we observe that despite the available UDAM literature and experiences suggesting otherwise, decision-making in UDAM practice tends to focus on information acquisition, cognitive processing, and judgmental processes. This can lead to known decision biases such as protection of mindset and following fragmented, path-dependent processes influenced by formal and informal structures or institutions. To improve decision-making in UDAM, it is necessary to look beyond optimization of existing assets within the pre-existing technical paradigm and instead work toward aligning it with governing structures and processes for effective decision-making at a system level. While the existing evidence – although limited and mostly anecdotal – is compelling, it does not allow for generalization or validation of theoretical propositions against practical findings and vice versa. We therefore see a need for strengthened efforts into a more systematic study of current UDAM practices that incorporates existing theories and empirical insights on decision-making from several disciplines. This will foster accumulation of knowledge and mutual learning to enhance the research and practice of UDAM decision-making.

Keywords: urban drainage asset management, decision-making, cognitive heuristics and biases, multi-actor problem-solving, decision quality, governance gaps, process blunders.

7.1 WHY A CLOSER LOOK AT DECISION-MAKING IN URBAN DRAINAGE ASSET MANAGEMENT?

In organizational and public life, the governance, policy making, and management of resources are inseparably intertwined with making decisions and the actions following therefrom. Decision-making is also the main activity through which asset management (AM) organizations align their choices, plans, and actions with their objectives in order to realize value from their assets. The achievement of these objectives relies on the coordinated decision-making of those who manage urban drainage (UD) assets within the given political, socio-institutional, and environmental context. This context is dynamic, involves many stakeholders and interconnected systems of technical assets, formal and informal institutions, and their natural environment. The success of an organization within such a context thus critically depends on the collective decision-making skills of those working in the organization and their ability to constructively interact with other decision-makers about decisions affecting the behavior of the system of interest.

Despite its centrality in urban drainage asset management (UDAM), little attention is being paid to understanding decision-making and decision quality in research and practice. Only a few dedicated studies exist, suggesting a strong reliance on intuition and experience in UDAM decision-making (van Riel *et al*., 2014, 2015). A large number of decision-support guidelines, analytical methods, and tools developed to aid water infrastructure AM (e.g., Tscheikner-Gratl *et al*., 2019; Zhang *et al*., 2014) suggests a perceived need for more analytic, evidence-based decision-making based on objective information and models. Obviously, UDAM is not the only human management activity that relies on decision-making and that is facing challenges in achieving them. Decision sciences provide a more nuanced perspective as to what decision-making is, what it entails as well as whether and when relying on intuition or deliberation using decision-support aids is (un)desirable. 'Decision sciences' is here used loosely as an umbrella term for the multi- and inter-disciplinary study of human decision-making and its outcomes, bridging across the social, natural, and applied (technical) sciences. As this research seems to have gone largely unnoticed in UDAM research in practice, with this chapter we aim to:

(1) Introduce and unpack selected concepts, perspectives, and theories that we deem useful for understanding individual and multi-actor decision-making.
(2) Expose known quality issues in multi-actor decision-making settings and illustrate these against examples from UDAM practice in the Netherlands and other countries.

While the suggested associations between the theoretical aspects and the examples presented are selective, based on our own subjective judgment and not independently validated, we hope these will show possible relationships that warrant further study. By this, our aim is to promote cross-disciplinary learning and enhance comprehension of the challenges encountered in UDAM decision-making research and practice. In closing this chapter, we will point to areas for future research, hoping to inspire constructive discussion on decision-making and decision support for quality UDAM.

7.2 UNPACKING DECISION-MAKING

7.2.1 Decision-making perspectives

The Cambridge Dictionary defines decision-making as 'the process of making choices, especially important choices' (Cambridge Dictionary. Last accessed 10 August 2022, https://dictionary.cambridge.org/dictionary/english/decision-making). However, much of the literature and everyday language make use of the term decision-making as a synonym to 'choice', suggesting that the process and outcomes resulting from it are the same – which is not the case. Decision-making scholars have studied human decision-making and its underlying processes from many angles. Three dominant philosophical perspectives include normative, descriptive, and prescriptive views, as illustrated in Figure 7.1 and elaborated upon in more detail in Bell *et al*. (1988).

The normative decision-making perspective is evaluative in nature and studies how humans ought to make decisions, as per some general ideals, values, norms, and standards of what is considered good or bad, right or wrong, acceptable or unacceptable. More specifically, it infers rationality in the strict normative sense whereby 'the rational man of economics is a maximizer, who will settle for nothing less than the best' (Simon, 1978, p. 2). A common behavioral assumption that aligns

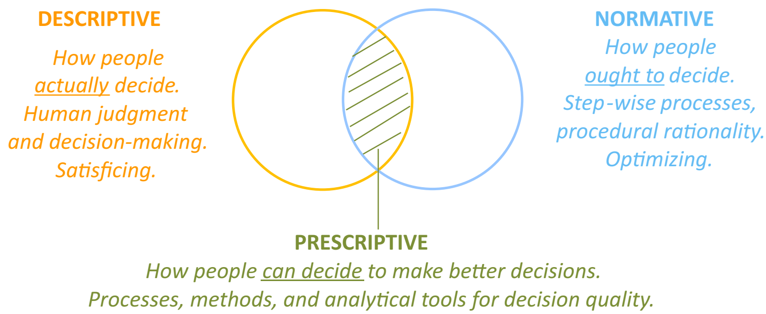

Figure 7.1 Three perspectives for studying human decision-making.

with normative rationality is the presumption of intentionality in choice, where someone's actions are believed to result from intentional, deliberate, and self-initiated choices (Goschke & Job, 2023). Another assumption is that the chosen action is deemed better than non-action or other choice options based on some appraisal of expected value.

Much present-day decision-making research on behavioral sciences is based on overwhelming amounts of sound empirical evidence that challenges rational decision-making assumptions in the strict normative sense as well as the assumption of intentionality being people's (in)actions. Instead, a descriptive perspective is taken to study and explain human decision-making. Descriptive decision-making deals with analyzing and describing how humans make decisions in the real world under uncertainty and cognitive complexity. From the descriptive perspective, decision-makers are 'boundedly rational' (Simon, 1982a, 1982b), that is, have limited knowledge, time, as well as limited cognitive and information-processing capacities. Therefore, not all potential alternatives and their consequences are considered. Instead, 'satisficing' strategies (i.e., from satisfy and suffice) are used wherein the first alternative that satisfies some minimal acceptability standard is chosen without exploring other options.

Under bounded rationality, intuitive and habitual responses go along with cognitive heuristics and shortcuts that serve to cope with the cognitive complexity of real-world decision-making. These so-called 'cognitive biases' resulting therefrom often refute the normative demands of substantive rationality and are frequently characterized as undesirable deviations that are to be avoided (Gilovich *et al.*, 2002; Tversky & Kahneman, 1974). Other scholars, however, argue that the use of cognitive heuristics is desirable and efficient in many environmental and social contexts, considering them important 'fast and frugal heuristics' that make up our 'adaptive toolbox' (Gigerenzer, 2004; Artinger *et al.*, 2015).

Studies into interventions to improve decision-making generally follow a 'prescriptive' perspective to decision-making. Prescriptive decision-making bridges normative and descriptive perspectives by studying how real people can make better decisions as informed by how people decide in the real world and how they can decide by adopting certain processes, decision aids, and decision-making behaviors leading to better decisions following common normative aspirations. This perspective endorses 'procedural rationality,' or 'the effectiveness, in light of human cognitive powers and limitations, of the procedures used to choose actions' (Simon, 1978). Given the need to make thousands of decisions every day, it makes sense to rely on satisficing, intuition, and automation to reduce the effort rather than taking a maximizing approach to identify and implement the optimal choice. Recognizing when intuitive decision-making approaches may lead us astray and when prescriptive decision-support and intervention are needed to achieve normative aspirations remains a subject of scholarly debate (Kahneman & Klein, 2009).

7.2.2 Individual-level decision-making

Empirical studies show that humans make use of different decision-making approaches, or strategies, reflecting a trade-off between time or effort and accuracy (Payne *et al.*, 1993). The approach is determined as prompted by the perceived situational cues, often without the decision-maker consciously noticing. In line with that, the overly simplistic but useful model of managerial decision-making by Schoemaker and Russo (1993) differentiates four common approaches in managerial decision-making and arranges these in a pyramid. This pyramidal structure reflects the frequency with which approaches are used and the degree of intuition or analysis they entail. Intuition herein refers to the associative processing and quick appraisal of a specific situation as perceived by the decision-maker and the contextual cues they are paying attention to. Accordingly, (1) intuitive judgments from intuition are most frequently used and require the least effort, followed by (2) rules and shortcuts, (3) importance weighting, and finally, (4) value analysis as the most analytical, deliberative, and therewith accurate, yet also most strenuous and least common approach. This pyramid is reflected in Figure 7.2, wherein the four decision-making approaches are mapped against the effort–accuracy trade-off of Payne *et al.* (1993) and another simplistic, yet useful theory of decision-making governed by 'two systems thinking' described by Kahneman (2011).

The effort–accuracy trade-off and the activation of different decision-making strategies by different cognitive processes have been confirmed by other studies that inspired later 'dual-processing theories' such as Kahneman's two systems. Already in the 1970s, Posner and Snyder (1975) presented a model that distinguished between automatic and conscious processing. Thereafter, several other dual-processing theories were developed that distinguish intuitive and reflective processes in learning, cognition, and judgment (e.g., reviewed in Evans, 2008). These theories are widely used to explain the occurrence of mental shortcuts in cognitive processing that underlie human judgment and decision-making and which contradict mathematical logic and economic rationality. They are often referred to as 'heuristics and biases,' following the seminal study of Tversky and Kahneman (1974). The heuristics and biases supposedly arising from dual processing in the brain are attributed to all kinds of 'irrational' thinking features (aka 'system 1' thinking) such as being automatic, quick, low-effort, and uncontrolled as opposed to 'rational' ('system 2') thinking that is conscious, slow, effortful, and controlled (Kahneman, 2011; Stanovich & West, 2000).

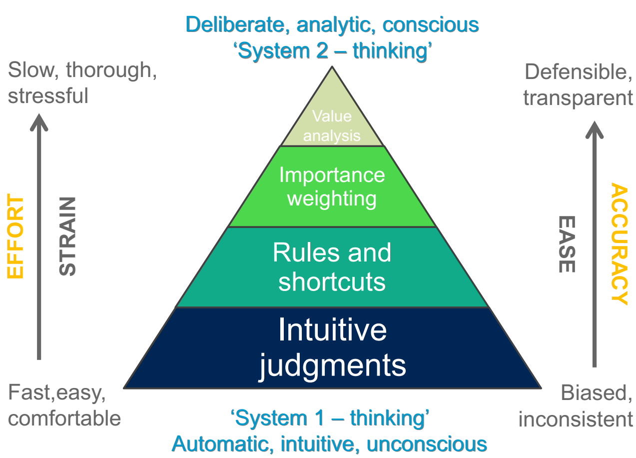

Figure 7.2 Overview of decision-making theories, mapping Schoemaker and Russo's (1993) 'Pyramid of Decision-making Approaches' against the trade-offs of Payne *et al.*'s (1993) effort–accuracy framework, Kahneman's (2011) 'System 1 and System 2 thinking' and attested implications for speed, consistency, affective response, and normative qualities from various 'dual processing theories' (Evans 2008).

When these dual-processing theories emerged in the mid-1970s, functional and structural neuroimaging was still in its infancy (Filler, 2009). In other words, it was not yet possible to link distinct locations of activity in the brain to the associated, abstract mental processes. More recent neuroscientific studies have debunked dual-process theories as too simplistic. As argued by Melnikoff and Bargh (2018), a multi-dimensional typology would better suit the observed interactions between two system features in automatic or deliberate information and emotion processing in the brain to describe, explain, and predict decision-making patterns that rely on both intuition and deliberation. Whether and in which situations reliance on automatic processing and intuition is useful or detrimental depends on the nature of the decision-making task and its context (Myers & Myers, 2002). Jumping out of the way when an object is racing toward you at very high speed will be a well-adapted use of intuition leading to immediate action, whereas rejecting a job candidate based on how well their appearance and demeanors fit with that of the 'in-group' is not. In the first situation, the reliance on intuition instead of pausing to deliberate about whether the object is likely to hit before acting is possibly lifesaving. In the second situation, the decision-maker may be discarding the candidate who is more suitable for the job and end up hiring someone who may look, speak, and act the way others do but is otherwise incompetent.

More recently, the impact of emotions on judgment and decision-making has received significant attention to explain real-world decision-making phenomena. Emotions have been shown to significantly influence decisions via content and depth of thought, as well as goal activation in individual and interpersonal decision-making (Lerner *et al*., 2015). Another important area of contemporary research concerns 'choice architecture,' which studies the influence of contextual cues, framing, and environmental (re)structuring on automatic processing on behavior (Johnson *et al*., 2012). Many 'nudging' interventions rely on changing the choice architecture to bring about desired choice outcomes (Münscher *et al*., 2016). The above reflects only a small selection of well-studied concepts and theories to understand human decision-making. While too simplistic to fully explain and predict decisions, they can be useful to identify and characterize aspects that significantly influence decision-making.

7.2.3 Multi-actor decision-making in and across organizations

Good UDAM requires coordinated action and decision-making of several individuals or groups. We refer to them as 'actors' to reflect their significant interest and leverage to influence the state of UD systems (Hermans & Cunningham, 2013). Within the AM organization, management of UD assets will typically involve actors holding different content expertise, typically, technical planning, technical operation and maintenance, finance, human resources, management, and management levels (operational, tactical, and strategic). The formal relationships within the AM organization are governed by the organizational hierarchy and distribution of tasks, as well as the relationship between these organizations. In the case of UDAM, these relationships are largely determined by the governance context. Governance here refers to the political and institutional frameworks to determine the distribution of roles and responsibilities and within which values and goals are defined and codified into the various political, administrative, legal, social, and economic systems. Many different governance arrangements exist that typically vary between countries (Romano & Akhmouch, 2019). The administrative, functional, and spatial overlaps resulting therefrom make interaction and coordination of activities with other sector organizations necessary such as national/regional/local government oversight bodies (e.g., related to water resources, environmental protection, public health), other infrastructure managing bodies (e.g., municipal road, energy, housing, public greens departments) as well as consultants and contractors. Public authorities have a wide array of policy instruments to influence the management of the various resources in accordance with their goals such as legal and regulatory instruments, economic incentives, instruments for information, and enablement. Management then focuses on specific actions and operational activities to achieve the goals (OECD, 2011).

These formal and informal socio-institutional structures and procedures, along with the broader socio-cultural context, shape individual and multi-actor decision-making behavior across vertical and horizontal decision-making levels. Interactions between individual and groups of actors are influenced by asymmetries in power, knowledge disparities, resource availability, as well as the different interests and action options available in line with their respective roles, responsibilities, and entitlements. It is within this force field that actors strive to identify and solve problems, using the actions and resources at their disposal within the given context. However, no single actor or organization has complete control over all options and resources. Different actors have different roles and responsibilities, such as formulating regulations or monitoring existing assets. The feasibility of these options depends on the availability of necessary resources such as funding, personnel, expertise, mental capacity, and time.

Given this situation, it is not surprising to find misalignment between the actors' system perceptions, needs, and goals, and therewith perceived problems, and possible solutions. Such misalignments in system boundary perceptions are often attributed to a lack of systemic and collective change (Pluchinotta *et al.*, 2022). In such situations, conflicting values, priorities, and demands contribute to a host of political behaviors wherein actors seek to set agenda's, influence the definition of goals and values guiding decision-making and action. Three well-known phenomena affecting multi-actor decision-making in this regard are (1) goal conflicts, (2) action conflicts, and (3) dilemmas (Hermans & Cunningham, 2018). Goal conflicts occur when actors have different desired outcomes for the same goal. Action conflicts arise when one actor's decision negatively affects another actor's goal. Dilemmas arise when an action has both positive and negative consequences for an actor's goals, requiring a trade-off.

The picture would be incomplete without consideration of (inter)personal needs that actors seek to satisfy, resulting in social dynamics that are not often considered in understanding multi-actor decision-making and decision support for UDAM. Social structures have to do with 'the distinctive, stable arrangement of institutions whereby human beings in a society interact and live together' (Wilderdink & Form, 1999). Social structures provide social identity, such as the mission of an organization or work unit and the legitimation for its existence (Smith *et al.*, 2015). Social structures and identity are closely intertwined with social norms that prescribe acceptable behavior within a group and determine who may legitimately wield power or influence over others. Social cognition arises within the context of social structures, it 'refers to a set of neurocognitive processes underlying the individuals' ability to "make sense of others' behavior" as a crucial prerequisite of social interaction' (Arioli *et al.*, 2018). It is within these socially construed structures that actors will seek to realize their personal and group's interests.

Empirical studies have shown the relationships between evolving social values, institutional arrangements, water management paradigms, and technical infrastructure (Hering *et al.*, 2012; Kiparsky *et al.*, 2013; Wong & Brown, 2009). Their impact on decision-making processes and outcomes are often overlooked in UDAM. With changing environmental and social conditions, multi-actor conflicts may arise around the distribution of material and social resources. Dynamics observed in this regard include 'in-group' vs. 'out-group' behaviors, such as mounting commitment to one's own group along with polarization between groups and in extreme cases seeking revenge and retribution (Smith *et al.*, 2015). These factors impact group decision-making performance, including biases in information search and processing, emotion and information cascades, and political behavior aligned with specific group perspectives and interests (Janis, 1982; Sunstein & Hastie, 2015). Changing conditions may also result in intergroup cooperation, wherein exploration of common values and goals leads to the construction of a common social identity. Intergroup cooperation comes with its own challenges in relation to multi-actor decision-making, such as an increased need for efforts upholding the (new) social identity and ensuring cohesion (including attracting and retaining valued members) while avoiding behaviors that undermine group cohesion, morale, and coordination.

7.2.4 Decision-making as a multi-actor problem-solving process

Often, we may only become aware that a decision needs to be made when confronted with an urgent or difficult problem, and especially those we cannot solve or decide on our own. A problem-solving process has been conceptualized in many ways, depending on the foci and units of interest of different fields, and whether it deals with individual or organizational problem-solving (Lang *et al.*, 1978). In the literature the terms 'problem-solving' and 'decision-making' are often used interchangeably, although they are not synonymous but complementary parts of a problem-solving or decision-making process. Problem-solving refers to an analytical process through which solutions to overcome a problematic situation are identified; decision-making is about choosing among different alternatives or choice options to reach a conclusion or judgment. It involves analyzing information, weighing different options, and making a choice based on the available information and the desired outcome.

As a result, most problem-solving and decision-making process models include roughly the same phases that span both problem-solving and decision-making (Harrison, 1996; Keeney, 1982; Lang *et al.*, 1978; Lunenburg, 2010; Nutt, 2008). This similarity between processes and phases also extends to policy making and design processes (Enserink *et al.*, 2010). Moreover, these processes may be described interchangeably as a stepwise process or as a cycle with iterations within and in between steps. These models of problem-solving processes and decision-making processes arguably have more commonalities than differences; for a review and comparison of problem-solving process models see, for example, Lang *et al.* (1978). They are conceptualized as a sequence of steps (also referred to as 'phases') that link problem sensing to the implementation of some solution to the problem. The key differences consist in the terminology used to name the steps, the number of steps into which key problem-solving activities are subdivided and the nuances considered.

Following one of the earlier conceptualizations introduced by Simon, problem-solving has at least four phases: intelligence, design, choice, and implementation (Simon, 1991). Intelligence starts from there being a gap between the desired and existing state as gauged on some goal, norm, or expectation, initiating a problem-solving – or improvement – process. This phase also includes situational analysis and gathering of information. Obvious preconditions for this phase being started is that any gap in the current situation or anticipated future situation has been noticed and attention has been paid to it, next to there being motivation to reduce the gap and being able to do something about it (Lang *et al.*, 1978). In some models, this phase may also include exploration and negotiation between stakeholders to come up with a shared, unambiguous formulation of the problem, its causes, and also the identification of preferences, values, and criteria that matter in addressing the problem. During the design phase, alternative solutions are identified through searches or via a purpose created as a means to address the gap. Then, during the choice phase, the alternatives are compared based on some form of appraisal, possibly involving additional analysis and judgment or evaluation against criteria, and a decision is made whether to adopt any of the alternatives and which. Finally, implementation entails actions to put the decision into effect, involving mobilization and coordination of people and resources, and possibly also monitoring of the effectiveness of the decision. Implementation may be linked back to intelligence, initiating another problem-solving cycle if the effect on the initial state is insufficient or the new situation leads to identification of other problems.

These process models depict a process that is in line with procedural rationality, reflecting normative perspectives. Or, as Lunenburg (2010) puts it, the assumption is one of decision-making under certainty where the alternatives and their outcomes on the decision criteria are known, such that an optimal choice can be made that is subsequently implemented. Obviously, that is not how most individuals and organizations make decisions and it is nearly unachievable in real-world situations. Instead, a more boundedly rational, if not completely intuitive, problem-solving, or decision-making process applies. As illustrated by, for example, Rizun and Taranenko (2014), these processes can still be characterized by the same phases, only that they are incompletely run through and in a way reflect bounded rationality and intuition-driven models. The intelligence phase may be restrained to identifying the problem and decision criteria 'sufficiently,' such as only attending to specific cues and monitoring deviation of an aspired state on a focal goal, without deeper comprehension of the problem faced (Lunenburg, 2010). Different system boundary perceptions may bring about different problem perceptions, which in combination with limited cognitive capacity will influence what information is processed and paid attention to when specifying a problem and identifying solutions. Design based on memory, pattern recognition, and limited searches may yield only those alternatives that are easily accessible and familiar (reflecting 'availability bias,' Tversky & Kahneman, 1973). Choice would then be informed by heuristic judgment and use of simple choice heuristics instead of more elaborate and objective appraisals. Implementation would focus on getting it done to achieve a satisfying improvement of the situation within limited effort.

Various other models exist beyond these so-called 'phase' models of decision-making processes, such as the 'garbage can model' (Cohen *et al.*, 1972), the 'multiple streams framework' (Béland & Howlett, 2016), or the 'rounds model.' For an accessible description of these models, see, for example, Teisman (2000) and Enserink *et al.* (2022). These models do not assume for certain phases to be completed in whichever order, but rather focus on different decision-making instances and dynamics in political and policy decision-making contexts. In these, political alliances and struggles around meanings, power, or influence over scarce resources are inherent to the decision-making process, reflecting different worldviews, interests, and roles come together. Many undesirable outcomes have been associated with political behavior in decision-making: self-serving and strategic behaviors may affect information flows; divisive dynamics are time-consuming and may lead to missing out on opportunities or profits due to delays. A focus on internal matters, power bases, and interests may blind a team or organization. This, in turn, may lead to the inclusion or exclusion of alternatives in line with powerful interests and to the overlooking of critical environmental constraints which may result in underperformance or failure to address the problem. Even when considered objectively 'better' for the organization and its members, establishing more rational decision-making processes is typically met by resistance, as it would involve changing existing mindsets, if not the political and organizational structures and procedures.

Research on the success of strategic decision-making processes in organizations (Nutt, 1999, 2008) found that more than half of these processes fail due to obvious process blunders in decision-making. Although considered more efficient, most organizations relied on top-down 'idea imposition' processes characterized by 'see first' tactics. Conversely, 'discovery processes' that endorse analytical 'think first' tactics were significantly more time efficient, had a 90% chance of decision adoption and resulted in higher, more evenly distributed satisfaction of the involved actors.

In the absence of a well-managed multi-actor process, organizational inertia and resistance are to be expected in decision-making, also in urban water management (Brown & Farrelly, 2009; Marlow *et al.*, 2013). A result is a strong tendency toward incrementalism, where only small adjustments (increments) are made with respect to the existing situation involving limited effort, based on a sequence of limited comparisons and change (Elbanna, 2006). Explanations for the prevalence of incrementalism include structural, cognitive, and political factors at individual, group/multi-actor, and organizational/governance levels. Cognitive factors include limitations in the acquisition, search, and analysis of information due to resource constraints. These may quite simply come down to time limitations and role expectations. For example, studies of the time allocation by decision-makers in leadership positions evidence a strong action-orientation where no more than a few minutes are spent on most activities and only a fraction of activities are being attended to for more than an hour (Lunenburg, 2010). Furthermore, important structural constraints are imposed by the need to adhere to institutionalized processes of planning, approval, and implementation or to act in line with certain self-concepts, institutionalized logics, or social norms. Political behavior may involve not upsetting an important ally or powerful opponent, or exploiting situations of asymmetric information to avoid that certain information may be used to one's disadvantage.

Lastly, the abovementioned constellations of factors that may play out within one particular multi-actor decision-making process are not independent from the earlier history of the organization and the actors involved in earlier decision-making processes. Along with technological path dependency, organizational path dependency exists, wherein various socio-institutional dynamics and self-reinforcing mechanisms may lead organizations to become locked into a situation of structural, procedural, and cognitive inertia (Sydow *et al*., 2009). To summarize, while there are many models reflecting normative aspirations or prescriptive guidance for decision-making processes that foster rationality in solving problems, decision-making reality is better described as some form of 'muddling through' that may combine elements of rational planning with incrementalism, cognitive limitations, and politics.

7.2.5 In search of decision quality

Many decision practitioners and scientists have prescribed ways to improve decision-making by individuals and groups. While achieving normative ideals of decision rationality remains difficult in the real world, increasing decision quality seems very much possible. A decision-quality framework shown in Figure 7.3 builds upon a set of six principles to satisfy to achieve decision quality (Spetzler *et al*., 2016):

(1) Appropriate framing that clarifies the problem or opportunity to be tackled and its main stakeholders.

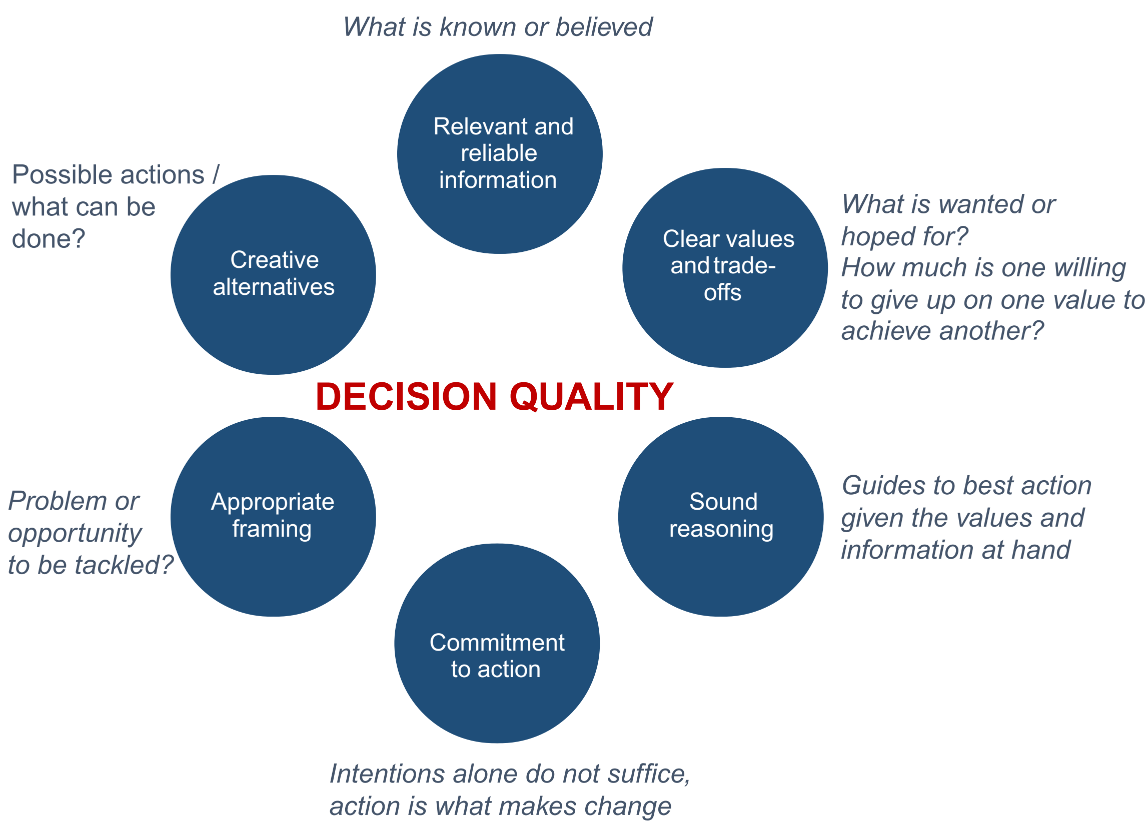

Figure 7.3 Decision quality and what it entails (*source*: adapted from Spetzler *et al*., 2016).

(2) Creative alternatives reflecting possible actions that can be taken by the people partaking in the decision.
(3) Relevant and reliable information amalgamating what is known or believed about the situation, problem, and solutions.
(4) Clear values and trade-offs concerning what one wants or hopes to achieve as well as how much one is willing to give up achieving one value over another.
(5) Sound reasoning in identifying the best alternative given the values and information at hand.
(6) Commitment to action as good intentions alone do not suffice and actions need to be implemented to make a change.

The framework posits that decision-makers should act in line with all six principles as shortcomings on any of these imply that decision quality is unlikely to be achieved. The most critical is to ensure a clear, appropriate framing, and hence clarity of the problem and its key stakeholders (Ackermann, 2012; Keeney, 2004; Rosenhead, 1996). In complex problem and decision-making situations, it is also common for disagreements about the problems or solutions to consider in decision-making to occur (Head & Alford, 2015; Rittel & Webber, 1973). Even with a clear, shared, and appropriate framing, no decision can be better than the outcomes of the best alternative considered. It is common that decision-makers are not clear as to the full range of the values considered relevant to a decision (Bond *et al.*, 2008). Without clarity of the values to fulfill, decision-making often consists of choosing between readily available alternatives following so-called 'alternative-focused thinking' (Keeney, 1996). There are many examples of solutions that address a wrong, unimportant, or even inexistent problem. A common failure to include non-standard alternatives or to design suitable alternatives as guided by the goals is a main barrier in strategic decision-making (Gregory & Keeney, 1994; Keeney, 1996).

The framing of the problem and the process followed to achieve multi-actor commitment, value identification, alternative creation, and appraisal are key to understanding the decision ultimately made and its odds for successful implementation (Nutt, 2008). Even when several objectives and innovative, suitable solutions are considered, challenges may arise when there is an undue tendency to optimize. Optimizing in decision-making refers to a situation wherein a decision-maker is invested in improving on at least one main goal while avoiding foregoing or 'losing out' on another, wherein the status quo serves as a reference. This avoidance of trade-offs when evaluating alternatives can result in a dilemma when one alternative is desirable in terms of improving on some focal goal, yet at the same time undesirable due to incurring a perceived loss on another. Avoidance of trade-offs and loss aversion are one of the several explanations behind procrastination and failing to take a decision especially when the stakes are high. These are but some of the issues and deviations from substantive rationality which are known to arise when making deliberate choices and weighing trade-offs between several goals (Keeney, 2002).

In addition, there are many 'hidden traps' (Hammond *et al.*, 1998) that may lead to various blunders impacting decision quality outside of the conscious awareness of the decision-makers. Cognitive and resource limitations, the use of heuristics, and motivated reasoning within a predefined decision structure or context are only some out of many explanations for what information is being processed and how. Spetzler *et al.* (2016) highlight five types of biases hindering decision quality in organizational decision-making: (1) protection of mindset, (2) personality and habits, (3) yielding to social influence, (4) faulty reasoning about (complexity and) uncertainty, and (5) relying on automatic associations and relative thinking. First, protection of mindset refers to avoiding changes to pre-existing mental models, assumptions, and preferences constructed in line with memories and lessons learned from experience. This includes biases such as sunk cost, status quo, confirmation, and hindsight bias. Overconfidence and avoidance of cognitive dissonance may arise. Second, personality and habits include habitual framing and preference-based habits, or different decision styles. Third, yielding to social influence involves conforming to group norms to avoid rejection and adjusting views to align with others. This can lead to judgment cascades and group thinking. Suggestibility and conformity may give rise to judgment cascades that prevent dissenting with (majority) judgment and groupthink that discourages diversity in views within a group. Fourth, faulty reasoning about complexity and uncertainty arises when dealing with complexity arising from many interrelated variables that may furthermore be highly uncertain. Confusion and inability to combine many cues into a coherent picture may give rise to selective attention and use of substitution heuristics. Lastly, overreliance on automatic associations in line with a certain framing or context can lead to overweighting certain information while discarding others based on vividness, narrative appeal, ease of recall, or familiarity. Altogether, interaction of these traps may give rise to 'decision mega biases' in organizational and group decision-making that undermine decision quality (Spetzler *et al.*, 2016).

To overcome these decision traps, biases, and judgment cascades, many deliberative and analytic approaches are available (e.g., Eisenführ *et al.*, 2010; Greco *et al.*, 2016; Hammond *et al.*, 2002; Howard, 1988; Keeney, 1982; Mingers, 2011; Mingers & Rosenhead, 2004; Rosenhead, 1996; Roy, 1991; Roy & Słowiński, 2013). These deliberative approaches combine a social process intervention with tools and techniques to support deliberation, analysis, judgment, and reasoning throughout a problem-solving and decision-making process. Although the value and potential of such 'discovery processes' has been clearly demonstrated, they are often perceived as arduous or cumbersome (Nutt, 2008). Processes that are perceived to misalign with organizations' mindset, culture, and habitual ways of doing, are likely to get rejected. Therefore, processes to achieve higher decision quality need to go beyond procedural rationality and suitable methods to tackle structural and cognitive limitations. Instead, given the complex nature of problem-solving in multi-stakeholder environments, the process itself may be contested. This is when moving from 'procedural rationality' toward endorsing 'processual rationality' is required (De Bruijn *et al.*, 2010). This, however, requires social process negotiation, moderation, and facilitation skills that many organizations are unaware of or may lack the expertise to implement.

7.3 DECISION-MAKING IN UDAM PRACTICE

7.3.1 Structural water governance and management gaps in UDAM

The Organization for Economic Co-operation and Development (OECD) suggests that multi-level water governance, regardless of countries' institutional features and organization of the water sector, often faces seven categories of 'gaps' when designing and implementing water policy (OECD, 2011). The OECD multi-level governance framework allows to diagnose vertical and horizontal coordination bottlenecks between levels of government, across policy areas (i.e., ministries and public agencies), and between local and regional actors at the sub-national level. These should be diagnosed and bridged in a systemic way as they are strongly interrelated and may reinforce each other.

7.3.1.1 Administrative gaps

The advantage of top-down task distribution is that decisions can be made routinely, and solutions found quickly. Decisions are relatively simple and straightforward. Yet, because tasks in water resources and infrastructure management are divided and different organizations are responsible for different parts, it becomes difficult to integrate AM activities. In the United Kingdom, all water infrastructure is managed by private-sector water authorities. In the Netherlands, different organizations are involved needing collaboration among drinking water companies, municipalities for the sewage system, and water boards for the wastewater treatment, except for the City of Amsterdam, where the utility company 'Waternet' holds combined responsibility for drinking water supply, wastewater conveyance and treatment, and surface water management. Furthermore, the provinces oversee managing groundwater and together with the national institute 'Rijkswaterstaat,' are responsible for the management of major waterways and (inter)national rivers. Moreover, there are challenges that lie at the interface of the different systems and organizational responsibilities for example, the challenges of aging of centralized infrastructure and climate adaptation of cities. There typically is neither clear authority nor framework for making decisions at this interface and institutional fragmentation affects collaboration and planning.

A study from Sweden suggests that the main challenges a public utility company has to overcome to implement an AM model are (Mårtensson & Rumman, 2019): (1) lack of strategic and long-term planning responsibility, (2) unclear division of asset responsibilities, (3) lack of commitment by senior management toward AM systems, (4) absence of standardized risk management, and (5) lack of information sharing between departments. A big risk when facing these challenges is that measures are taken that do not provide an adequate solution or, in extreme cases, only reinforce the problem. Ineffective interventions can affect trust and acceptance by residents as well as other parties and their willingness to invest (more) into UDAM. Interdisciplinarity also creates issues in terms of available knowledge and capacities. For example, the need for in-house technical capacity in Sweden has led to the creation of inter-municipal bodies (Alm *et al.*, 2021). Differences in water quality are not tolerated and economies of scale are being used.

In the Netherlands, a solution to this challenge is sought in closer cooperation between water management organizations as formalized in 2011 in the National Governmental Water Agreement (in Dutch: 'nationaal bestuursakkoord water,' hereafter BAW-2011). Cooperation between municipalities and water boards has been long-standing and is by now well established. An important starting point was the optimization of wastewater systems to greatly reduce emissions. By combining the knowledge and skills of several municipalities and the water boards in so-called work units, the need for interdisciplinary knowledge and technical capacity is being met. Subsequently, another main argument was cost savings in not letting water rates rise too much, which could be achieved through mergers of management organizations as well as sharing of expertise and machinery in operational tasks (Gerritsen & Sterks, 2004; Oosterom & Hermans, 2013). This also called attention to the quality and vulnerability of many organizations. Looking back, much has been achieved, especially in terms of cost savings. Further analysis revealed, however, that cooperation takes place mainly at the operational level and sometimes at the tactical level. It tends to focus on the coordination of activities to achieve cost savings rather than on determining which actions are possible and jointly arriving at the most appropriate joint intervention. More cooperation at the strategic level could lead to a great improvement in UDAM implementation and its outcomes.

7.3.1.2 Objective gaps

Local administrations face multiple pressures and competing agendas within and beyond UDAM. Climate change, population growth, and urbanization as well as increasing environmental and economic concerns, highlight the limitations of traditional wastewater practices and thereby challenge the management of urban water systems. Both in theory and in practice, it has been widely acknowledged that the challenges of the 21st century require solutions that address problems in a more integrated, systemic way. Although the demand for integration is obvious, implementation has proved challenging given the lack of clarity as to misalignment of objectives.

In the Netherlands, cost reduction is an important goal in sewer maintenance and therefore renovation instead of replacement is often chosen. This makes system change aimed at increasing water retention almost impossible. The emphasis on financial resource efficiency seriously hampers the redesign of public spaces with the intent of climate adaptation. Projects to renew roads and sewers would provide opportunity for climate change adaptation; however, they are often not taken advantage of due to a lack of integrated policy (Bassone-Quashie, 2021).

While current urban water challenges clearly need a more integrated approach, practitioners disagree on what such an integrated approach exactly means in terms of goals and solutions. Integration could therefore be described as a 'wicked' problem (Head & Alford, 2015), with practitioners having a different understanding of the opportunities and challenges they should focus on, of what to achieve as to climate adaptation, and of resource recovery or collective replacement. This lack of consensus challenges decision-making, and thus the implementation of integration (Nieuwenhuis *et al.*, 2022).

7.3.1.3 Policy gaps

The specificity of and scale at which policy is formulated can vary widely between different levels of government and government agencies. In the Dutch situation, municipalities have the most direct link to residents. In the plans and projects of municipalities, issues such as nuisance during work, design and appearance, and management are often directly considered. However, in the plans of the national, provincial, and water boards such criteria are often excluded; instead, the focus is entirely on the aspirations and investments required.

The mutual coordination of policies, and the goals that these should achieve, can obviously cause major problems. In the Netherlands, the tasks of a water board may have primarily a long-term focus, for example, considering not only flooding but also replenishing groundwater, combating drought, and strengthening biodiversity (Waterschap de Dommel, 2021). In contrast, solving flooding is the primary concern for many municipalities. The difference in perspective leads to a gap between the relevant policies at hand.

7.3.1.4 Capacity gaps

Within AM, three main roles may be distinguished: asset owner, asset manager, and service provider. Each of these roles has its own scope. The asset owner's role is to translate the perceived needs of stakeholders into goals. The interpretation of goals and risk preferences of asset owners may be different from those of other stakeholders. The asset managers focus primarily on optimizing the existing assets, whereas service providers are primarily concerned with the availability and reliability of the assets.

In a small organization, one is forced to combine these roles. This can be at the level of the asset owner, where sewer system management is only one of many tasks. At the level of the asset manager, for example, several types of assets that are very different in nature might fall under his responsibility, for example, roads, public lighting, sewers, parks, green space, and so on. Ideally, these three roles are filled independently to ensure that the potentially conflicting interests are well balanced in a decision-making process. However, when these roles are combined, such as the asset manager also being the service provider, then one of the roles – typically depending on the knowledge, skills, and interests of the person involved – can become dominant.

Most municipalities in the Netherlands are understaffed. Qualified personnel are scarce and at the same time, the portfolio of tasks continues to broaden. Sectoral standards distinguish several areas of interest, each requiring its own specialized knowledge and skills (RIONED, 2021). In smaller organizations, only one person tends to oversee UD. Knowledge then focuses on policy, sewer system management, or project management. Sector studies have shown that the other task areas then typically do not receive adequate attention because knowledge or skills are lacking. Attempts to call this to the attention of municipal councils have not yielded much to date. Sewer systems are invisible and the lack of attention at present is likely to manifest itself in a few years down the road. Given the delay in feedback, there is no urgency to act.

7.3.1.5 Knowledge gaps

The question is how decision-making within AM can be advanced given the problems in practice and the search for decision quality. The importance of sufficient competency of UD professionals in terms of knowledge and the associated skills was recognized several years ago in the Netherlands. In addition to calling broad attention to the subject and taking a critical look at existing vocational training programs, it was decided to define a minimum required level of knowledge with associated competencies. This model developed by the RIONED Foundation has been called the 'sector standard': RIONED is the sector organization of urban drainage management professionals in the Netherlands and the umbrella organization in which public bodies, industry, and the educational sector collaborate. It distinguishes 12 knowledge fields related to the general activities of UD professionals: (1) policy, law, and regulations, (2) water management, (3) working methods/basic principles of other

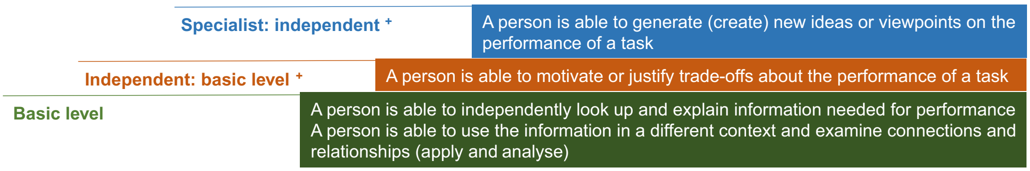

Figure 7.4 Three levels of the Dutch sector standard for UD professional competences.

disciplines, (4) embedding in organization and plans, (5) finance and personnel, (6) research methods and techniques, (7) processing, recording, and validating data, (8) assessing research results, (9) hydraulic calculations, (10) technical knowledge of design, (11) technical knowledge of measures for maintenance, renovation, and replacement of assets, and (12) outsourcing and contracting.

Three competence levels are distinguished (see Figure 7.4). A basic level was determined as the minimum knowledge that would be required to outsource the work and to assess and evaluate the results. This is because many Dutch municipalities – especially the smaller ones – rely heavily on outsourcing to contractors, consultants, or specialized companies. The activities that are most often outsourced include planning and project consultancy, cleaning and inspection, removal of blockages, and rehabilitation works (Oosterom & Hermans, 2013). Billing and troubleshooting services are often still offered by the municipality. A group of experts was asked to indicate the minimum level of knowledge required. In addition to this basic level, the degree of knowledge that must be available to execute the work or tasks independently was also identified, as well as the qualifications required to be considered an expert (see Figure 7.4).

7.3.1.6 Funding gaps

The financial resources at the disposal of organizations are a crucial factor in their ability to manage their staff and assets, which influences the balancing of investment decisions vs. risks of disruption. The use of financial resources for a particular purpose may be time-bound or legally bound to sectoral tasks.

In the Netherlands, there is a dedicated tax or charge for sewerage for which the municipality is responsible and can determine the tax or charge rate (Huisman, 2002). The sewerage charge is an example of a so-called earmarked charge with associated (legal) restrictions as to its use and degree of cost recovery. Weighing of social interests plays an important role in determining the tax or charge rate. Once the tax or charge has been set, asset managers have considerable latitude as to how to use these resources, with operational costs often considered less important than other urgent investments. With limited maintenance and repair budgets being made available for other types of municipal infrastructure as well, collaboration to bridge funding gaps is advisable. This is often achieved using multiple streams of funding; for instance, using road maintenance budgets funded by the municipal mill rate or property taxes and dedicated taxes or charges for water supply and sewer infrastructure (Alm *et al.*, 2021; Bassone-Quashie, 2021).

The Dutch water boards can also levy taxes or charges to fulfill their specific tasks of surface water quality and quantity management, which includes AM of the wastewater treatment plants and the transport of sewage from the urban settlements to the treatment facilities. This 'water treatment levy' is used to finance all the costs of transporting and treating wastewater. The operational costs of treatment are relatively high and therefore the short term (operational costs) and long term (capital expenditures) are treated differently.

Similarly, the availability of funding made available through climate change incentive schemes tends to require submissions for funding or subsidies to be submitted by a certain date. These time limits can act as a major influencing factor barring or enabling UD climate change adaptation projects in the Netherlands (Bassone-Quashie, 2021). Furthermore, as there is no specific levy for the management of urban green space in the Netherlands, it has to be paid from the general municipal tax base which means that the continuity of this funding is not guaranteed but rather subject to the whim of the municipal councils. As these are democratically elected bodies, with inevitable changes in composition and priorities over time, long-term planning of such spaces is highly uncertain.

7.3.1.7 Accountability gaps

An evaluation of the different approaches adopted by the major municipalities in the Netherlands in their approach to 'rainproof cities' illustrates how accountability gaps have become visible in the implementation of climate change adaptation of UD systems (Dai *et al.*, 2018). Under Dutch law, addressing pluvial flooding is a shared responsibility between residents and local government (i.e., the municipality in question). Many different policy instruments exist ranging from local regulations and approval/permitting systems to subsidies and facilitation of participatory projects. Despite common values in terms of equity, flexibility, sustainability, and long-term thinking, the three major municipalities of Amsterdam, Rotterdam, and Utrecht have adopted different approaches to climate proofing via UDAM. On the one hand, the cities of Amsterdam and Rotterdam present climate change and the associated adaptation policies as opportunities to brand their cities or to raise awareness. The city of Utrecht, on the other, is lagging behind without a clear direction that explains or legitimizes its climate change policies (Dai *et al.*, 2018).

In explaining the differences between these three municipalities, Dai *et al.* (2018) identified how clarity about public/private responsibility is important. Urban space in the Netherlands is often privately owned and residents are legally obliged to take care of rainwater on their own property. However, municipalities often act beyond their formal duty of care by collecting runoff from private plots along with runoff from public property to avoid flooding. Consequently, residents are often not aware of their private responsibility and may conveniently shift responsibility to public authorities (Krijnen, 2020). This illustrates how a municipality that is active in addressing pluvial flooding without accompanying public education as to the role of residents on how to protect themselves and their neighbors can result in passivity among its residents, which hampers effective climate change adaptation.

Altogether, the use of policy instruments plays an important role. Binding rules and obligations provide clarity to the division of roles and responsibilities, thus increasing legal certainty. They also make compliance and enforcement easier. Although the soft nature of non-binding policies can yield flexibility to municipalities, accountability mechanisms need to be in place to implement the necessary measures.

7.3.2 Process blunders hindering decision quality and decision implementation in organizations

7.3.2.1 Strategy blunders hindering decision-making success in organizations

Bassone-Quashie (2021) attempted to match decision-making process types and tactics as per Nutt (2008) to interviews conducted about decision-making in 12 sewer system AM and climate change adaptation projects. She found that projects were predominantly initiated by classical UDAM needs such as sewer rehabilitation and neighborhood redevelopments and not due to climate change adaptation needs. Rather, projects targeting standard UDAM works were used as an opportunity for climate change adaptation. According to the studies of Nutt (2008), opportunity-driven processes are on average less successful than discovery processes. In line with that, Bassone-Quashie (2021) observed that the projects involving climate change adaptation generally required bargaining tactics during the selection and evaluation phase (which often involved additional actors), whereas projects addressing rehabilitation projects would rely on analysis. Although half of the projects roughly aligned with decision-making tactics of a discovery process (i.e., the more desirable/successful strategies), there was a strong reliance on less effective tactics for solution development and evaluation in decision-making. This entailed, for example, deciding by edict and persuasion rather than intervention with sound reasoning or structured actor participation (Bassone-Quashie, 2021).

7.3.2.2 Failure to clarify the problem or opportunity to be tackled and its main stakeholders

The first principle that needs to be satisfied to enable decision quality is an appropriate framing that clarifies the problem or opportunity to be tackled and its main stakeholders. The organization of water management influences strongly the framing and to what extent the drinking water supply, UD, and sewerage treatment facilities are managed by one or several organizations. Different organizations all have their own organizational setup, roles, and responsibilities and administrative processes with respective stakeholders. When all UDAM facilities are controlled by one entity, the coordination and decision-making take place at the asset owner level. All interests will be taken into account simultaneously. This coordination does not usually take place when different organizations are responsible for water management. The structure of a decision-making process is different for each of the organization (e.g., drinking water – private, municipal and water board – public/government). The coordination then often takes place at the level of asset managers. Given the interdependence of other tasks in the organizations involved, this coordination becomes difficult, and trade-offs will often be made at the level of the service provider. The tendency is to put the interests of infrastructure (e.g., lifetime, disruption) at the center of the considerations because underlying societal interests are more difficult to weigh at this level.

The situation in Flanders (Belgium) is a good example, where different organizations are discussing coordination of operational efforts (Vlaamse Regering, 2020). For example, the Flemish government has made arrangements between the various managing organizations (i.e., Aquafin, Aquaflanders, de VVSG, VMM, and Vlario) to achieve optimal coordination of AM of the municipal and regional sewerage networks. A characteristic of these differences is the level at which coordination takes place, that is, at the level of the asset owner, the asset manager, or the service provider. The underlying problems and goals cannot be compared and are therefore not discussed.

7.3.2.3 Missing creative alternatives for actions by the people partaking in the decision

In evaluating business cases, the economic book and replacement values of existing assets often play a dominant role. Municipalities, water boards, and drinking water companies have invested enormous sums of money in their infrastructure over the decades to achieve the current service levels. There is thus a high sunk cost, wherein the existing technical infrastructure creates path dependencies that limit changes or new developments (Maurer, 2022). In an economic assessment, rehabilitating existing assets like-for-like is often more beneficial than implementing more innovative technology that requires adapting other parts of the UD system as well.

For example, in the region around the city of Eindhoven in the Netherlands, the Water Board of De Dommel operates one large wastewater treatment plant with a reasonably high treatment performance (i.e., mostly nutrient removal). Over the last century an extensive sewer network was created to connect surrounding municipalities to this treatment plant. The realization of a new smaller treatment plant for one of the furthest small municipalities could not be economically realized. Upgrading or optimization of the existing assets was considered cheaper and hence preferred (Waterschap de Dommel, 2021).

7.3.2.4 Relevant and reliable information and beliefs about the situation, problem, and solutions

The extent to which AM practice has matured within organizations can greatly influence the availability and reliability of information. As a result, the perception of a problem and its possible solutions differ. The data that are available or can be readily obtained tend to receive more initial attention and can prejudice the perception of the problems and required action away from the overarching or more important values and goals. This issue can be exacerbated when the search for information is mostly guided by the available information which may, in fact, be questionable in itself. A case in point is the frequent use of modeling in UDAM practice given the increasing availability of data and the many potential associated benefits (Eggimann *et al.*, 2017). Given the common use of modeling in water management in the Netherlands, one could conclude that all issues require modeling. However, the risk of creating insights based on models is whether or not the decision-making problem lends itself to being modeled and whether it can be sufficiently validated given the available data.

Poor availability and quality of data is often attributed to limited resources, personnel capacity, and knowledge within smaller organizations. Therefore, cooperation between municipalities is strongly encouraged in the Netherlands and formalized via the BAW-2011. Yet, in these cooperations between municipalities operational issues dominate the discussion, reflecting shared information bias and a need for mutual agreement and understanding in decision-making. This hinders the clarification of, discussions about, and balancing of values within and across organizations. A similar problem exists in decision-making between municipalities and water boards. For example, Water Board De Dommel is struggling with its own data management, as different systems are in use and data cannot be validated. As a result, there are difficulties with assessing the condition of pumping stations and pressure mains. The city of Eindhoven, which lies within the catchment area of the De Dommel Water Board has more advanced data management and more accurate condition data. Mutual coordination and decision-making are severely hampered by these differences. In contrast, Waternet (the water utility company serving the city of Amsterdam) has been evolving its AM for years, moving toward an integrated water management approach that considers operational, tactical, and strategic AM aspects.

7.3.2.5 Sound reasoning in identifying the best alternative given the values and information at hand

The concept of a business value and risk matrix is widely used in AM and decision-making in the Netherlands and beyond. An important question pertains to how values are defined. Figure 7.5 shows an example of a typical business value matrix. Three different kinds of potential consequences are presented: finance, safety, and reliability. There are several challenges. First, three values (and their respective goals) are rarely adequate to reflect the various aspirations that organizations take into

	Potential consequences			Likelihood				
	finance	safety	reliability	unlikely	remote	probable	annual	monthly
extreme				moderate	high	very high		
serious				low	moderate	high	very high	
considerable				neutral	low	moderate	high	very high
moderate				neutral	neutral	low	moderate	high
small				neutral	neutral	neutral	low	moderate
negligible				negligible	negligible	negligible	negligible	low

Figure 7.5 Exemplary business value matrix with relevant risks commonly used in Dutch AM.

account in their decision-making. Thus, while tractable, the matrix is often overly simplistic in nature and more appropriate to guide and justify intuition rather than being able to provide tangible decision support in weighing different trade-offs between goals and respective risks.

The inability to explicitly specify all relevant objectives is a known limitation frequently mentioned in decision-making research (Bond *et al.*, 2008). Once the values and goals have been defined, an important question arises as to how to quantify and weigh the different consequences as well as the different risk levels attached to these consequences. Financial consequences are largely quantitative and relatively easy to determine. Reliability is somewhat more difficult but in essence also quantitative. Near misses or unsafe situations are typically of a more qualitative nature. In UDAM these considerations are often handled in a compensatory manner in simplified models or tools, even when they are in fact incommensurate (e.g., a low likelihood of serious injury or death is not commensurate with a high likelihood of a small impact on financial or service outcomes.

In decision-making the consequences that can be quantified with a reasonable amount of effort – generally governed by data that have been routinely collected and processed following current business, operation, and management processes – are over-emphasized. At least, within the technical realm, there is a tendency to rate quantitative information as more objective or valuable than qualitative information. Something that can be measured and displayed as a simple number may receive more attention than a qualitative elaboration of a value. As a result, easily available or accessible quantitative information receives more attention. Depending on the background of the decision-makers, the number of technically educated managers may dominate, which will lead to an even stronger emphasis on the quantitative aspects. To overcome this challenge, attention is needed to define the relevant values that matter. Only then can the appropriate indicators to be used for assessments be selected and decisions be made as to how these will be appraised individually and in concert (Keeney & Gregory, 2005).

7.3.2.6 Commitment to action

The Netherlands is well-known for the 'polder model' way of decision-making (which is even called 'polderen' in Dutch). Problems and possible solutions are discussed by a large group of people with a wide range of stakeholder participation. It takes time to express all different positions and reasoning. The enthusiasm and vigor of individuals can strongly influence decision-making. The impact of selected individuals is not the only problem that may occur. Multiple sessions are typically needed to reach an understanding of the problem, consent on desirable interventions, and a decision for implementation. Decisions are easily revisited again for additional debate at the next session whenever the composition of the group changes. As the respective problem framing, values at stake and potential solutions continue to change, problems tend to drag on and support may even disappear before arriving at a final decision.

7.3.3 Biases in organizational decision-making

7.3.3.1 Protection of mindset

Climate change adaptation efforts may sometimes be at odds with established practice. Appropriate solutions may differ across jurisdictions, which take a lot of effort to identify, design, and implement. When standard solutions or routine measures do not fit, new solutions have to be devised. However, a new, non-standard solution generally is perceived to have a higher risk because it is not well-known, and it is hard to anticipate potential problems and create contingencies for dealing with them. Two examples from the Netherlands include:

- issues with the maintenance of vacuum sewers along with post-construction structural adaptations in houses to meet noise requirements for a novel blackwater collection and treatment system in the city of Amsterdam (Waternet, n.d.), and

- the costly construction of a sewer network in a residential area in the city of Almere-Oosterwold. There, the originally intended nonconventional solution with decentralized treatment, which was based on citizen buy-in, adoption/and action, did not meet the required effluent standards (van Karnenbeek *et al.*, 2021).

Those accountable for decision-making, such as technical asset managers in the case of UDAM, may shy away from novel solutions given the lack of experience and uncertainty about longer-term functioning and associated costs. Pressure on budgets is always present and the unconscious tendency is to avoid risk and keep costs as low as possible. This is unfortunate in that one may thus overlook solutions that may ultimately prove to be attractive and more cost-effective. Small-scale pilot projects where failure scenarios have been thought through and addressed and where post-mortems are executed provide opportunities to overcome the inherent inertia.

Available capacity is a major problem at many municipalities in the Netherlands. Not all proposed works are carried out and programmed investments are only partially realized. Benchmarking of sewerage works showed that, on average, only 60% of all plans had been realized (RIONED, 2005). Management faced with this challenge routinely chooses outsourcing and using external, third-party resources as a solution. The underlying belief is that staff capacity can never be the problem; after all, if there is 'enough' money, this is merely an administrative issue. Reality often tends to be different. Even when external, third-party resources are utilized, data are still needed, procedures must still be adhered to, and coordination with other activities in the public realm must still take place.

7.3.3.2 Personal norms and habits

In a technical environment, for example, UD management, there is a very strong reliance on accumulated experience. A proposed measure is only taken seriously as a solution if it has been successfully applied, in real-world practice within the jurisdiction in question, several times before (Bassone-Quashie, 2021).

In the case of climate change adaptation, this can be a major roadblock. Climate change adaptation requires new infrastructure solutions, or a solution must be sought in other realms, for instance by redesigning public space or adapting the water system. Yet, there may be no clear, standardized, legally 'waterproof' guidelines for designing, building, commissioning, and maintaining new solutions. As long as these guidelines are not in place, implementation of new solutions may require a level of initiative and self-reliance to accommodate unfamiliar practices – often including additional demands – which the staff in charge may not be able or willing to provide.

A second example is the transition to relining and the slow diffusion of its use as an alternative to (open trench) sewer rehabilitation. Standard processes for planning, scheduling, and rehabilitating sewers entailed the open-trench replacement or repair of sewers. Relining required adapting these. The uncertainty about the remaining life span and worries about household service connections were additional reasons not to change the traditional open-trench practice for a long period of time. Successful application elsewhere and the broad sharing of experiences changed this over time as the benefits became more widely apparent and the social norms around viable practices changed.

7.3.3.3 Yielding to social influence

Earlier, when climate change was not yet a major issue discussed in the public realm, government bodies were strongly motivated to relieve their citizens and to take full control of and responsibility for UD. Times have changed and the Dutch law and regulations clearly state that households are responsible for managing rainwater (Dai *et al.*, 2018). Only when households cannot reasonably be required to discharge the rainwater runoff onto or into the soil or into surface waters (e.g., in an old city center) must the government take action by draining stormwater from the boundary of the private property (Dutch Parliament, 2006).

In the mindset of many municipal politicians and the technicians to whom tasks are delegated, the customary social norm of the municipality taking full responsibility for storm water drainage is still valid. Limited organizational capacity in facilitating citizen action while ensuring coordination with public measures is another perceived bottleneck. As a result, approaches seeking to find solutions within public space under full legal, financial, and operational control of the municipality dominate and other solutions are often not even considered.

7.3.3.4 Faulty reasoning about uncertainty

Most of our present-day drainage infrastructure was designed decades ago, when dimensions were determined using relatively simple models and rules of thumb. One of the most basic principles used is that, given certain restrictions, systems can be designed independently. Under extreme conditions of pluvial flooding or prolonged drought, interference between UD and surface waters becomes apparent in terms of water quantity or quality impacts. This complexity of interference is often neglected by continuing to design systems independently. The occurrence of extreme rainfall events is simply taken into account by designing bigger pipes and centralized treatment and pumping capacity, rather than integrating alternative solutions to retain, store, evaporate, treat, and discharge or infiltrate drainage water locally. This may be required within the lifespan of the infrastructure with advancing climate change impacts, yet is given insufficient consideration given limited understanding and consideration of uncertainty and exponentially shifting patterns in drought or rainfall frequency and intensity.

7.3.3.5 Relying on automatic associations and relative thinking

A popular measure for government organizations to introduce or support new policies is to offer financial incentives. To speed up climate change adaptation the Dutch government and several water boards offer municipalities financial incentives through subsidies or co-financing if they realize projects in which climate change adaptation is considered. There are many different arrangements to get funding. Most municipalities are understaffed, and evaluations related to funding are deemed critical, receiving high corresponding levels of attention. Because time is limited, the question often no longer pertains to how much money is needed and where to invest it to achieve the highest return on investment with respect to climate change adaptation, but rather which project can most easily be used to get additional external funding. Getting additional funding is highly rated by many municipal officials and may also reflect positively on their career prospects within the organization.

Furthermore, when looking for solutions, a person's background subconsciously plays a major role in terms of which solutions come to mind and are hence explored. Operations staff who have risen through the ranks to gradually obtain management positions are likely to reason differently than staff having a, say, urban planning or business administration background. Someone who is predominantly familiar with underground infrastructure will likely consider, and trust, such solutions more readily than others who may be familiar with above-ground possibilities to reduce or eliminate nuisance from stormwater flooding.

7.3.4 Outlook

As outlined briefly in Section 7.2.5, there are tried and tested methods that can be used to improve decision-making and decision quality in UDAM. These combine multi-actor decision-making process support along with deliberative and analytic methods and tools to ensure all elements of decision quality are properly addressed. However, only a few such applications have been reported in UDAM.

The state of the art in UDAM thus centers around either 'analytical' measures or (re)enforcement of 'structural' measures. For example, swift change in governance and institutional arrangements including legal, regulatory, and fiscal policies were shown to be highly effective in achieving the development and implementation of proactive, systematic AM efforts in the Portuguese water sector (Alegre *et al.*, 2020). Also, several examples of stepwise processes for indicator identification and assessment by AM organizations (e.g., Cardoso *et al.*, 2012) or oriented toward the application of multi-criteria analysis methods exist (e.g., Carriço *et al.*, 2021; Joubert *et al.*, 2003; Sa-nguanduan & Nititvattananon, 2010; Scholten, 2013; Zheng *et al.*, 2016). They typically include the clarification of goals, of ways to assess these goals, and of ensuring data quality when assessing the current state of the infrastructure and planning into the future. There are, however, only very few documented studies on more processual approaches of how a multi-actor decision-making process can be designed and supported using deliberative methods that are, in practice, capable of addressing the contextual and multi-actor complexity. A few examples include Lienert *et al.* (2015); Alhamed (2020); Scholten (2017, 2018); and Scholten *et al.* (2015).

Of these, the study of Alhamed (2020) has seen continued uptake in practice. During her Professional Doctorate in engineering activities at the Delft University of Technology and Waternet in the city of Amsterdam, Alhamed (2020) bridged the gap between academia and strategic developments in UDAM practice at Waternet. Her research combined stakeholder analysis and multi-actor problem structuring with a tactical, risk-based multi-criteria analysis framework for rehabilitation planning of sewer assets. An important challenge in this study was to align this framework with operational sewer AM needs as well as broader strategic goals of the organization. During the process, 8 decision-makers and 54 subject matter experts were continuously involved. Several group workshops were organized, interlaced with bilateral or small-group discussions with subject matter experts, to ensure a common understanding, consensus, buy-in, and comprehensiveness of the approach. The deliberative methods, and especially problem-structuring using group cognitive mapping techniques, led to the exploration and mapping out of the problems as perceived by different actors and the critical interdependencies. It also helped to facilitate a common understanding and to agree on a common purpose and goals. The identified 5 main strategic goals of the organization were linked to 11 tactical goals for sewer AM, which were either further broken down into sub-goals or directly matched with indicators that could be used to assess performance using operational data. Also, as detailed risk assessments were deemed unviable, a simpler (i.e., 'satisficing') approach was adopted, see Alhamed (2020) for details. Many of the participants praised the inclusivity, adaptability, and usefulness of the approach. By taking part in the process, social learning and alignment at various levels had taken place. After the project was complete, the resulting assessment framework was prepared for operational roll-out to assess all 120 drainage areas in Amsterdam, thereby contributing to improved decision-making in sewer AM.

Building on the above, we believe that both the need and the potential of strengthened efforts in transdisciplinary work across practice and academia is necessary to understand and improve decision-making in UDAM practice.

7.4 CONCLUSIONS AND RECOMMENDATIONS

UDAM is characterized by multi-actor decision-making processes that take place within a complex system setting. The main characteristics are identifiable. To manage the complex system, tasks and responsibilities are divided across different governmental agencies, organizations, or parts of an organization. A number of institutional barriers that result from such fragmentation have been identified both from theoretical literature and empirical examples. Structural solutions such as a different division of tasks and responsibilities may be effective yet will not resolve the fundamental challenge of bridging across fragmented responsibilities and multi-actor decision-making in complex contexts. It is easy to resolve one problem within a complex system with a band-aid while creating others elsewhere in the same or in an adjacent system.

An important explanation is related to the fact that no matter which way the governance and management of water systems are structured, each will imply some form of fragmentation that will serve achievement of some goals better than others. That is because functional fragmentation generally goes along with fragmentation of responsibilities, subject matter expertise, perceptions of the relevant system boundaries and related interests, goals, resources, and legitimate action options. The tendency of managers to avoid complexity can be attributed to the integral picture becoming too complex as system boundaries are broadened beyond the limits of their immediate control and responsibility. Limiting the scope eliminates problems and the need to consider needs and interactions with others. When problem analysis is missing or limited (as it is a 'given' contingent on the perception of the respective actor given their specific context), not all options are considered or not all relevant parties are considered in a decision-making process. Another important consequence of the fragmentation is that UDAM decisions are made such that they make sense and are defensible and doable within a specific political, organizational, and social context. The issue is that the result of these decisions across the organizations or organization units involved in UDAM does not, by definition, translate into a satisfactory solution for the whole. Many barriers resulting from institutional fragmentation can be reduced or even removed within the current division of roles by adapting formal decision-making processes and institutionalized norms, multi-actor arrangements, and the judgment and decision-making tactics used.

In theory, decision-making processes in UDAM can be described by distinct phases to go through to achieve high-quality – if not optimal – decisions that have higher odds of resolving difficult problems. In practice, however, the process plays out differently, where phases are either skipped or cut short, often leading to a less satisfying result. The effects of governance and social structure, political and social dynamics as influenced by social and individual cognition have an important effect on decision-making. Within organizations, there is often an unwritten consensus on how decisions are made, because that is the way things have been done for a long period of time and which reaped satisfactory results earlier. This approach may be suitable for routine tasks and recurring management activities that can be controlled entirely by the organization (unit) without a need for interaction with others. Non-routine problems and decision-making, such as coordination of works for stormwater management and climate change adaptation, however, require a decision-making process that follows its own dynamic and can accommodate the perceptions and needs of several actors to ensure their support and commitment to action. Pushing the system boundaries creates a different picture of the processes driving observed system behavior and issues as well as the players, interests, and possible interventions. In a dynamic natural and institutional environment along with changing social priorities, UDAM is challenged to change as well.

Throughout the process, cognition and judgment underlying decision-making are strongly framed by context and in many cases informed by emotions and gut feeling. Objective reasoning and arguments are often absent or may be constructed in hindsight to align with intuition. A deliberate processing of information in decision-making to align choices and actions toward the achievement of the set objectives is necessary if UDAM strives for a more objective substantiation of decisions. This requires support by data of appropriate quality, and which should be informative to assess progress on the objectives to be achieved through UDAM decisions. Although modeling can provide significant benefits, not all decision-making requires nor lends itself to being modeled in light of the questions at stake and the data situation. Expert knowledge can be systematically elicited to fill the gaps. These can be bolstered by employing decision-making strategies shown to deliver higher quality decisions.

In UDAM, we have long been able to seek more 'optimal' solutions that have direct added value for all parties involved in the decision-making. With climate change adaptation, aging infrastructure, more intensive use of available space, and conflicts around limited resources, negative outcomes can no longer be avoided; instead, trade-offs must be faced and negotiated. Continuing to look for a painless, regret-free solution is delaying decision-making processes and action needed to adapt UD systems. This is short-sighted as it may unduly shift and exaggerate problems into the future or onto other interlinking systems and actors until they can no longer be avoided. Problems that get out of hand typically require more intense intervention that is unlikely to achieve better outcomes than timely, proportionate and adaptive intervention following quality decision-making could achieve.

There are already many examples of possible adaptations in UDAM that reach beyond attempts to merely optimize interventions following the current technical and managerial paradigms. For instance, municipal councils can adapt the norms for climate change adaptation for new developments and redevelopments, which forces adoption of new solutions on both public and private land, while reducing pressure on the system and facilitating the accumulation of experience and precedents for transition within existing infrastructure. In addition, improving interaction with local communities and involving them in earlier stages of the decision-making process, such as the design and development phase, can help commitments to action and reduce the stalling of processes. Other examples include policies to spend a percentage of the UD fees on climate change adaptation measures, providing training and cross-organizational exchanges to facilitate learning and adopt new practices. Behavioral analysis of context and the actors can be employed to better anticipate upon biases and barriers arising from the interplay of formal and social structures with individual and group cognition to adapt policies, technical solutions, and the communication about them in a way to shift social and personal norms and facilitate implementation.

To enhance the understanding of decision quality, it is important to gather practical cases from the sector, analyze them systematically, and discuss them from both a practical and scientific perspective. This will serve as a valuable foundation for developing more effective strategies and processes tailored to specific problems through targeted interventions. This will also promote mutual recognition and comprehension of decision-making challenges, identify areas for improvement, highlight the need for training, and explore methodologies to facilitate multi-actor decision-making processes. There is already a wealth of knowledge, methods, and empirical evidence available from other fields of decision-making research and practice. When combined with a thoughtful consideration of the specific issue at hand, these can greatly enhance decision-making quality in UDAM practice. A systematic study will further provide insights on how to integrate, adapt, and enhance approaches for diverse decision-making situations in UDAM.

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