Breaking Hierarchical Barriers to Improve Collective Intelligence

Exploring Artificial Swarming Intelligence within the Dutch National Police

JIP Team 6.1.1

TU Delft

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Preface

This report explores how Artificial Swarming Intelligence can enhance collaborative processes within large organisations, specifically focusing on the Dutch National Police. By developing a solution, we aim to enhance the collective intelligence, improve the efficiency of information sharing, and facilitate the decision-making processes.

The project would not have been possible without the invaluable support of the Dutch National Police and the guidance of Amir Niknam, whose encouragement and expertise provided great insights throughout every stage of the project. We extend our gratitude to the JIP-team for giving us the opportunity to contribute to this field alongside such dedicated professionals.

Our interdisciplinary team, composed of six members with diverse backgrounds and expertise, played a vital role in addressing the various challenges we encountered. This collaborative approach not only enriched our perspectives but also resulted in a more well-rounded and effective solution. We believe that this diversity of skills and viewpoints significantly strengthened our project and contributed to the positive outcomes we achieved.

This report is intended for the educators and academic leaders of TU Delft & JIP, the Dutch National Police, and anyone interested in advancing collective decision-making processes within complex organisations. We hope that our findings and the solution's potential will spark further exploration in this promising area of study.

Summary

Today, huge volumes of information flow at unprecedented speeds, and large organisations like the Dutch National Police face significant challenges. Efficiently sharing, processing, and prioritizing information is essential but has become increasingly difficult to achieve. These challenges often hinder their ability to make sound and timely decisions. This study investigates innovative methods to enhance collaborative decision-making within such complex environments.

The main goal of this study is to research and test the potential of Artificial Swarming Intelligence to enable collective ranking of information based on its importance. The resulting Proof of Concept offers a new method for improving the efficiency of information sharing, enhancing collective intelligence, and facilitating the decision-making processes within the police force.

Drawing inspiration from natural swarming behaviour seen in species like bees, the platform allows participants to rank multiple pieces of information during collaborative sessions. This process helps to highlight the most significant topics, enabling quicker access to critical insights.

The Proof of Concept is structured as a digital platform designed to improve real-time decision-making. For our case study, we focused on the policy advisors of the Dutch National Police. The Proof of Concept operates as a client-server model, ensuring that user interactions are efficient while providing live updates on rankings. This allows participants to engage actively and see the evolving importance of various pieces of information.

However, despite the progress achieved, several limitations became evident. First, some envisioned functionalities were not fully developed or implemented within the project's time frame. In addition, current design faces challenges in scalability, particularly when engaging larger groups of users. Issues related to user accessibility and potential biases in decision-making processes also came into view. To guide further work, we have highlighted key areas for future research and provided specific considerations that address these limitations, aiming to support the Proof of Concept's development into a complete and fully scalable platform.

Ultimately, this Proof of Concept presents a promising approach to enhancing decision-making processes at the Dutch National Police. It lays the foundation for future research and development, with opportunities to refine its functionality and expand its use within the organisation. By improving how information is shared and prioritised, the Dutch National Police can enhance its collective intelligence and improve its decision-making processes.

Nomenclature

Abbreviations

Abbreviation	Definition
AI	Artificial Intelligence
ASI	Artificial Swarming Intelligence
CSI	Conversational Swarm Intelligence
DNP	Dutch National Police
FAQ	Frequently Asked Questions
FFA	Free-for-all
LIF	Leaky Integrate and Fire
MFA	Multi-Factor Authentication
MVP	Minimum Viable Product
PoI	Piece of Information
PoC	Proof of Concept
PPP	People, Planet, Profit
RQ	Research Question
SDG	Sustainable Development Goals
SMART	Specific, Measurable, Achievable, Relevant, Time-bound
UI	User Interface

Terminology

Term	Definition
Abductive Approach	The foundational form where a researcher starts with a surprising observation and seeks the simplest and most plausible explanation based on current theory or understanding.
Emergence	The process in which a group collectively finds a solution to a problem, without centralized control, that surpasses the solution(s) the individuals might have found independently.
Swarming	A process in which participants work together in real-time, connected through feedback loops that allow them to collectively converge on solutions in synchrony
Tacit Knowledge	Knowledge that people hold but cannot easily articulate or transfer to others. It includes personal experiences, skills, perceptions, intuitions, mental models, beliefs, and feelings.

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1 Introduction

The Dutch National Police (DNP) is the unified police force of the Netherlands. With approximately 65,000 employees (Politie, 2023), the force is dedicated to maintaining public safety, enforcing the law, and protecting democracy. In recent years, both the volume of information and the number of employees within the DNP have grown exponentially (Politie, 2023). The DNP's hierarchical structure, with teams nested within groups and clusters, is not designed to efficiently exchange information across its many employees (Police, n.d.). This results in significant communication overhead, where coordinating with other teams often takes longer than the task itself.

Furthermore, one's influence is directly linked to their position in the hierarchy. This structure presents ”gatekeepers” (i.e., individuals who decide which information is passed up the chain), potentially introducing bias in the process. The large number of people involved generates noise, such as social hysteria (Clapson, 2022), irrelevant information, or even fake news. Hence, potentially valuable information could either be blocked by bias or lost in the noise, causing employee dissatisfaction (Vieira, 2017), and making communication inefficient and time-consuming.

Artificial Swarming Intelligence (ASI) is explored as a potential solution to these problems. Swarming behaviour can be observed in nature, where large groups of organisms, such as birds, fish, and ants, collaboratively solve problems beyond the capabilities of individual members (Rosenberg & Willcox, 2020). Unlike other social species, humans have not developed a natural capacity for swarm intelligence. While animals depend on highly evolved sensory feedback mechanisms, humans lack these instinctual connections (Rosenberg & Baltaxe, 2016). Therefore, ASI focuses on replicating natural swarm behaviours through technology, enabling humans to collectively solve problems beyond individual capabilities.

In this exploratory study, quantitative and qualitative methods are used in an abductive approach. The objective is to design, build, and test an ASI-based Proof of Concept (PoC) that allows individuals to collectively prioritize Pieces of Information (PoIs) in a less biased and more decentralised manner. Although the scope excludes the integration of the PoC into the DNP infrastructure, implementation suggestions are provided. To guide this study, the following research question is formulated:

How can Artificial Swarming Intelligence be used within the Dutch National Police to enable collective intelligence in its decision-making processes?

In order to answer the research question, sub-questions are formulated, which are as follows:

- **RQ1:** How can existing swarming algorithms be adapted to foster emergent behaviour within a (decentralised) decision-making system?
- **RQ2:** How can users be engaged and empowered to contribute to information sharing through the solution?
- **RQ3:** What methods can facilitate the integration and ongoing optimization of the Artificial Swarming Intelligence based system within the existing internal environment and daily workflows?

This study makes the following contributions toward advancing the application of ASI within the DNP:

1. **Thorough ASI Research:** Comprehensive study on the potential of ASI to enable collective intelligence, applying natural swarm behaviours to human organisational challenges.
2. **Proof of Concept Development:** A functional ASI-based PoC enabling users to collectively prioritise information with reduced bias and decentralised decision-making.
3. **Mockup Prototype for Enhanced UI:** A design showcasing an envisioned user interface and features, representing the idealised version of the system.
4. **Future Research Directions:** Identification of research avenues to improve the initial PoC.
5. **Integration and Technical Recommendations:** Strategies and technical suggestions for integrating the PoC within DNP's processes and infrastructure.

The report is set out as follows. In the next chapter, essential background concepts are provided. Chapter 3 introduces the context of the problem, outlining the objectives and development plan. In Chapter 4, the process for selecting the optimal solution is detailed, leading to Chapter 5, which discusses the design decisions and practices that guided the creation of the final product, described in technical detail in Chapter 6. Chapter 7 highlights an improved UI mockup, with the risks and ethical considerations discussed in the following chapter. The limitations, future research, and integration are elaborated in Chapter 9, followed by a summary of key insights in the final chapter.

2
Background

To explore ASI as a potential technology for decision-making, several topics of background information need to be explained. Section 2.1 starts with describing the challenges introduced by hierarchical structures. Next, Section 2.2 examines natural and artificial swarming behaviours to understand how decentralised coordination can drive collective intelligence. Finally, in Section 2.3, the concept of emergence is explored to consider the potential of unpredictability.

2.1. Hierarchy-induced challenges

Hierarchical structures are widely used in organisations as they establish clear lines of authority and control (Mihm et al., 2010). This organisational model helps maintain order and accountability (Mihm et al., 2010). Figure 2.1 illustrates the police's structured layers, showcasing a top-down chain of command. While hierarchical models provide a framework for decision-making and oversight, they can also lead to inefficiencies. The following sections discuss these challenges.

2.1.1. Information flow

In large organisations, the flow of information is often constrained by the organisational structure itself. Information flow refers to the movement of data, insight, and knowledge through different levels of an organisation (Kovacks, 1991). While hierarchies provide a clear line of command and accountability, they can restrict the free flow of information (Mihm et al., 2010).

One of the challenges in hierarchical organisations is the vertical flow of information (Mihm et al., 2010). While information is generated at all levels of the hierarchy, frontline personnel, such as patrolling officers and operational teams within the DNP, often interact directly with problems on the streets. However, decisions are typically made at higher levels, creating a dependency on information traveling upward through multiple layers of management (Reitzig & Maciejovsky, 2015). Each layer acts as a filter, processing and modifying the information based on its

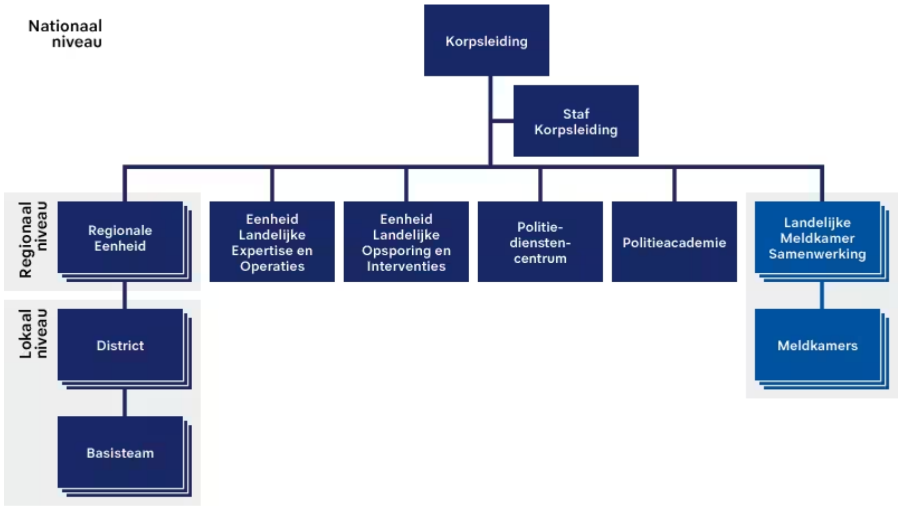

Figure 2.1: Overview of the organisational structure of the DNP (Police, n.d.)

understanding, biases, and priorities (Reitzig & Maciejovsky, 2015). As information moves up the hierarchy, it may become distorted or selectively passed along, losing crucial details or context in the process (Mihm et al., 2010). Additionally, this vertical flow introduces time delays, as information needs to be reviewed and approved by each layer before moving further up.

This vertical flow introduces 'gatekeepers' - individuals in the hierarchy who control what information is passed up to higher levels (Bang & Frith, 2017). Gatekeepers might filter or modify information based on their own perspectives, preferences, or biases (Bouhnik & Giat, 2015). Research shows that such filtering can prevent important information from reaching the top, leading to decisions based on incomplete or inaccurate data (Vinkenburg, 2017).

Another problem that arises from the hierarchical flow of information is the loss of context due to fragmentation (Mihm et al., 2010). As in many organisations, the DNP operates across multiple levels — national, regional, and local — and each consisting of distinct units and departments. As seen in the organisational structure in Figure 2.1, communication flows vertically from the regional units and local base teams to the top management (Korpsleiding) at the national level. Information generated at the operational level is often rich in detail by the specific circumstances in which it was collected. However, as it moves up the hierarchy, these details are often oversimplified to make it more digestible for higher levels of management (Bouhnik & Giat, 2015). What reaches the top is often a summary or an aggregate of various pieces of information. This lacks the richness that could provide a more accurate understanding of the situation.

2.1.2. Bias

Biases, both conscious and unconscious, play a role in information flow within organisations. Individuals tend to rely on past experiences and personal preferences when processing information, often at the expense of integrating new, more relevant data (Bang & Frith, 2017). This can lead to the reinforcement of pre-existing beliefs and further entrenchment of biases.

Given that decision-making within the police in theory should be based on well-researched topics that influence both police action and society in general, decisions made under the influence of bias should be minimised as much as possible.

Biases can occur in both individual settings and in groups. Some biases that can influence personal decision-making are as follows:

- **Confirmation bias**
  Under the influence of confirmation bias, individuals tend to favour information that confirms their preexisting beliefs (Koslowski & Maqueda, 1993). For instance, if one believes that a certain solution is the best, they might only seek out supporting evidence and ignore contradictory information. This can lead to a skewed perception of reality and poor decision-making.
- **Anchoring bias**
  The anchoring bias entails the disproportionate influence on decision-makers to make judgments that are biased towards an initially presented value (Furnham & Boo, 2011). For example, if an initial report suggests a certain policy is best for a given scenario, subsequent decisions might be unduly influenced by this characterisation, even if later evidence suggests otherwise.
- **Status quo bias**
  The status quo bias leads individuals to prefer things to stay the same rather than change (Zeckhauser & Samuelson, 1988). This can result in resistance to new ideas or innovations, even when change might be beneficial, which can slow down progress.

Although the previously mentioned biases can occur both individually and in a group context, the following biases are primarily found in group settings

- **Group polarisation**
  Group polarisation is a phenomenon in which group discussions can lead to polarised attitudes about a certain topic, which can be more extreme than the positions of the individual group members (Hou et al., 2022). For example, a group of advisors who are initially moderately positive about a risky investment as part of their proposal may become much more enthusiastic and risk-taking after discussion, which is not always beneficial.
- **The framing effect**
  The framing effect highlights how the wording of an object or event description, also called its framing, systematically influences evaluations of the object (Barking et al., 2022). For example, people might react differently to a choice described as having a "90% success rate" versus a "10% failure rate," even though both descriptions are statistically identical (Barking et al., 2022).

- **Groupthink**
  Groupthink bias is a phenomenon where members of a group are more concerned with being liked, adhering to group norms, not challenging potentially ill-conceived ideas, and making decisions that all group members agree with (Forbes, 2024). This can result in decisions that are sub-optimal.

- **Authority bias**
  Authority bias leads individuals to unquestionably accept and follow opinions and instructions of people in positions of authority (Howard & Howard, 2019). This can lead to situations where potentially better ideas are overlooked, and decisions are made based on authority rather than merit.

2.1.3. Information overload and decision paralysis

People at the top of the hierarchy are often confronted with a volume of information. As data flows through multiple layers, it accumulates, presenting the top with the challenge of processing vast quantities of information in a limited amount of time (Filippov & Iastrebova, 2010). This is called information overload. It occurs when the amount of data exceeds the people's capacity to process it effectively (Filippov & Iastrebova, 2010). In organisations like the DNP, the complexity and volume of data are amplified by the diverse sources of information that must be considered. One of the consequences of information overload is decision paralysis. Decision paralysis is a state in which people are unable to take timely action because they are overwhelmed by the complexity and volume of information (Dyer et al., 2009). It is not just about delays; it also comprises the quality of the decisions made.

A factor in information overload is the lack of consistent validation of the data being used. As discussed before, data is passed through multiple layers of management. By the time the information reaches the top, it may be unreliable, incomplete, or skewed toward particular viewpoints (Gray et al., 2023). This lack of validation can worsen the effects of information overload, as decision-makers may become paralyzed by the uncertainty of the data they are working with (Dyer et al., 2009). When information is unreliable or conflicting, it becomes even more challenging to identify the best course of action.

On top of this, in large organisations, the top often requires input from multiple sources (i.e. different departments, teams, and stakeholders) (Mihm et al., 2010). While this diversity of input can enrich the decision-makers, it also introduces complexity. The challenge of integrating these inputs can slow down the decision-making process, as leaders struggle to reconcile conflicting perspectives or weigh the relative importance of different pieces of information. In some cases, this can lead to factionalism, where different groups within the organisation advocate for competing solutions (Dyer et al., 2009). This fragmentation of input can further contribute to decision paralysis, as decision-makers become overwhelmed by the task of balancing competing demands.

2.1.4. Decision-Making Processes

Decision-making in hierarchical organisations such as the DNP is a multi-faceted process that is influenced by various structural and cognitive factors. In such systems, decision-making often follows a top-down model, where higher-ranking officials hold the authority to make key decisions based on information received from lower levels of the hierarchy (Reitzig & Maciejovsky, 2015). However, this centralised approach, while providing control and accountability, can slow down the decision-making process, particularly in complex, rapidly changing situations where timely responses are critical (Mihm et al., 2010).

One challenge of decision-making in hierarchical organisations is the balance between centralised control and decentralised input. In many cases, front-line officers, who are directly involved with operational issues, have valuable insights but may have limited decision-making authority (Reitzig & Maciejovsky, 2015). This disconnect can result in decisions that are informed by incomplete or outdated information, as the higher-ups may not be fully aware of the ground realities due to delays or distortions in information flow, as discussed in Section 2.1.1. For example, a strategic decision about resource allocation could be made without taking into account the on-the-ground operational needs that front-line officers are more familiar with. This can lead to suboptimal decisions, affecting both efficiency and outcomes (Vieira, 2017).

Furthermore, decision-making in such structures is subject to a range of biases, as highlighted in Section 2.1.2. One specific bias prevalent in hierarchical organisations is authority bias, where individuals tend to place more weight on the opinions or directives of higher-ranking officials, even when they might not be fully informed about the situation at hand (Howard & Howard, 2019). This deference to authority can stifle critical thinking and prevent innovative solutions from being considered, particularly when lower-ranking officers feel hesitant to challenge their superiors (Howard & Howard, 2019). This issue is further compounded by the pressure to conform to the group, as discussed in the context of groupthink bias in Section 2.1.2, which can lead to subpar decisions being accepted by the group without careful examination.

Moreover, the pace of decision-making can be impacted by the amount of information leaders have to process. As noted in Section 2.1.3, information overload is a significant challenge in hierarchical structures. Decision-makers at the top are often overwhelmed by the volume of data they receive from various levels of the organisation, leading to slower decision-making and, at times, decision paralysis (Mihm et al., 2010). This is particularly concerning in law enforcement agencies like the DNP, where swift action is often necessary to address critical issues like public safety. Research suggests that implementing decision-support tools and improving the filtering of relevant information can mitigate these effects (Vinkenburg, 2017), but the inherent complexity of the organisation continues to pose challenges.

2.2. Swarming

2.2.1. Natural Systems

Over the past decades, biologists and natural scientists have been studying the behaviours of insects and animals. Swarming behaviours, such as sweeping movements of birds across the sky, synchronised fleeing of fish in schools, or organised foraging of ants, illustrate the power of group coordination in nature (Bonabeau et al., 1999). These phenomena, called biological swarming, enable groups of organisms to collaboratively solve problems beyond the capabilities of individual members (Rosenberg & Willcox, 2020). More examples of swarm intelligence in natural systems include colonies of termites, herds of animals, rookeries of penguins, plagues of locusts, hawks hunting, and bacterial growth (Liu & Passino, 2000). The flocking and schooling are examples of highly coordinated group behaviours, where no leader is in charge and each individual bases its movements decision just on locally available information.

Biological swarming is essentially a form of distributed problem solving (Bonabeau, 2009; Bonabeau et al., 1999; Rosenberg & Willcox, 2020). For example, a single ant may be limited in its capacity to find food, but collectively, an ant colony can efficiently locate and harvest resources in a large area. Similarly, a flock of birds can navigate vast migratory routes or avoid predators by rapidly sharing information through subtle cues in their movements. These natural examples of collective intelligence have provided significant insight for researchers in fields ranging from biology to systems theory (Rosenberg & Willcox, 2020).

By observing and studying these behaviours, scientists recognised that biological swarming offers a model for solving complex problems through simple, decentralised interactions (Bang & Frith, 2017; Bonabeau, 2009; Bonabeau et al., 1999; Rosenberg & Willcox, 2020). The group operates as a system where each individual follows local rules, such as alignment with neighbours or avoiding obstacles, and yet a coherent, intelligent group-level behaviour emerges.

2.2.2. Humans and Swarming

Unlike other social species, humans have not evolved natural swarm intelligence due to the lack of instinctual feedback mechanisms. In animals such as fish, birds, and bees, sensory feedback allows near-instantaneous synchronisation in response to environmental changes (Rosenberg & Baltaxe, 2016).

However, humans are limited by *tacit knowledge*, which includes personal experiences, skills, perceptions, intuitions, mental models, beliefs, and feelings (Brockmann & Anthony, 2002). This is knowledge that people hold but cannot easily articulate or transfer to others, hindering swarm intelligence in humans.

Technology has unlocked new ways to apply swarm intelligence to human problem-solving. As Krause et al. (2011) point out, digital platforms now enable real-time social interactions between large, distributed groups, facilitating decision making in ways that resemble the behaviours observed in animal swarms.

2.2.3. Artificial Swarming Intelligence

Inspired by these natural phenomena, computer scientists in the late 1980s began exploring how the principles of biological swarming could be applied to Artificial Intelligence (AI) (Bonabeau et al., 1999). The field of swarm intelligence emerged with the aim of harnessing the collective problem-solving capabilities of groups for artificial systems (Roy et al., 2014). It studies how individual agents can collectively achieve goals by following simple rules and local interactions.

One of the most notable applications of swarming behaviour in AI has been the development of algorithms that mimic natural swarms. Examples include Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), and Artifical Fish Swarm (AFS), which replicate the collective dynamics of behaviour observed in nature (Tang et al., 2021). An overview of the most used AI swarming algorithms can be found in Table A.1 in Appendix A.

2.3. Emergence

Emergence is a fundamental concept in complex systems. Multiple definitions exist depending on the context and field. Kordon and Kordon (2010) describe emergence as an effect where individual agents of a group follow simple rules by acting on local information. These actions lead to a collective behaviour the single agents can not perform, without any centralised control.

One of the places emergence can be found in nature is, for example, in ants. A single ant has limited memory and is only capable of performing simple actions. However, when in a group, ants are capable of finding solutions to complex problems such as finding the shortest routes from their nest to a food source (Kordon & Kordon, 2010).

De Haan (2006) aims to find a general definition of emergence applicable to multiple fields. They denote that emergence is the property or phenomenon that somehow transcends the level of the objects that produce it.

Keeping these definitions in mind, we define emergence as:

The process in which a group collectively finds a solution to a problem, without centralized control, that surpasses the solution(s) the individuals might have found independently.

3

Research Context and Plan

Following the examination of the literature, it became evident that large hierarchical organisations, such as the DNP, face several challenges. This chapter provides the context and strategic plan guiding this research. It begins by establishing the problem statement and detailing the reasons behind the focus on policy advisors as a target group. Followed by an exploration of the business environment and identification of key stakeholders. The chapter also addresses societal impacts and ethical considerations. Finally, the project's value proposition, SMART objectives, and structured project plan are introduced, which set the stage for the report and development efforts that follow.

3.1. Research Foundation

3.1.1. Problem statement

To this end, the following problem statement was formulated, grounded in theoretical insights outlined in the previous chapter, and based on consultation with the DNP.

The Dutch National Police faces challenges in ensuring efficient information sharing, as pieces of information must pass through multiple biased hierarchical levels. People may selectively pass or block data based on personal preferences, leading to difficulties in validation, innovation, and decision-making.

3.1.2. Case Study

To address the complexities of the DNP, this study adopted a top-down perspective of the organisational hierarchy. While hierarchical structures create widespread issues across all levels, we chose to concentrate on policy advisors for a few reasons.

Policy advisors play a crucial role in synthesising information, shaping strategic decisions, and providing recommendations to top-level decision-makers (Baehler, 2008). Hence, they are a key group for implementing solutions designed to improve the flow of validated information and the mitigation of bias. Moreover, selecting a single layer allowed us to test our methods effectively. Compared to the approximately 30,000 street officers, there are only 500 policy advisors (Politie, 2023). This makes them a manageable and practical target group for initial testing. Additionally, given our proximity within the same building, policy advisors were the most accessible group for this study.

3.2. Project Context

3.2.1. Business context

The business context of an organisation includes its internal and external environments, both affecting performance (vom Brocke et al., 2016). The external environment of the DNP, beyond the organisation's control, involves national laws and changes in the market, society, and technology. The internal environment, which can be managed, includes the organisational structure, decision-making processes, management systems, and human resources.

Due to the aforementioned challenges in innovation and policy decision-making caused by hierarchical structures and rapid growth, there is a high demand for a tool that connects internal capabilities with the changing external environment.

3.2.2. Stakeholder analysis

Stakeholders are important in the process of creating and implementing innovations. The identified key stakeholders with a significant influence in shaping the decision-making process were categorised using a power-interest grid (Eden & Ackermann, 2013) and also divided into direct and indirect stakeholders. See Figure 3.1 for a visualisation of the power-interest grid showcasing the DNP's stakeholders for this project. The stakeholders are: Policy Advisors, Decision-Makers, the Innovation Department, the IT department, the Dutch government, and Dutch citizens.

Direct Stakeholders

Policy advisors were the central focus of this project as they are the key players in integrating information and providing recommendations to top decision-makers in the DNP. They value access to accurate, validated data, and their influence over policy decisions makes them highly relevant stakeholders. Their power is considered high as they play a role in shaping decisions. Their interest is also high, as the ASI system aims to improve their decision-making processes.

Decision-makers are critical to the approval and scaling of innovations. Their power is high because they hold ultimate authority whether this project is adopted and integrated into the organisation. While they might not be involved in daily project execution, their interest is high, as they will benefit from decision-making processes being more efficient.

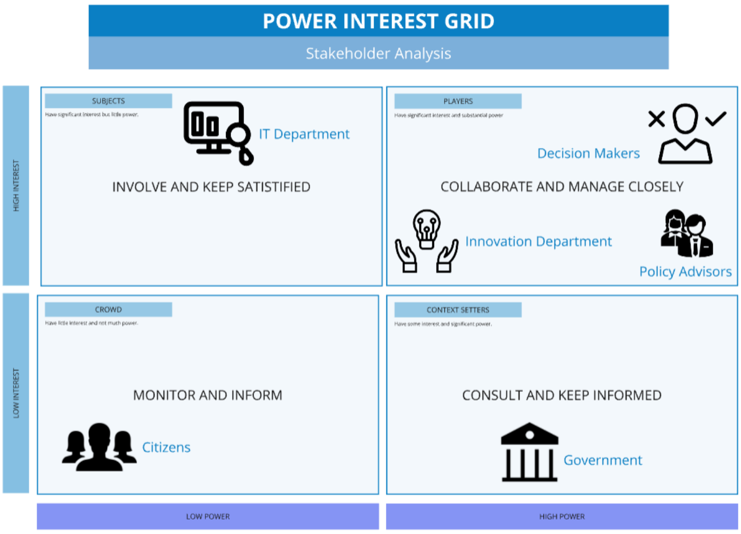

Figure 3.1: Power-interest grid

The Innovation Department plays an important role in advancing new technologies and processes within the organisation. They value creativity, improvement, and the potential for a tool to improve the overall decision-making process. As the department is responsible for overseeing technological projects like this, they have a high interest in the project. While they don't hold final decision-making power, their influence on the project's direction gives them medium power.

Indirect Stakeholders

The IT Department is responsible for integrating and developing an eventual tool into the existing infrastructure of the DNP. They value security, feasibility, and effective resource management. Although their power is moderate as they did not directly influence the project's direction, their technical expertise is crucial to its successful deployment, making their involvement essential in the later stages of the project.

The Dutch Government serves as the primary financier of the DNP and sets the broader legislative framework under which the force operates. They value effective governance, cost-efficiency, and the protection of citizen welfare. They are not directly involved with DNP decision-making, but as they provide funding they have some power. Their interest was low in the early stages of the project but could increase as the project matures.

Citizens stand to benefit from the improvements that the tool could bring to the DNP's decision-making processes. They value transparency, security, and effective policing. As indirect beneficiaries, their power in this project is low, and their interest remains low during the development phase. However, they will ultimately be impacted by the project as the improved decision-making processes translate into better public safety and more efficient policing.

3.3. Societal Impact and Ethics

In addition to addressing organisational and business context, this project also considered broader societal impact and ethical principles. Particularly, concerning the People-Planet-Profit (PPP), Sustainable Development Goals (SDGs), and ethical principles.

3.3.1. People, Planet, Profit

The project was centered around the ”People” dimension of the PPP framework. This dimension highlights a human-centered, inclusive development. The goal of this project was to empower individuals within the organisation and allow them to participate in decision-making processes regardless of their rank or position.

While the primary focus of the project was on people, it could also indirectly impact the ‘Profit’ dimension. Enhanced decision-making processes could lead to more efficient and effective outcomes, which ultimately can improve the organisation’s performance and public services. Although the ‘Planet’ dimension was not a central focus, the SDGs discussed in Section 3.3.2 could contribute to long-term sustainability by promoting fair practices.”

3.3.2. Sustainable Development Goals

In 2015, the United Nations (UN) adopted 17 Sustainable Development Goals (SDGs). These goals aim to set attainable targets that can be achieved as a 2030 agenda for sustainable development (Cf, 2015). The sections below discuss how this study considered three SDGs during this project.

- **SDG 8 - Decent Work and Economic Growth:** This SDG focuses on promoting sustained, inclusive, and sustainable growth, as well as full and productive employment (Nations, n.d.-b). One of the goals was to ensure internal processes could become more efficient. By offering a solution to address inefficiencies in decision-making processes, policy advisors could contribute more effectively to decisions being made. Indirectly, this could contribute to growth and stability.
- **SDG 10 - Reduced Inequalities:** Inequality within organisations can arise due to hierarchical structures. Certain voices may not be heard or given equal weight. The project tries to address this.
- **SDG 16 - Peace, Justice, and Strong Institutions:** This SDG highlights the importance of promoting just, inclusive, and accountable institutions (Nations, n.d.-a). The project has the potential to strengthen institutional transparency and accountability within the DNP. By ensuring that decisions are made based on validated, collective input rather than the preferences of a few individuals, the tool contributes to more transparent, fair, and accountable decision-making processes .

3.3.3. Ethical Considerations

Throughout the project, the principles of bias mitigation, inclusivity, anonymity, and transparency served as ethical guiding principles.

Bias was a central focus from the start, with particular emphasis on addressing the biases that can occur in hierarchical organisations, as discussed in Section 2.1.2. Cognitive biases, such as confirmation bias and groupthink, are common in decision-making, and the aim is to reduce their impact on the swarming process.

Inclusivity guided the project as well. The DNP is a diverse organisation, and ensuring that all policy advisors can participate in decision-making is important.

Anonymity was another key principle that shaped the project's development. In a hierarchical organisation, anonymity helps to neutralize the influence of rank and power dynamics in decision-making. It should allow participants to share their opinions freely without fear of repurcussion or pressure to agree with the views of superiors.

Transparency was essential to building trust within the system. This project has prioritized making the decision-making process clear and understandable for all participants. By promoting openness in how information is shared and decisions are formed, transparency aims to ensure that each participant feels informed and engaged.

3.4. Objectives and Planning

3.4.1. Value proposition

Following the establishment of the problem statement and the analysis of the organisational context, this section introduces the project's proposed value to the DNP.

By addressing the challenges posed by a hierarchical structure, this study aims to streamline and decentralise decision-making processes for policy advisors. This project proposes a solution to improve information flow, reduce bias, and enhance decision-making efficiency within the Dutch National Police. The core value lies in creating a decision-making environment where information can be collectively ranked, thereby minimising biases that commonly arise within hierarchical layers.

3.4.2. SMART Objectives

To work toward this value proposition, the project was guided by a series of SMART objectives. This abbreviation stands for Specific, Measurable, Achievable, Relevant, and Time-bound. The following objectives were defined:

- **(S):** Research and identify existing swarming algorithms and adapt them to foster emergent behaviour within a decision-making system.
- **(M):** Test a solution with at least 30 participants to gather data and collect feedback for improvement.

- **(A):** Build and test a functional solution.
- **(R):** Ensure the solution directly addresses inefficiencies within the DNP's hierarchal structure.
- **(T):** Complete, test, and evaluate the solution within a ten-week period, with the final report submitted by November 1st 2024.

3.4.3. Project Plan

This project adopted a structured, phased approach that guided the progression and organisation of both the development process and this report. Each phase was designed to move the project towards its final objectives.

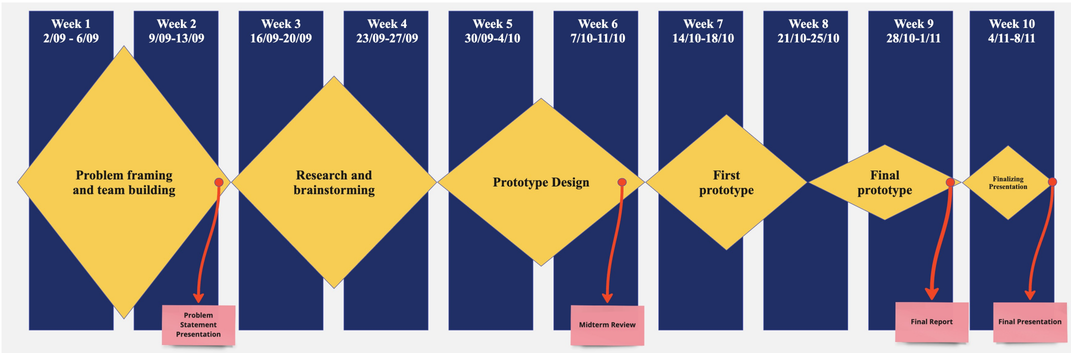

Figure 3.2: Timeline of the project

As can be seen in Figure 3.2, the project's approach is phased through the Double Diamond model. This is a framework in design thinking that highlights alternating between divergent and convergent thinking (Tschimmel, 2012). In each "diamond" of our timeline, we first expanded our understanding and possibilities through divergent thinking. Then, we narrowed down our focus with specific insights and decisions through convergent thinking.

The initial phases concentrated on exploring the problem. Here, divergent thinking allowed us to gather broad insights on the DNP's hierarchical challenges and the needs of policy advisors, while convergent thinking helped us clarify the problem statement, objectives, and the targeted stakeholder group. This foundational work, covered in Chapters 2 and 3, created a clear direction for our approach.

The subsequent phases, as outlined in Chapters 4 to 7, shifted our focus toward solution development. We applied divergent thinking to brainstorm potential solutions and research relevant technologies. Followed by convergent thinking to refine and test the solution. This approach led to structured decision-making in solution selection, UI design, and the PoC's development. Each phase built upon the previous one, moving us closer to delivering a viable tool for the DNP's needs.

With the groundwork laid, the following chapter explores potential solutions.

4

Solution Selection

Building on the research context, this chapter explores methods for enhancing group decision-making. It begins with discussing the traditional methods and the examination of harmonisation and polarisation in group settings. It is followed by an introduction of swarming methodologies as a novel approach. Finally, this leads to the selection of an optimal solution for the DNP.

4.1. Decision-Making in Groups

Making decisions as a group can be both powerful and complex (Tindale & Winget, 2019). Collective decision-making allows for a diversity of perspectives and opinions, ideally leading to a collective outcome. However, it also requires methods that can capture input from all members. The following sections examine traditional and innovative approaches to group decision-making and how they often result in harmonisation or polarisation.

4.1.1. Traditional Approaches

In group decision-making, several traditional methods are commonly used to gather collective input and reach consensus. Methods like voting, polling, and ranking provide structured approaches to capture preferences, often simplifying the process of making a decision. While effective for straightforward choices, these methods often fall short when tackling more complex issues.

Voting and polling, for example, reduce decision-making to simple choices. It can oversimplify varied perspectives and ignore minority opinions. Ranking allows for a more detailed expression of preference, but it is too open to bias. Influential voices or dominant perspectives may skew outcomes, resulting in decisions that only reflect the majority. Thus, while these traditional methods offer a foundation for decision-making, they may not fully support the collaborative, unbiased decision-making needed in the DNP.

4.1.2. Harmonisation vs. Polarisation

Group decision-making often results in either harmonisation or polarisation. Harmonisation occurs when group members align on shared viewpoints, creating unity (Sunstein, 1999). On the other hand, polarisation is a potential risk where opinions can diverge. Sometimes, this creates division rather than consensus within the team. This challenge is particularly relevant for the DNP. Policy advisors must balance collaboration with independent input. Voting and ranking can amplify polarisation if group members feel compelled to conform majority opinions or if influential voices dominate.

In swarming environments, however, continuous feedback and interaction encourage harmonisation because it uses continuous feedback loops and adjustments (Bonabeau, 2009). Participants interact dynamically, adjusting their inputs based on the evolving group consensus, which naturally discourages extreme divergence (Willcox et al., 2019, 2021). While polarisation often occurs in group settings (Sunstein, 1999), it is less common in structured swarming environments due to the continuous feedback. The nature of swarm intelligence relies on decentralised interactions and weighted input from all participants. This mitigates the risk of polarising and influences dominating the decision-making process.

Thus, the exploration of swarming methodologies becomes essential as a potential solution to improve traditional decision-making methods. The following section transition to an exploration of potential swarming solutions, which offer a novel approach for the DNP.

4.2. Initial Swarming Methodologies

The starting point for finding a solution was the research for existing swarming methodologies, both in nature and artificial, that could be useful to tackle the discussed problems. As a result, four possible approaches were selected:

1. **Bee inspired swarm:** In this solution, participants would get shown a hexagon, with six topics on its corners. They are tasked to select the most optimal solution during a swarm round. The topics that are swarmed about are chosen in a probabilistic method that takes their fitness scores into account. This score is based on the results of previous swarms.
2. **Hyperswarm:** Within this approach, a ranked list of PoIs would be produced. It is inspired by the behaviour of birds and fish, discussed in Chapter 2.2. In this swarming mechanism, individuals would be assigned a set of POIs, which are unique per participant, but has overlap with sets from other participants. In this way, behaviour from others has impact on the outcome of the swarm, without the individuals knowing who did what.
3. **Slider swarm:** This swarming methodology is a two-step process that includes (i) personal consideration and (ii) groupwise deliberation (Willcox et al., 2022). In the first stage, participants are shown a certain set of PoIs, which they rank individually. In the second part, the aggregated results of all individuals will be shown. Based on this outcome, participants can adjust their scores and ranking during a collaborative session.

4. **Conversational Swarm Intelligence:** In this decision-making approach, based on research from Rosenberg et al. (2023), participants are divided into groups, each receiving the same set of information. Within each group, members deliberate on the importance of various factors related to the information. Participants present arguments for or against specific statements. These arguments are then passed to an LLM, which acts as a moderator by evaluating the arguments and distributing them to other groups. The LLM helps to facilitate the discussion across groups by ensuring that important points are shared, enabling a more comprehensive and collaborative decision-making process.

Although the chosen approaches initially appeared reasonable, a discussion with our company coach revealed they were unsuitable for our problem. These solutions enable participants to collectively identify the most important PoI from a set of PoIs without centralized control. However, they do not achieve emergence, a key client requirement, and are inadequate for the large and continuously expanding DNP data set. The solutions are limited to handling only a small group of information, making them unsuitable for such a large data set. Furthermore, emergence is not realised because, within a small group of PoIs, individuals can independently identify the most important one, conflicting with the definition of emergence outlined in Section 2.3.

4.3. Change of Approach

As a result of the initial broad solution proposals that failed to yield the desired emergent behaviour and are not suitable for the large data set of the DNP, we shifted focus towards developing a more general system architecture, which will be further described in Chapter 6.

In this system, users interact with a simple interface (the front-end) where they can either submit new information or participate in swarming-based ranking sessions. The front-end sends their input to a server (the back-end), which processes the data. Information is stored in two buckets: ”new” and ”old”. During a ranking-round, the ranking server draws items from these buckets and the participants rank them through the swarming-based algorithm. Each PoI contains a fitness score, which is updated by a rating algorithm based on its rank in the round. Over time, multiple rounds are performed by different groups of people with changing PoIs. This ensures that the architecture can be used in the large data set of the DNP, even though a single round only contains a small part of the database.

The combination of ranking and rating enables emergence. Firstly, ranking through a swarming-based algorithm achieves collective decision-making without centralized control. Secondly, a solution to our problem is found, since the most important PoIs can be identified by examining the ratings. Finally, the size of the data set increases the likelihood of surpassing the solutions of individuals.

4.4. Adjusted Solution Exploration

Through an iterative brainstorming process, coupled with research into various swarming and ranking methodologies, three new potential solutions were developed. While the overall system architecture remains constant across these solutions, the primary difference lies in the ranking approach used in each. Given the adopted system architecture, ASI can enhance option prioritisation and facilitate the emergence of insights (Rosenberg & Willcox, 2020). In summary, the solutions are:

1. **Synchronous solution:** Policy advisors rank information in real-time, providing instant feedback and results.
2. **Asynchronous solution:** Policy advisors can submit and rank information over a longer period of time, providing flexibility with slower feedback.
3. **Hybrid solution:** A combination of both synchronous and asynchronous elements.

4.4.1. Option 1: Synchronous solution

The synchronous solution is based on Unanimous AI's paper about ASI (Rosenberg & Willcox, 2020). In this approach, participants engage in real-time decision-making using a visual representation of the information, similar to the circle diagram provided in Figure 4.1 . The items to be ranked are positioned equidistant from the centre of the circle, represented by points (A, B, C, D) along the radius.

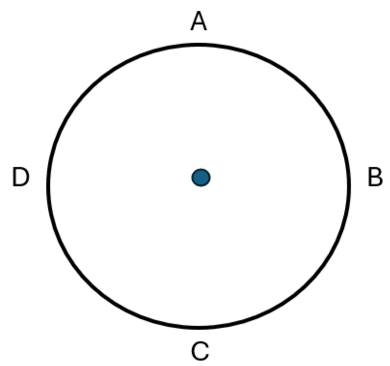

Figure 4.1: Visualisation of Circle Diagram

During the process, individuals "vote" by moving their cursor to pull a virtual "puck" toward the option they believe to be the most important. The puck moves dynamically in real-time, influenced by the collective inputs from all participants. As each participant makes their choice, the puck adjusts to the collective decision, providing instant feedback to everyone in the swarm.

This process involves *n*-1 rounds, where *n* is the number of items. The swarm selects the highest priority item each round. This iterative method ensures all items are ranked in order of importance.

4.4.2. Option 2: Asynchronous solution

In the asynchronous solution, participants follow a process similar to that of the synchronous approach as visualised in Figure 4.1. However, this method is adapted to accommodate the client's preference for avoiding the simultaneous presence of employees. As in the synchronous approach, participants view a circle with PoIs arranged along its edge, and a puck, representing the current group decision. After either reaching group consensus or the expiration of a designated time window, the best option is selected. This process is repeated *n*-1 times to generate a ranked list of information. The key difference between the synchronous and asynchronous approaches is that in the asynchronous method, participants can modify their input (i.e., cursor position) over an extended period of time, eliminating the need of simultaneous presence.

4.4.3. Option 3: Hybrid solution

The hybrid solution introduces a mix of synchronous and asynchronous components. It is a two-step method based on the slider swarm, researched by Willcox et al. (2022). In the first step, participants begin with an asynchronous poll, during which they individually rank their top three out of *n* pieces of information. Participants will receive a time window in which they can submit their ranking.

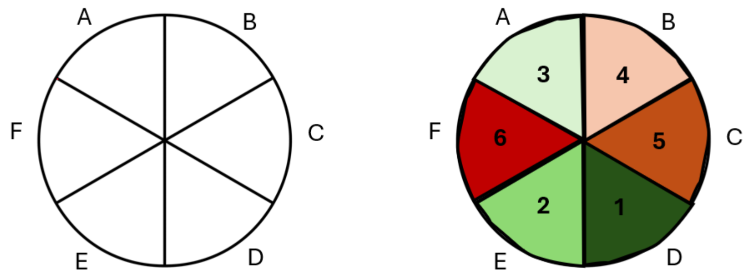

Figure 4.2: Visualisation of Pizza Diagram

In the second step, the preferences of the individual participants are aggregated into a visual representation. This will be a colour-coded "pizza" diagram, where each "slice" reflects the group's ranking of each piece of information. See Figure 4.2 for an example with six pieces of information. The system uses a colour scale that ranks the top choices based on intensity, from dark green (most important) to red (least important). Participants then engage in a real-time (synchronous) feedback loop, during which they adjust their rankings based on the aggregated poll results. They will be given a fixed amount of time to do so. This visualisation enables participants to observe the distribution of votes and how it changes, as indicated by the colour of the pizza slice representing the collective importance assigned by the group. After completing one round of the hybrid approach, a ranked list of information is produced.

4.5. Selection Process

In order to compare the three possible solutions, a set of criteria for selecting the most suitable approach was established. These criteria have been thoroughly researched to ensure that they address the problem statement.

4.5.1. Swarming Criteria

For this project, swarming is defined as a process in which participants work together in real-time, connected through feedback loops that allow them to collectively converge on solutions in synchrony Willcox et al. (2019). Unlike traditional decision-making, where individuals work independently, swarming involves synchronous adjustments to shared information, enabling participants to make decisions collectively. Based on literature (Askay et al., 2019; Bonabeau et al., 1999; Rosenberg & Willcox, 2020), the following criteria were identified for implementing swarming in this PoC, and are visualised in Figure 4.3:

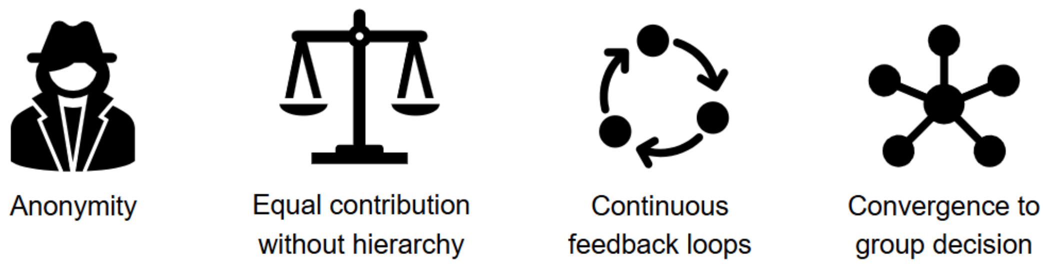

Figure 4.3: Swarming criteria based on literature

- **Anonymity**: To avoid social pressure or biases, the swarming process maintains the anonymity of participants.
- **Equal contribution without hierarchy**: All participants contribute equally to the process. Inputs are not weighted based on authority, status, or role.
- **Continuous feedback loop**: The process enables ongoing interaction between participants. This closed-loop feedback system ensures that each participant can see and react to the group consensus.
- **Convergence to a group decision**: The goal of the swarming process is to provide convergence toward a single, optimized group decision. As participants adjust their inputs based on feedback, the system continuously moves towards a collective solution. In the end, it should reflect the optimal ranking.

4.5.2. Comparison of options

The comparison involves evaluating the alignment of each approach with the swarming criteria, and the scalability and social influence trade-offs. This comparison is intended to highlight which option should be further developed to address the initial problem statement.

Alignment with the swarming criteria

In terms of **equality and anonymity**, synchronous swarming ensures that all participants contribute equally and anonymously in real-time, reducing social biases and the risk of post-hoc influence. Asynchronous swarming, however, may introduce delays and risks of bias due to the extended time windows for participation. The hybrid approach also strives for equality but introduces complexities in merging asynchronous and synchronous inputs, which could affect the overall fairness of the process.

The synchronous approach strongly aligns with the swarming criteria, particularly in terms of **real-time interaction** and **continuous feedback loops**. This method is great in providing real-time feedback and efficiency, making it ideal for scenarios requiring rapid decision-making (Askay et al., 2019; Rosenberg & Willcox, 2020). Participants can observe collective decisions as they unfold, enhancing engagement and allowing for immediate adjustments based on group dynamics.

In contrast, asynchronous swarming lacks this real-time interaction, which results in a slower decision-making process and fragmented participation. This approach may also resemble a polling mechanism more than true swarming, as decisions are aggregated post-participation, rather than being influenced dynamically during the process.

While the hybrid approach offers a balance between flexibility and feedback, it lacks the immediacy and fluidity of fully synchronous methods due to the polling component.

Scalability

Synchronous swarming poses challenges in scalability. The need for participants to engage simultaneously in multiple rounds to produce ranked options places significant demands on both participants and the system. Each round determines only the top option, limiting the scalability of the method in larger group settings.

Asynchronous swarming, in contrast, provides more flexibility by allowing participants to contribute at their convenience, which makes it suitable for larger groups or situations where synchronous participation is impractical (Willcox et al., 2021).

The hybrid approach combines synchronous and asynchronous elements, offering a compromise between scalability and interactivity. It allows participants to revise their input based on real-time group feedback, producing a ranked list after just one round (Willcox et al., 2022). However, the hybrid method is computationally demanding, requiring resources to manage both the asynchronous polling and real-time feedback components.

Social Influence

Synchronous swarming has the advantage of minimising external social influence due to its real-time engagement. Participants make decisions concurrently, reducing the likelihood of bias caused by prolonged exposure to external opinions. This ensures that participants' decisions are based on collective group dynamics in the moment, with fewer opportunities for external influence.

In contrast, asynchronous swarming presents a higher risk of influence, as participants are not required to engage simultaneously. The extended time window for input can expose participants to external opinions, leading to potential bias in their decisions.

The hybrid approach also introduces opportunities for external influence during the time gaps between polling and feedback. While it addresses some of the concerns associated with delayed feedback, the hybrid method still cannot fully mitigate the risks of prolonged decision times and potential biases.

4.6. Selected Option

Each swarming method offers advantages and limitations, as can be seen in Table 4.1

Option	Advantages	Limitations
Synchronous	• *Minimal* external social influence • *Short exposure* to external opinions	• Requires *simultaneous* participation. • *Multiple rounds* needed for ranking.
Asynchronous	• *Flexible* participation. • Highly *scalable*.	• *Slow* decision-making. • *Multiple rounds* needed for ranking • *Long exposure* to external opinions
Hybrid	• *Outputs* ranked list after *one round* • Scalability-flexibility *trade-off*	• Computationally *complex and demanding* • *External social influence* between the steps.

Table 4.1: Comparison of Swarming Solutions

After considering the advantages and limitations of each solution, we have chosen to proceed with the **synchronous swarming approach** for the development of the PoC. This decision was made based on its strong alignment with the criteria and its ability to produce rapid, collective decisions. While scalability remains a challenge, the efficiency and immediacy of synchronous swarming make it the most suitable option for addressing the problem statement.

4.6.1. Requirements for Minimum Viable Product

The Minimum Viable Product (MVP) was designed to meet the following requirements to deliver a functional PoC:

1. The system should maintain two distinct buckets (new and old) from which, before the swarm, PoIs are drawn, based on certain criteria (fitness and swarm scores).
2. A user interface where policy advisors can easily submit, view, and interact with informa-

tion.

3. A swarming mechanism for real-time collaborative decision-making, enabling users to be part of the outcome by interacting with the ”puck” in a shared environment.
4. All participants should contribute equally without any biases, and the swarming process must ensure anonymity to prevent social pressure.
5. The system should be able to handle multiple users interacting in real-time.
6. The system must update the ratings (fitness scores) of each PoI after they are ranked in the swarm, reflecting their current relevance and performance
7. A transparent system for displaying the ranked PoIs, making the results of the swarming sessions clear and accessible.

5

Design Process

After navigating through the exploration and selection of potential solutions, we have chosen the **Synchronous Swarming** approach as the most suitable. The next sections will cover the design considerations that influenced the design implemented to bring the solution to life.

5.1. User Interface (UI) Design

5.1.1. User-Centered Design Principles

The Universal Design Principles are common design strategies that can be universally applied to all types of designs, mediums, purposes, and users. Its intent is to make our human-made world as accessible and usable as possible for as diverse a user population as possible (Story, 2001). There are 7 guiding principles: equitability, flexibility, simple and intuitive, perceptible information, tolerance for error, low physical effort, and size and space for approach and use (Story, 2001). Each of the seven guiding principles should be considered. Table 5.1 outlines how these principles could be applied within the PoC. These considerations can contribute to the platform being intuitive, flexible, and accessible.

Universal Design Principle	**Application in the Proof of Concept**
Equitable use	The platform should be fully anonymous and accessible to all policy advisors within the DNP, ensuring everyone can participate equally in swarming without concern for rank or role. It should maintain transparency with a visible leaderboard and shared results.
Flexibility in use	While the synchronous nature of swarming limits flexibility in participation timing, the platform should increase work flexibility by reducing time compared to traditional meetings.

Simple and intuitive use	Gamification elements and strategically placed buttons should make the platform engaging and easy to navigate. A help page should be available for additional support, ensuring users have guidance and quick access to assistance if needed.
Perceptible information	Icons, notifications, and the use of certain colours should provide intuitive visual cues. Explanations should be available by hovering over information, ensuring all necessary details are accessible during the swarming process.
Tolerance for error	If a swarm fails to collaboratively rank information in the given time frame, the process should automatically stop. This built-in failsafe should prevent misaligned results and ensures that only successful swarms contribute to decision-making outcomes.
Low physical effort	Minimal effort should be required, as users only need to read provided information and use their cursor to indicate preferences. The design should reduce physical demands, focusing on ease of movement and participation.
Size and space for approach and use	The platform should be designed for use on standard laptops and computers, which aligns with the device access most users have within the organisation. Interactive elements should be appropriately sized for ease of use on these devices.

Table 5.1: Application of Universal Design Principles in the Proof of Concept

5.1.2. Information Architecture

Before development, the information architecture of the system was examined to ensure that users can navigate intuitively on the platform. A well-structured information architecture is important for user experience, allowing smooth and efficient interaction with the content (Kirkwood, 2001).

A hybrid organisational structure, similar to a website, was adopted to optimize user flow and accessibility (Kirkwood, 2001). This structure combines hypertext, hierarchical, and linear organisation styles, ensuring that users can access related information easily while also making it easy to access related information when needed. The main information collection in the system includes an entry page, a home page, a swarming page, section for adding new information, and a leaderboard view.

To further enhance usability, labels throughout the platform were designed to be clear, using simple and direct language. Navigation follows a linear structure, guiding users through each section and eventually bringing them back to the “Homepage.”

Additionally, the platform will offer contextual links, such as direct access to tutorials or resources, when helpful. This approach keeps the platform user-friendly, intuitive, and easy to navigate.

5.1.3. Colour theory

Colour theory is an important aspect of UI design as it influences what the user experiences (Swasty & Adriyanto, 2017). Research shows that colour choices can affect readability, user engagement, and even emotional responses. Table 5.2 shows what user experience is associated with a certain colour. For instance, some colours could be used for important actions, while others could create a calm and focused environment.

Colour	Promotes
Red	Importance, power, youth
Orange	Uniqueness, friendliness, energy, movement
Yellow	Happiness, enthusiasm, antiquity (darker shades)
Green	Growth, stability, financial themes, environmental themes
Blue	Safety, calm, openness (lighter shades), strength, reliability (darker shades)
Purple	Luxury, romance (lighter shades), mystery (darker shades)
Black	Power, edginess, sophistication, timeless white
White	Simplicity, cleanliness, virtue
Gray	Formality, neutrality, melancholy
Ivory	Elegance, simplicity, comfort
Beige	Traits of surrounding colours, humility, secondary or background colour

Table 5.2: Colour Emotion on Web UI Design Swasty and Adriyanto, 2017

In developing the user interface, future iterations should consider the impacts of colour, as presented in Table 5.2. The selected colour palette, visible in Figure 5.1, features shades of blue, gray, black, and white, each chosen for specific reasons. Blue should convey a sense of calm, openness, and reliability, which are essential for a platform intended for decision-making. Gray and black should provide neutrality and formality, promoting professionalism and allowing other elements to stand out. Finally, white should promote simplicity and cleanliness, enhancing the overall user experience by keeping the design uncluttered.

Figure 5.1: Chosen Colour Palette for Proof of Concept

5.1.4. Cultural Dimension in UI Design

Understanding the cultural orientation of users could influence the effectiveness of UI design. Since the DNP consists of 65,000 employees (Politie, 2023), it is assumed that there are cultural differences in the organisation that should be taken into account. Hofstede's six cultural dimensions offer insights into how cultural differences can affect user preferences on the platform (Chessum et al., 2022). Below are the relevant dimensions and how they could be considered in the design of the PoC. Figure 5.2 shows a visualisation of the relevant dimensions.

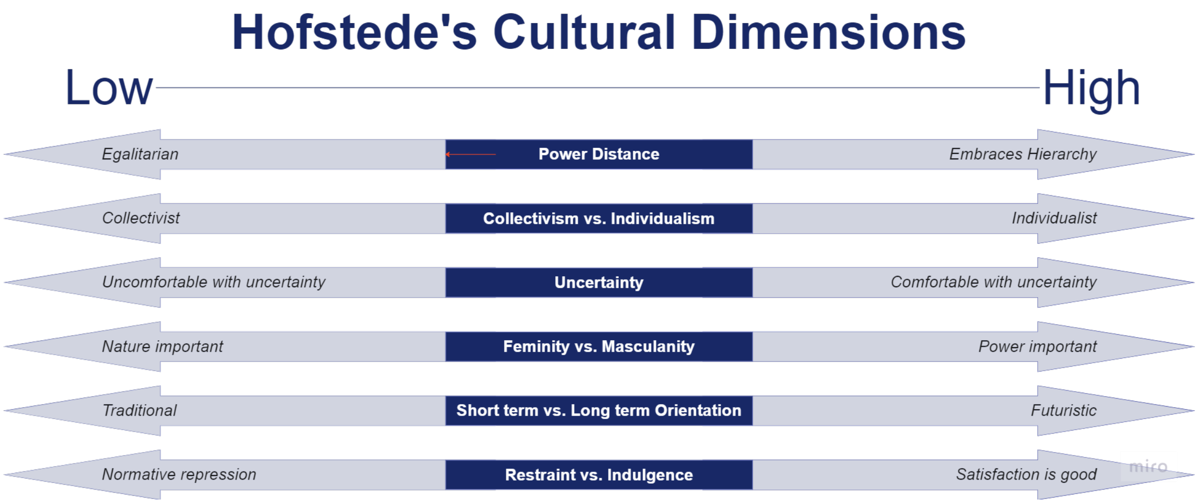

Figure 5.2: Hofstede's Cultural Dimensions Theory (Chessum et al., 2022)

Power Distance

To support inclusivity and equal participation, the platform should minimise hierarchical cues. By keeping user inputs anonymous and not displaying ranks, the design should reflect a low power distance within the platform.

Collectivism vs. Individualism

The DNP's focus lies on collective decision-making, which should align with the platform's swarming approach. While individuals submit information independently, the ranking process should be entirely collective. This reinforces teamwork over individual recognition. The collective focus should be embedded in the platform's design, which should highlight the group's overall results rather than individual contributions.

Uncertainty

Since the DNP prefers structured processes, the platform should integrate gamification elements to make structured interactions more engaging. Features like guided ranking rounds and visual cues should assist users in navigating the process, reducing uncertainty.

Feminity vs. Masculinity

The platform's purpose should focus on improving efficiency rather than encouraging competition. There should be no competitive scoring or direct rewards for individual performance, which aligns with a more feminine orientation. Instead, the focus should be on creating a cooperative environment, reducing the need for lengthy meetings.

Short-term vs. Long-term orientation

The DNP values long-term, sustainable outcomes, but the platform should also provide immediate feedback to improve user engagement. After each swarm, participants should be able to see a ranked list of the top four items. It should also be possible for participants to see an overall leaderboard that tracks the top 10 information pieces of all swarms.

Restraint vs. Indulgence

Though the platform should aim to standardize the decision-making process, it should offer some flexibility to accommodate user preferences. For instance, users should be able to navigate to the leaderboard, which provides an overview of top-ranked information pieces, supporting transparency and user curiosity. However, the platform should also issue cautionary notifications to prevent users from overindulging in this feature.

5.2. Gamification

Gamification refers to applying game design elements to non-game settings to boost user engagement, motivation, and performance. It is particularly effective in environments where tasks may feel routine or require a high level of focus (Deterding et al., 2011). Within the PoC, gamification creates a more dynamic and interactive experience for the policy advisors, making the decision-making process both more enjoyable and efficient.

Leaderboard

Research shows that participants' engagement increases when they know their input will be visualised and compared to others (Deterding et al., 2011). Based on this, we should incorporate a leaderboard into our PoC to provide this sense of visibility and accountability. By displaying the top-ranked information, the leaderboard encourages users to take the decision-making process more seriously, fostering thoughtful input and enhancing engagement. Furthermore, real-time feedback on choices helps create a sense of immediacy and relevance, which makes the process even more engaging (Zichermann & Cunningham, 2011).

Visualisation

Large and clearly visible buttons make navigation easier for users as simpler interfaces tend to reduce errors (Koivisto & Malik, 2021). Research supports that using fewer buttons helps prevent users from feeling overwhelmed, especially in contexts requiring focus and clarity. Therefore, we should include as few buttons as possible so that users (particularly the older policy advisors) can concentrate on the task at hand without being distracted by complex navigation or excessive choices (Koivisto & Malik, 2021). This minimalistic yet coherent design ensures clarity and ease of use throughout the swarming process.

Ranking

Research shows that breaking processes down into phases helps prevent fatigue and maintain a smooth flow (Deterding et al., 2011). Based on this, we should implement a ranking system with subsequent rounds. Each ranking round lasts a maximum of 30 seconds, where participants evaluate the best option in the current pool of information. Once the top choice is selected, the process continues with the remaining pieces of information. This phased ranking structure helps to manage cognitive load, making the task simpler and more manageable for the target audience (Deterding et al., 2011). It also allows users to adapt quickly without losing track of the overall goal.

Immediate Feedback

In line with the literature on feedback mechanisms in gamified settings, we should also implement real-time feedback to maintain user engagement and support collective decision-making. This quick feedback keeps users engaged and ensures that momentum is maintained throughout the decision-making process (Zichermann & Cunningham, 2011). As users move their cursors toward a particular piece of information, they can see where others are leaning, which encourages collective decision-making. Once the top choice is selected in each round, it's immediately displayed, and the process seamlessly moves to the next round. These visual cues combined with the immediate feedback, sustains momentum and reinforces engagement (Zichermann & Cunningham, 2011).

5.3. Swarming Process Design

5.3.1. Swarming Group Size

Swarming studies demonstrate effective performance with group sizes ranging from as few as 3 participants (Willcox et al., 2020) to as many as 36 (Rosenberg & Willcox, 2018). For our study, a swarm size of 5 was selected as an optimal starting point for user evaluation. While larger groups could potentially prove more beneficial, initial tests are constrained by the server's capacity to handle higher request volumes. Additionally, assembling student groups of more than five members for synchronous participation proved challenging, further supporting the rationale for the chosen swarm size.

5.3.2. Swarming Information Count

The UI for the swarming process was designed as a circle due to its dynamic nature, which allows for the addition of any number of options. This circular layout simplifies the physics involved in the system, particularly in terms of vector calculations related to the puck's movement. A detailed discussion of the underlying physics will be provided in Section 6. Regarding the number of options presented to each swarm, previous research indicates that when individuals are presented with more than six options, they experience 'information overload', which can lead to suboptimal decisions or even losing interest in the decision process (Rosenberg & Willcox, 2020). Considering the need for $n - 1$ rounds to rank the pieces of information and the time required to rank n items, we selected a final number of four PoIs per round. To ensure continuous feedback loops and rapid ranking, each round is set to 30 seconds. If the group fails to converge within this timeframe, the round restarts, encouraging compromise and driving the group toward an optimal decision.

5.4. Final Design

Based on the described design principles, a final UI for the PoC was created, discussed in the following subsections.

Landing Page

Figure 5.3 shows the Landing Page of the website. When participants access the website, they are directed first to the landing page, where they are prompted to enter their full name. This step is implemented solely to track swarm receipts as per client requirements; the swarming process itself remains fully anonymous.

Figure 5.3: Final UI - Landing Page

Homepage

Figure 5.4 shows the homepage of the website. After entering their name, participants are redirected to this page. It provides an overview of all site functionalities, which will be explained in the following sections.

Figure 5.4: Final UI - Homepage

Help Page

When the user clicks this button, they are redirected to a video that provides an in-depth explanation of how swarming is performed in the PoC. You can view the video on YouTube[1].

Add New PoI

The PoC also allows participants to submit information anonymously. Figure 5.5 shows this feature. This feature is important, as it enables participants to contribute PoIs during ongoing

[1] Explanation Video

discussions without concern about the potential repercussions of their contributions. Once submitted, the information is stored in the new bucket, making it accessible for the swarming process. However, it does not mean that the submitted PoI will be chosen in the next swarm that takes place.

Figure 5.5: Final UI - Add New PoI

Join a Swarm

Participants can engage in swarming to evaluate and rank the PoIs. Upon clicking the button, they are placed in a waiting room until the required number of swarmers, five in this case, join the session.

PoI Information

The swarmers are then redirected to a page displaying the four topics they will be evaluating, see Figure 5.6. On the left side, they can quickly glance at the titles and brief descriptions of each topic. If they want more details, they can click on any topic to reveal a longer description on the right side of the screen. Participants have two minutes to read about the PoIs. Once they finish reading, they can click the "Ready" button. The swarming process will begin once all participants are ready or when the two minute time limit has elapsed, whichever comes first.

Figure 5.6: Final UI - Swarm Waiting Room

Swarming

The actual swarming process begins with participants viewing a circle displaying the PoIs positioned around its edge, as displayed in Figure 5.7. Participants can move their cursors to provide input, while red dots indicate the positions of other players. The puck's movement is determined by the positions of all the cursors, and a decision is made when the puck is close enough to one of the options, prompting the round to restart with the remaining topics. On the right side of the screen, participants can see the current leaderboard for the swarm. This process continues for three rounds, allowing the group to rank the four PoIs in order of their relative importance to one another. These functionalities enables real-time, collective decision-making. The real-time feedback loop of the swarm ensures that participants can respond to the group's shifting consensus.

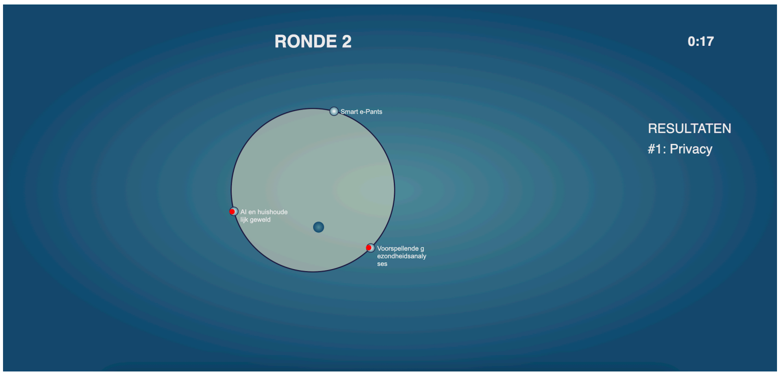

Figure 5.7: Final UI - Swarming

Swarm Results

Once the swarm is over, participants are redirected to a results page that displays the outcomes of the swarm. For an example see Figure 5.8. Here, they also have the option to rate their experience with the swarming process. If they wish to provide additional feedback, participants can share their thoughts and interpretations about the topics. After submitting their feedback, they are redirected back to the homepage.

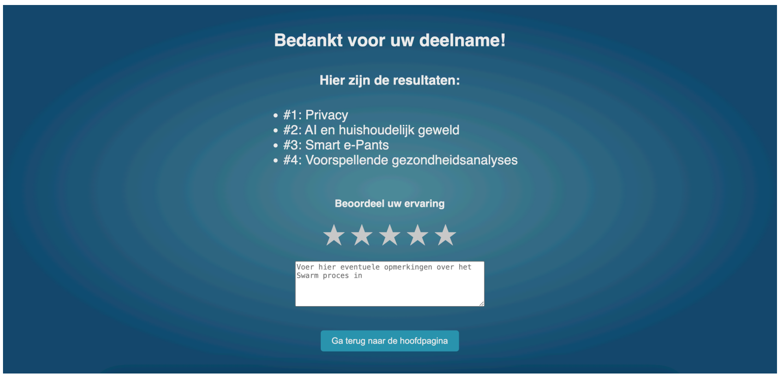

Figure 5.8: Final UI - Swarm Results

Leaderboard

In addition to submitting and ranking information, the platform offers a leaderboard where participants can view the top 10 PoIs resulting from all swarming sessions conducted so far. Figure 5.9 illustrates an example of a leaderboard. This feature provides a quick overview of the topics considered most relevant by the collective, helping participants easily understand current priorities and support their decision-making process.

Figure 5.9: Final UI - Leaderboard

6

Final Solution

Having detailed the considerations and design principles that guided the creation of the UI design of the PoC in the previous chapter, this section will discuss the final stage of the project—the realisation of the platform.

6.1. Technical Specifications

6.1.1. Overview of the PoC

Before diving into the technical specification, a short explanation of the PoC is provided here. The primary purpose of the PoC is to improve decision-making processes within the DNP by using ASI. Therefore, a website is built. The core objective of this website is to enable policy advisors to individually submit, evaluate, and collaboratively rank PoIs.

Our PoC draws inspiration from the swarming behaviour of bees, where each PoI can be thought of as a potential location of a food source, and the participants represent the bees selecting these locations. During each swarming session, individuals rank four PoIs, determining their order of preference. In this context, the top two PoIs are viewed as more relevant as compared to the bottom two. This ranking process mirrors how bees assess and communicate the value of different foraging sites. This ensures that when a PoI is favoured by numerous swarms, it gains traction and visibility, reflecting its increasing relevance on a leaderboard.

6.1.2. System Architecture

The system architecture, as seen in Figure 6.1, is based on a client-server model with clear separation between the front-end (client-side) and the back-end (server-side). This separation ensures that user interactions are handled asynchronously and efficiently, with the front-end primarily focused on user interface and experience, while the back-end processes logic-heavy tasks such as ranking and rating updates.

The front-end interacts with users, allowing them to submit new information and request rankings of PoIs. The system leverages WebSockets for real-time communication between the front-end and back-end. This allows live updates of ranking data, enabling users to see the ranked results as they are calculated. WebSockets are well-suited for such interactive, stateful communication, where the front-end continuously fetches puck updates and ranked results from the back-end in response to user activity.

The back-end consists of two key components: the Ranking Server and the Rating Algorithm. Upon receiving requests from the front-end, the back-end draws PoIs from the database, processes the rankings through the Rating Algorithm, and returns the ranked list of PoIs back to the front-end. The ranking server is responsible for ensuring these computations are processed efficiently and updates are communicated back to the front-end.

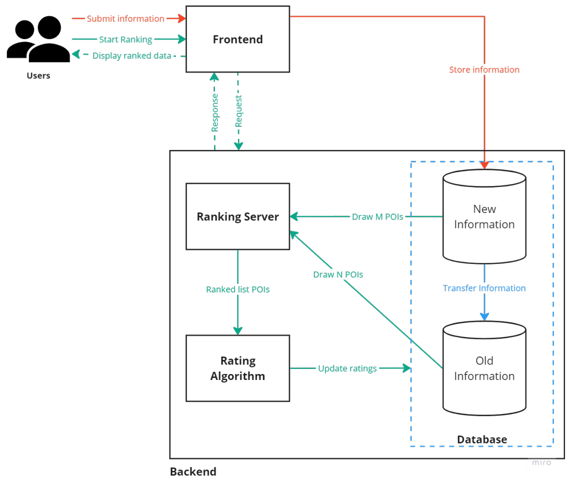

Figure 6.1: System Architecture

6.1.3. Frameworks & Libraries

The final product was developed using a modern tech stack, combining the following frameworks and libraries:

- **Front-end**: The front-end is built using *Vue.js* and *Nuxt.js*. These frameworks allow for creating a reactive user interface (UI) and managing routing. The use of Vue provides dynamic, component-based views, while Nuxt.js simplifies server-side rendering, boosting performance, and providing an out-of-the-box development structure.
- **Back-end**: The back-end is built using *Node.js* and *Socket.io* to enable real-time bi-directional communication between users and the server. *Python scripts* are used for the rating algorithm and swarming pre-processing. Node.js is responsible for handling API requests, maintaining active user connections, and controlling the real-time nature of the application. Socket.io allows for real-time communication between the server and the connected users.
- **Data Management**: The PoI data is stored in *JSONL* (JSON Lines) format, which is an efficient way to handle structured data across multiple lines. Each line in the file

represents a distinct PoI with its relevant attributes (ID, title, one-liner, description, fitness, and swarm score). This approach makes it easy to add new entries or update existing ones without requiring a full database infrastructure.

6.1.4. Swarming Preparation

Before each swarming session, the platform must prepare the topics (PoIs) which the participants will rank. The preparation process involves the selection of topics from two data sources: a new bucket containing recently submitted PoIs, and an old bucket containing previously evaluated PoIs.

The topics are selected from the buckets using two strategies. In the old bucket, the selection process employs Roulette Wheel Selection, where the probability of selection is based on the fitness of each PoI. Fitness values indicate the relevance of a topic, with those that performed well in previous sessions being more likely to be selected. In contrast, the new bucket operates on a first-in, first-out (FIFO) basis. Once a topic is selected and swarmed on, its swarm score increases by one, and it is then placed at the back of the queue for future consideration, ensuring that each topic in the new bucket is swarmed on at least once before any previously swarmed topics are picked again. This approach ensures that newer submissions receive fair attention while also allowing for ongoing evaluation of previously ranked topics. The number of topics drawn from the buckets can be manually set in the backend. For testing the PoC, we select all four topics from the new bucket, as these have been newly added specifically for this testing phase.

6.1.5. Physics of the Puck

Puck Movement

In the system, the movement of the puck is powered by the interaction between user cursors and the puck through vector-based calculations of virtual forces. Each user's cursor position is collected in real-time, allowing the system to compute the combined influence on the puck. Let the position of the cursor of each user be a vector $\mathbf{p}_i = (x_i, y_i)$ and the position of the puck be the vector $\mathbf{p}_{\text{puck}} = (x, y)$.

User cursor positions are frequently captured from the front-end, and each cursor's position $\mathbf{p}_i$ is calculated relative to the puck's position $\mathbf{p}_{\text{puck}}$ to obtain the relative position vector $\mathbf{r}_i$:

$$\mathbf{r}_i = \mathbf{p}_i - \mathbf{p}_{\text{puck}}$$

Normalizing the relative position vectors yields a virtual unitary force $\hat{\mathbf{F}}_i$ on the puck in the direction of the cursor position of a participant:

$$\hat{\mathbf{F}}_i = \frac{\mathbf{r}_i}{\|\mathbf{r}_i\|}$$

Using a unitary force ensures that each participant has the same influence on the puck's movement. The overall force $\mathbf{F}$ on the puck is then given by:

$$\mathbf{F} = \sum_{i=1}^{N} \hat{\mathbf{F}}_i^{\text{norm}}$$

where N is the number of participants. The displacement of the puck $\Delta\mathbf{p}_{\text{puck}}$ in the direction of the force can now be calculated as:

$$\Delta\mathbf{p}_{\text{puck}} = \alpha \cdot \Delta\mathrm{s} \cdot \hat{\mathbf{r}}$$

with:

- $\hat{\mathbf{r}}$ being a unitary acting in the direction of $\mathbf{F}$ defined as:

$$\hat{\mathbf{r}} = \frac{\mathbf{F}}{||\mathrm{F}||}$$

- $\Delta\mathrm{s}$ ensuring a constant speed of the puck when all participants pull in the same direction. It is set so that in this case the puck reaches the edge of the circle from its centre in 3 seconds. Defining r as the circle's radius and Δt = $100 \cdot 10^{-3}$ as the time interval after which the cursor positions are gathered, $\Delta\mathrm{s}$ is given by:

$$\Delta\mathbf{s} = \frac{\mathrm{r}}{\Delta\mathrm{t}}$$

- α being a scaling factor influencing how fast the puck moves depending on the force acting on the puck. If all participants pull in the same direction, α = 1, meaning that the puck will move $\Delta\mathbf{s}$ in the direction of $\mathbf{F}$. It is defined as:

$$\alpha = \frac{||\mathbf{F}||}{\mathrm{N}}$$

Finally, the new position of the puck, $\mathbf{p}'_{\text{puck}}$ can be calculated as:

$$\mathbf{p}'_{\text{puck}} = \mathbf{p}_{\text{puck}} + \Delta\mathbf{p}_{\text{puck}}$$

Boundary Handling

To ensure the puck remains within the swarming area, the system checks if the new puck position exceeds the defined boundary (a circle of radius r). Let $\mathbf{p}_{\text{centre}} = (x, y)$ be the vector corresponding to the centre of the circle, the distance from the puck to the centre is then defined as:

$$\mathrm{d} = ||\mathbf{p}'_{\text{puck}} - \mathbf{p}_{\text{centre}}||$$

If d > r, the puck is repositioned to the edge of the circle by adjusting the new position:

$$\mathbf{p}''_{\text{puck}} = \mathbf{p}_{\text{centre}} + \mathrm{r} \cdot \frac{\mathbf{p}'_{\text{puck}} - \mathbf{p}_{\text{centre}}}{\|\mathbf{p}'_{\text{puck}} - \mathbf{p}_{\text{centre}}\|}$$

Topic selection

A topic is selected once the puck comes sufficiently close to its position on the circle's edge. To determine this, the distance $\mathrm{D_i}$ between the puck and a topic is calculated at each time step as:

$$\mathrm{D_i} = \|\mathbf{p}'_{\text{puck}} - \mathbf{p}_{\text{i,topic}}\|$$

where $\mathbf{p}_{\text{i,topic}} = (x_i, y_i)$ represents the position vector of a given topic. When $\mathrm{D_i} < 18$ pixels, the ith topic is selected. This distance was determined through trial and error as the most effective value.

6.1.6. Rating algorithm

One of the key components of the system is the rating algorithm, which updates the fitness and swarm scores of each PoI based on their ranking in the swarm. For this purpose, the platform uses the TrueSkill[1] rating system, a widely used algorithm for ranking players in competitive environments. TrueSkill works by updating two parameters for each entity that is ranked: μ, which represents the average skill (or performance), and σ, which represents the uncertainty in the estimate of that skill.

- μ: in the context of the PoC, this represents the fitness score of a PoI. A higher μ value indicates that the PoI has been consistently ranked higher in previous swarming sessions.
- σ: This measures the uncertainty in the fitness score. A higher value of σ indicates more uncertainty μ, typically for newly introduced PoIs. Over time, as the PoI is evaluated in more swarms, σ decreases.

For our project, TrueSkill is well-suited because it dynamically updates the fitness score of each PoI based on its ranking in swarming sessions, ensuring that highly relevant PoIs rise in the ranks. The algorithm's ability to manage uncertainty is particularly useful when new PoIs are introduced, as it allows the system to gradually refine their rankings as they are evaluated over time. Furthermore, TrueSkill's pairwise comparison mechanism makes it efficient in handling the ranking of multiple PoIs by comparing them directly, making it useful for real-time, collective decision-making in swarming processes.

The TrueSkill rating function used is:

$$\text{rate}(\text{rating\_groups}, \text{ranks}) \rightarrow \text{rated\_rating\_groups}$$

[1] https://trueskill.org/

Where:

- **rating_groups**: A list of tuples containing ratings (μ, σ) for each PoI.
- **ranks**: A list specifying the final ranking of the PoIs after a swarm.

Given the ranked list of PoIs, the function recalculates the μ and σ values for each PoI using pairwise comparisons. This can be represented as:

$$\mu' = \mu + \Delta\mu$$

$$\sigma' = \sigma + \Delta\sigma$$

Where:

- μ' and σ' are the updated values for each PoI.
- $\Delta\mu$ and $\Delta\sigma$ are the adjustments made by the TrueSkill algorithm based on the ranked outcomes of the swarm.

The rating algorithm proceeds as follows:

1. Initialize ratings: Each PoI is initialized with a fitness score (μ) and uncertainty (σ), using default values (μ = 25, σ = 8.333).
2. Rank updates: After each swarm, the ranking of PoIs is passed into the TrueSkill algorithm, which updates the μ's and σ's of each PoI based on its position in the ranked list. The new ratings are computed using pairwise comparisons within the ranked list.
3. Threshold check: If a PoI in the new bucket reaches a swarm score of 5, it is moved to the old bucket. This prevents PoIs from remaining in the new bucket indefinitely. Moving occurs after 5 rounds of swarming, which is the number of rounds needed to initialize μ and σ in a 4 player free-for-all (FFA) game for the Trueskill algorithm (Microsoft, 2024). In our case, the players are the PoIs and we use FFA because they ”compete” against each other during the swarm.
4. Save updated ratings: All the scores from the PoIs in the swarm are updated in their respective bucket.

6.2. Evaluation

The primary goal of this evaluation was to assess the effectiveness and usability of our PoC for collective decision-making. With the PoC now operational, we aimed to gather comprehensive feedback from participants to understand its impact on group decision processes. This evaluation focused on collecting qualitative and quantitative data to measure user satisfaction, ease of use, and the tool's ability to facilitate efficient and unbiased decision-making. We sought to identify any areas for improvement and validate the tool's potential to enhance collaborative decision-making in various contexts. The outcome of this evaluation informed the development of future tool features and identified points for further research, discussed in Section 9.3.

6.2.1. User evaluation

Participants

We recruited 30 participants in total, with 22 in the 18-24 age group, 3 in the 25-34 age group, 4 in the 45-54 age group, and 1 in the 55-64 age group. During testing, groups always comprised of five participants. However, one participant in the age category 18-24 was not able to fill in the survey.

Procedure

The testing procedure began with an introductory video [2] designed to familiarize participants with the tool's functionality. After watching the video, participants were instructed to continue independently, remaining silent and avoiding any discussions. During the swarm, they were given the question, "As a group, what would you like to do this evening?" and presented with a variety of fun activities to choose from, such as "Karaoke" and "Escape Room," ensuring that the topics were straightforward and easily understandable.

After the session ended, they were asked to fill in a survey. For an overview of the questions in the survey, see Appendix B.

Measurements

The questions aimed at measuring different aspects of the tool:

- Perceived usefulness (PU)
- Perceived ease-of-use (PEU)
- Decision process

The questions related to PU and PEU were derived from the Technology Acceptance Model framework (Davis, 1987). For the majority of questions, participants were requested to indicate their level of agreement using a 5-point Likert scale, ranging from 'Strongly Disagree' to 'Strongly Agree'. In addition to these questions, qualitative data was collected through open-ended questions, allowing participants to elaborate on their previous responses.

6.2.2. Result Analysis

This section presents the participants' responses to the survey questions. For a visual analysis of the data, a mosaic plot is utilized, and for the statistical analysis, a one-sample t-test is performed to assess the significance of the participants' responses against the hypothesized benchmark.

[2] Explanation Video

Quantitative

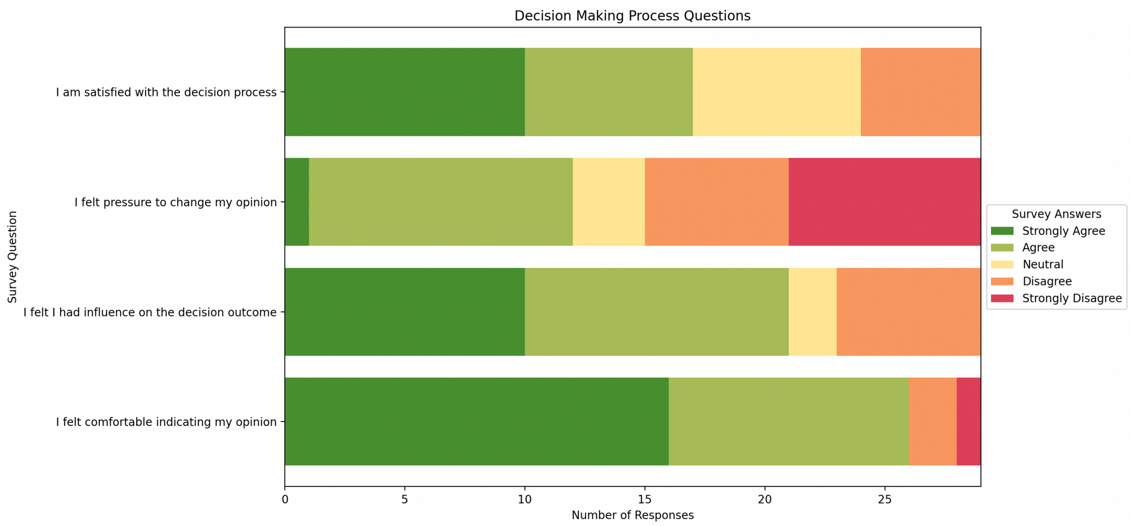

Figure 6.2: Distribution of answers to the 'Decision Making Process' questions

Figure 6.2 illustrates participants' responses to four survey questions about the decision-making process. For the question "I am satisfied with the decision process", responses inclined positive, with most participants selecting Agree or Strongly Agree, suggesting a high level of satisfaction overall. In contrast, responses to "I felt pressure to change my opinion" show a notable number of participants selecting Agree and Strongly Disagree, along with some in Neutral and Disagree. This distribution indicates that, while a substantial portion of participants did feel some pressure, there was still a spread across all categories, suggesting mixed experiences regarding perceived pressure. Responses to "I felt I had influence on the decision outcome" were concentrated in Strongly Agree and Agree, showing that participants felt they had considerable influence in the decision-making process. Lastly, for "I felt comfortable indicating my opinion", there was a strong majority in the Strongly Agree category, with some additional responses in Agree and very few negative responses, suggesting that participants felt comfortable sharing their opinions. Overall, the plot reveals that participants generally felt comfortable and influential in the decision-making process, with minimal pressure to conform.

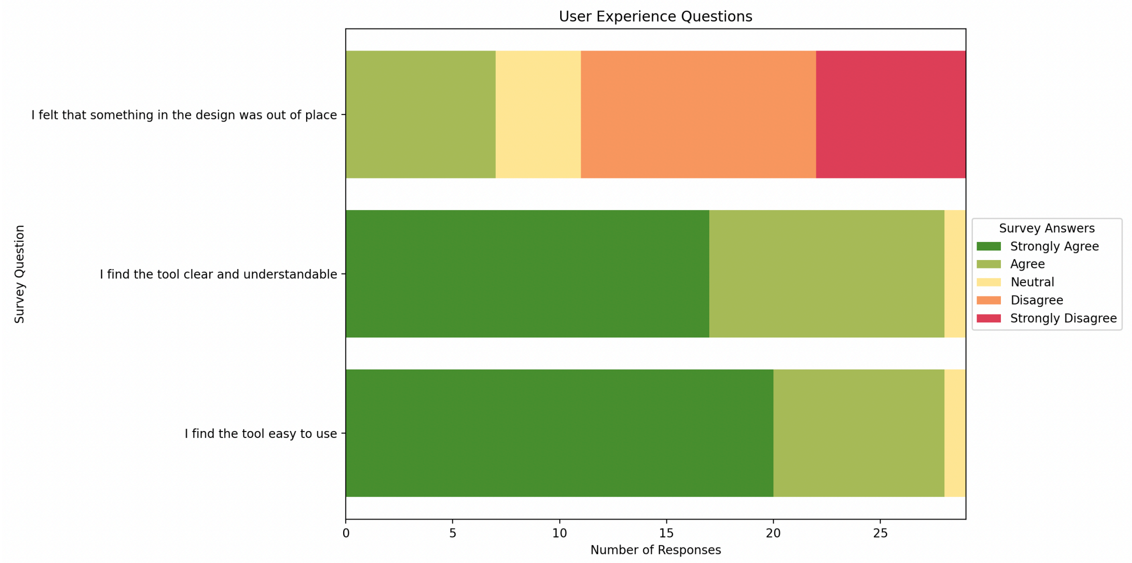

Figure 6.3: Distribution of answers to the 'User Experience' questions

Figure 6.3 displays participants' responses to three survey questions focused on user experience, with responses measured using the Likert scale. For the question "I felt that something in the design was out of place", responses are spread across all categories, with fewer Agree responses and a notable portion selecting Disagree and Strongly Disagree. This suggests that while some participants felt elements of the design were misplaced, a considerable portion did not share this view. For "I find the tool clear and understandable", most responses fell under Strongly Agree and Agree, with few participants choosing Neutral and none disagreeing, indicating that participants generally found the tool to be straightforward and easy to understand. Similarly, responses to "I find the tool easy to use" were overwhelmingly positive, with most participants selecting Strongly Agree and some selecting Agree, demonstrating that the tool was widely considered user-friendly. Overall, the plot suggests high levels of clarity, understandability, and ease of use, with only minor concerns about design elements. Nevertheless, some participants offered suggestions for improvements, which will be explored in the coming sections.

In combination with the mosaic plots, a one-sample t-test was conducted, which evaluates whether the mean of a single sample differs significantly from a specified value. This analysis is important for assessing whether responses significantly deviate from a hypothesized neutral mean. Each question's responses were analysed using a one-sample t-test with a hypothesized mean of 3, as this value represents neutrality on the Likert scale. Significant deviations were tested using a p-value smaller than 0.05. The p-value means the probability, for a given statistical model that, when the null hypothesis is true, the statistical summary would be equal to or more extreme than the actual observed results (Nahm, 2017). The one-sample t-test is calculated using the following formula:

$$t = \frac{\bar{x} - \mu}{\frac{\sigma}{\sqrt{n}}}$$

in which:

- $\bar{x} =$ sample mean
- $\mu =$ hypothesized population mean
- $\sigma =$ sample standard deviation
- $n =$ sample size

For each question analysed, we formulated a null hypothesis (H_0) and an alternative hypothesis (H_1):

- **Null Hypothesis (H_0)**: The sample mean is equal to the hypothesized mean (3), indicating no significant deviation from neutrality.

$$H_0 : \bar{x} = 3$$

- **Alternative Hypothesis (H_1)**: The sample mean is not equal to the hypothesized mean (3), indicating a significant deviation from neutrality.

$$H_1 : \bar{x} \neq 3$$

The two-tailed nature of this test allows us to determine whether participants' responses significantly differ in either direction from the neutral point.

Question	Mean	Standard Deviation	t-Statistic	p-Value
I felt comfortable indicating my opinion	4.31	1.03	6.79	2.224e-07
I felt that I had influence on the decision outcome	3.86	1.12	4.13	0.00029
I felt pressure to change my opinion	2.69	1.34	-1.25	0.2223
I am satisfied with the decision process	3.75	1.12	3.64	0.0011
I find the tool easy to use	4.65	0.55	16.13	1.05e-15
I find the tool clear and understandable	4.55	0.57	14.60	1.28e-14
I felt that something in the design was out of place	2.38	1.12	-2.997	0.00566

Table 6.1: Mean, Standard deviation, t-statistic, p-value for the quantitative questions from the survey.

The results of the one-sample t-test, summarized in Table 6.1, provide insight into the participants' perceptions of the decision-making process and the tool used. The p-values indicate significant differences for most questions, suggesting that participants generally expressed strong opinions about their experiences. Notably, the high means for comfort and clarity indicate a positive reception of the tool, while the responses regarding pressure to change opinions highlight areas for potential improvement.

Qualitative Analysis

Following the quantitative analysis, qualitative data was collected through optional open-ended questions integrated into the survey, as illustrated in Appendix B. Upon analysing these results, two major areas for improvement emerged:

- **UI Design:** Several participants suggested that the design and user interface of the tool could be significantly enhanced. They noted that the tool's aesthetic appeal is lacking, with a substantial portion of the screen appearing empty and blue. Additionally, the red dots displayed during the process were reported to cause confusion, contributing to a chaotic overall experience.
- **Lack of Discussion:** One participant expressed a desire for a way to deliberate to be included in the decision-making process.

Furthermore, in addition to feedback on the swarming experience, one participant recommended incorporating sounds to make the tool more engaging and attractive.

6.2.3. Expert Evaluation

Tests within the police were conducted at the DNP headquarters, where ten advisors were randomly selected and invited to participate in a brief evaluation of the tool. During the test, each group comprised of five individuals.

Procedure

The testing process mirrored that of regular users, beginning with an introductory video to ensure participants were well-informed. They were then provided with topics relevant to their profession, as recommended and suggested by the company coach.

Qualitative feedback was collected during post-test discussions between the test groups and the facilitation team, with the company coach present as a supervisor.

Analysis

During these discussions, several constructive feedback points were noted.

- **Enjoyable Experience:** Several participants remarked that using the tool was an enjoyable and novel way to make decisions. The ability to see others' actions in real-time was appreciated, as it indirectly influenced their own decision-making process.
- **Bias Mitigation:** The majority of participants noted that the tool effectively has the potential to mitigate various biases and diminish the influence of hierarchical power, thereby fostering a more democratic decision-making process.
- **Versatile Use Cases:** Participants described their current decision-making processes, such as using post-its and sharing opinions in meetings to reach consensus. One partici-

pant noted that the tool could serve as an effective way to initiate discussions in meetings, potentially providing direction to the topics discussed and saving significant time.

On the contrary, several critical points were also identified:

- **Pressure to Decide:** Some participants agreed that they felt pressured to make a decision, whereas they would have preferred more time or might not have made a decision at all. They felt that having no opinion or being 'neutral' is not equivalent to having an opinion.
- **Lack of Collectiveness:** In some cases, few participants felt that the decision-making process did not foster a collective approach, as everyone was isolated during the process. They indicated that they adhered to their personal decisions without considering the best choice for the group.
- **Conformity Pressure:** There was a strong sense of needing to conform to the majority opinion, even though this did not affect those who voted against the most popular option.
- **Lack of Context:** The majority of participants indicated that there was a lack of reasoning provided for why certain options were chosen during the swarming process. Additionally, some expressed a need for readily accessible background information on the topics during the swarming, which is currently only available in the preparation stage.
- **Influence of Information Positioning:** Although not perceived as a significant issue, some participants suggested that the positioning of information prior to the swarm might influence their opinions. They recommended randomizing this information for each participant to minimise potential bias.

7 Envisioned Mockup

During the exploration of ASI as a potential technology for efficient decision-making and the development of the tool, numerous features to be included in the design were identified. As the developed website serves as a PoC of ASI and is developed within a limited time frame, several features have gone understudied while still potentially beneficial to the functioning of the tool.

7.1. Walkthrough of Visualisations

A mockup is developed to illustrate how the platform could look and function in the future. A detailed overview of visualisations of the mockup can be found in Appendix C. While built upon the initial working PoC and evaluation, this mockup introduces several enhancements that reflect both our current understanding and long-term vision for the platform. The following sections provide a walkthrough of the mockup and the envisioned capabilities.

7.1.1. Homepage and Starting a Swarm

Figure 7.1 shows the homepage of the website. The dashboard serves as the central page for navigation, where users can access a range of functionalities. These include starting a new swarm, viewing active swarms, checking the leaderboard, and accessing help resources.

This mockup makes it possible for any user to start a swarm. This functionality builds upon the capability of the PoC, where users could submit their own information. The mockup provides users the ability to create and organise sessions on topics that are most relevant to their specific work or challenges. In addition, people can also set the amount of participants for a swarm as well.

Figure 7.1: Visualisation of the Mockup Dashboard

7.1.2. Join an Active Swarm

The ability to join active swarms is a new capability we envision. Users will be able to view a list of currently active swarms through a dedicated section of the platform, ensuring they can easily identify which swarming sessions are happening simultaneously and real-time. Figure 7.2 shows an example of this, where active swarms are listed. The swarm listings themselves will be detailed. Each swarm will display a clear title that summarizes the subject matter, ensuring that users can understand what the swarm is about. In addition to the title, a set of keywords will be included to provide more context, such as ”technology,” ”innovation,” or ”policy.” These keywords will help users quickly identify swarms that are relevant to their expertise. Furthermore, the number of participants in each swarm will be visible, giving users insight into how large or small a particular discussion is. Finally, the status of the swarm will be clearly marked, indicating whether the swarm is still active, closed to new participants, or has completed and produced results.

Figure 7.2: Visualisation of Active Swarm Page

This visibility is important, as it allows users to make informed decisions about which swarms they want to contribute to. For example, if a user sees that a swarm on the digital transformation is active and matches their expertise, they can join and offer their input. See Figure 7.3 for a visualisation of this page.

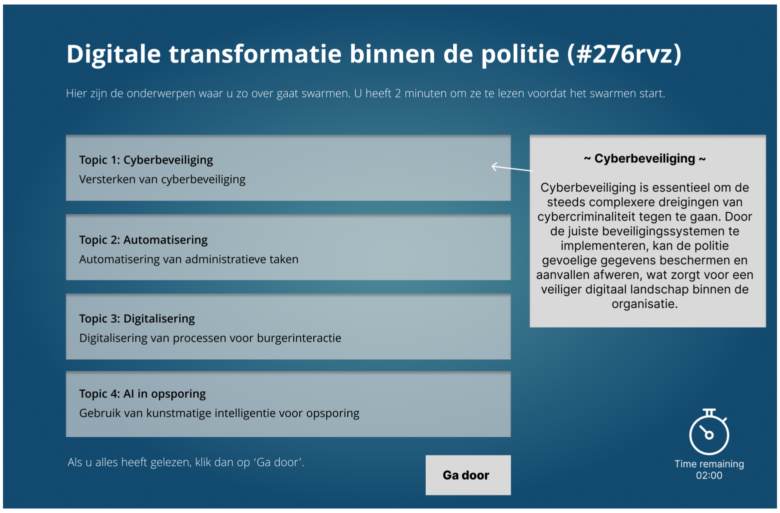

Figure 7.3: Visualisation of Information about Active Swarms

Moreover, not all swarms will be open to new participants at all times. Some swarms might be in advanced stages, such as "Round 2," where the swarming process is already underway and new participation is not allowed. This structure ensures that once a swarm has progressed beyond a certain point, its integrity is maintained by only allowing those who have been present from the beginning to contribute. However, even if a swarm is closed, users will still be able to view its results once a swarm has concluded. The results of the collective decision-making process will be available for review, see Figure 7.4. This creates an environment of transparency, where decisions are not made behind closed doors, but are instead visible to all, even if direct participation is restricted.

Figure 7.4: Visualisation of Results Concluded Swarms

7.1.3. Top 10 Leaderboard

The Top 10 Leaderboard page in the mockup closely mirrors the one developed in the PoC. It displays the top-ranked decisions or pieces of information from concluded swarms. It provides a clear overview, as visualised in Figure 7.5.

Figure 7.5: Visualisation of Leaderboard Page

However, before accessing this page, users will encounter a warning; see Figure 7.6. This warning is designed to remind participants that their decisions or interpretations may be influenced by cognitive biases, such as groupthink or confirmation bias, and that they should critically assess the rankings they view. The goal is not to undermine the leaderboard's results but to encourage users to reflect on potential influences that could skew their judgment.

Figure 7.6: Visualisation of Warning before Accessing Leaderboard Page

7.1.4. Help and Support Page

Given that users may come from diverse backgrounds and hold varying levels of familiarity with digital tools, help and support are integrated into the website. The help and support page will be accessible from the homepage, as visualised in the Figure 7.1. These pages will serve as a resource for users needing guidance or clarification on any aspect of the platform.

One of the core components of the help and support is the Frequently Asked Questions (FAQ) section. This feature will address common questions and challenges that users may encounter while interacting with the website. For example, it will include questions such as ”What is a swarm?” or ”How do I stay anonymous?”. Each question will be answered with clear instructions, sometimes accompanied by visual aids. The FAQ question is envisioned to be dynamic, meaning that as more users engage, the content will be updated regularly. Figure 7.7 shows how the FAQ page is visualised.

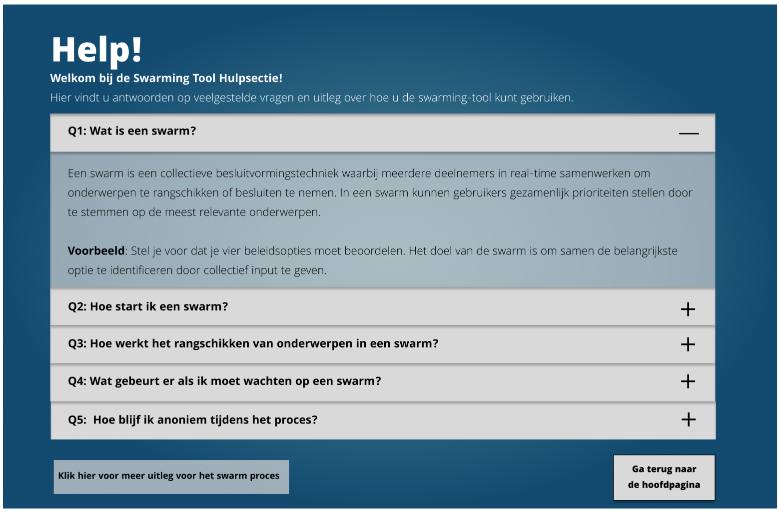

Figure 7.7: Visualisation of the FAQ Page

In addition to the FAQ, a Step-By-Step Guide provides an in-depth walkthrough of the swarming process. This guide is designed to help users who need more detailed assistance, breaking down each phase of the swarming process. The first step of the guide is shown in Figure 7.8.

Figure 7.8: Visualisation of Step-By-Step Guide

8

Risk and Ethics

8.1. Risk Analysis

8.1.1. Risk Assessment and Mitigating Actions for the DNP

The implementation of our solution within the DNP presents several risks that must be carefully managed. One primary risk concerns data security, as sensitive information could be compromised if appropriate safeguards are not in place. Furthermore, the anonymous nature of the platform increases the importance of cybersecurity measures, such as encryption and regular audits, to prevent unauthorised access or misuse of data. Additionally, there is the potential risk of system manipulation, where users might attempt to influence rankings unfairly. To mitigate this, the platform should include integrity checks, such as monitoring unusual patterns in user behaviour, and ensuring that the algorithms used for ranking are transparent and robust against exploitation.

Another significant risk lies in the possibility of over-reliance on the solution. While the platform is designed to enhance collective input from the police force, it should not replace the need for expert judgment in complex situations. The platform generates an overview of what the broader police force deems important, but some topics may be ranked by individuals who may not fully understand the intricacies of the issue. This creates a risk of oversimplified or misguided prioritisation. To address this, it is essential that decision-makers regularly evaluate the platform's outputs alongside expert analysis, ensuring that the final decisions are informed by both collective perspectives and specialised knowledge. The platform's contents should therefore serve as a complementary tool, providing valuable insights instead of dictating the final decision.

8.1.2. Impact and Risk Analysis for Society

The introduction of the solution has the potential to create a significant positive impact on society by improving decision-making processes within the DNP. By incorporating a wide range of perspectives through the swarming process, the platform promotes inclusivity and incorporates input from all participants. This could lead to more representative and fair decision outcomes, particularly in operational areas that affect public safety and resource allocation. Moreover, by reducing hierarchical pressures and bias, the platform may contribute to a more transparent and accountable police force, fostering greater public trust.

However, there are also some societal risks to consider. One concern is that the collective ranking process may elevate popular opinions over more informed or nuanced views, which could result in an oversimplified understanding of complex issues. This risk is particularly critical in high-stakes contexts, such as those involving public safety, where decisions require deep analysis rather than consensus-driven prioritisation. Additionally, if the solution does not adequately capture the diversity of perspectives within the police force, it risks sidelining less common or minority viewpoints, potentially leading to outcomes that do not represent the full spectrum of needs within society. To mitigate these risks, the platform should be subject to ongoing refinement, ensuring it remains inclusive and reflective of a wide range of inputs. Regular feedback loops and inspections will be essential to ensure that its outputs are balanced, align with societal expectations, and adhere to legal and ethical standards.

8.2. Ethical Considerations

As discussed in Section 3.3.3, four ethical principles guided this project: bias, inclusivity, anonymity, and transparency. The development and implementation of the solution carry several ethical considerations, particularly when it comes to the use of collective intelligence in decision-making processes.

8.2.1. Bias

One of the primary ethical concerns in the PoC is the risk of biases infiltrating the decision-making process. While the platform seeks to promote collective intelligence, the system is not immune to cognitive or social biases, which have been discussed in Section 2.1.2.

Cognitive biases, such as confirmation and anchoring bias, can distort how participants evaluate information. These types of biases can lead to participants favouring familiar, easily accessible, or pre-existing beliefs rather than objectively assessing new data. For example, participants may be more inclined to support a policy or decision that aligns with their prior experiences or departmental practices.

Moreover, social biases, such as groupthink or authority influence, can exacerbate this issue. In hierarchical organisations like the DNP, there is a risk that lower-ranking participants may conform to the opinions of higher-ranking officers, even if they disagree, in order to avoid conflict or gain approval. This hierarchical influence can skew the results of swarms, leading to decisions that favour the perspectives of more powerful individuals or groups, rather than reflecting the collective insights of all participants.

To address the risk of certain biases, the solution integrates several design elements aimed at minimising its influence. The warning system is a feature that serves as a reminder to participants before viewing the results of a swarm. Another important feature is anonymity during the swarming process. This helps reduce social and hierarchical pressures.

However, despite these interventions, it is important to recognise that eliminating all bias is an inherently difficult task, if not impossible. The complexity of group dynamics, combined with social and cognitive patterns, means that some degree of bias may persist despite best efforts. Therefore, it is recommended that the platform should include ongoing mechanisms for bias monitoring and evaluation. This could involve periodic audits of swarm outcomes, examining whether certain groups or departments disproportionately influence decisions, as well as gathering user feedback to assess perceptions of fairness within the platform.

8.2.2. Inclusivity

Inclusivity is another ethical consideration, given the DNP's diverse workforce. Ensuring that all policy advisors, regardless of their rank, department, or background, can participate equitably in decision-making processes is essential to creating a platform that genuinely reflects a wide range of perspectives.

The platform's design aims to be as accessible and inclusive as possible, allowing every advisor to contribute their insights without structural or social barriers. However, inclusivity is multifaceted, which extends beyond simple access. True inclusivity requires consideration of different levels of digital literacy, potential language barriers, and the accessibility needs of individuals with disabilities. In this regard, the platform's initial design may not fully address the diverse needs within such a large organisation.

Furthermore, while the platform seeks to promote equal participation, there may be underlying biases or challenges that hinder full inclusivity, such as variations in familiarity with digital tools or differing levels of engagement across departments. These challenges highlight the importance of continued research and adaptation to ensure that the platform can accommodate the unique requirements of a diverse workforce.

In summary, while the solution incorporates inclusivity as a guiding principle, achieving inclusivity will likely require additional iterations and ongoing adjustments. Future development should focus on refining the platform's accessibility features and conducting regular feedback sessions with users to address any barriers to full participation.

8.2.3. Anonymity

Anonymity is a key ethical consideration in the solution, particularly in an organisational context like the DNP, where hierarchy and rank can influence interactions. By allowing participants to contribute anonymously, the platform aims to reduce the potential influence of power dynamics on decision-making, encouraging open and honest contributions without fear of repercussion or the pressure to align with other people.

In theory, anonymity helps to level all participants by ensuring that each participant's input is considered equally. However, anonymity can also introduce its own set of challenges. For instance, the lack of accountability that comes with anonymity might lead to disengagement or less constructive contributions from participants. Furthermore, anonymity could unintentionally undermine trust if users feel uncertain about the transparency of the process or are skeptical of the system's impartiality.

While the solution addresses anonymity with a goal of neutralising hierarchical influence, it is important to acknowledge that anonymity alone may not fully eliminate the impact of organisational power structures. Participants may still infer colleagues' identities based on the content or style of their contributions, reintroducing social or hierarchical biases.

Therefore, while anonymity is a beneficial feature in promoting a fairer decision-making environment, it should be supplemented with ongoing user education and transparency about how the system protects user identity. Future iterations of the platform could also explore flexible levels of anonymity, where users have the option to reveal their identity in certain situations, which might balance the benefits of anonymity with the need for accountability and trust.

8.2.4. Transparency

Transparency within the solution is essential to ensure that users trust the platform and feel confident in the fairness of the swarming process. By making the decision-making process visible and understandable to all participants, transparency helps to build a sense of collective ownership. This includes openly displaying how contributions are processed, how swarms are ranked, and how final outcomes are reached.

However, balancing transparency with anonymity and bias reduction presents challenges. While transparency is beneficial for user trust, revealing too much detail about the inner workings of swarming might lead participants to try to influence outcomes or could unintentionally highlight certain biases. For instance, if users are aware of which groups typically sway results, they may focus their responses accordingly, subtly undermining the platform's neutrality.

Moreover, the level of transparency must be managed to ensure that users feel secure in the anonymity of their contributions. Anonymity requires careful design to avoid linking specific input to individual users, especially in an environment where participants may be concerned about impact in their work environment.

In conclusion, while transparency is a foundational principle of the solution to promote trust and accountability, it must be handled carefully. Clear communication about data handling, anonymisation, and result processing can help users understand and trust the system.

9

Discussion

The outcomes of this research have provided insights into the exploration of ASI for decision-making processes. However, the results should be interpreted with caution due to the limitations of the current research. The following sections discuss the primary limitations encountered and propose potential areas for further exploration and improvement.

9.1. Interpretation of Evaluation Results

The second research question of the study was addressed by examining user feedback on both quantitative and qualitative aspects of their experience. Overall, results indicated that the tool effectively supported ease of use and clarity, both key elements for fostering engagement. Responses to the subset of questions measuring user engagement were mostly positive. This suggests that users found the tool accessible and easy to navigate, a critical factor in encouraging continued engagement.

Participants' responses also highlighted areas for improvement, particularly in terms of the tool's visual design and interaction options. Qualitative feedback revealed that several users found the design too simple to the point of being visually unappealing. An appealing interface could strengthen the user's connection to the tool and improve the overall experience of information sharing, recommendations for which will be provided.

The findings suggest that while the tool is user-friendly and easy to understand, improvements to its design could further empower users and enhance their engagement in the information-sharing process. These potential enhancements will be explored in detail in the coming sections.

9.2. Limitations

Despite the development of the PoC, several limitations became apparent.

Throughout the development of the PoC, the primary focus of this research was on exploring the swarming process. This narrowed scope meant that several envisioned functionalities were either not investigated or only developed as mockups. Key features, such as a help page, including FAQ sections and step-by-step guides, as shown in Chapter 7, were designed but not implemented or tested within the limited timeframe. Similarly, while the ability for users to view and join swarms based on specific topics was included in the mockup, it was not explored in depth. This was largely due to the focus on developing the foundational elements of swarming so it could handle basic decision-making processes.

Another limitation of the current platform is related to scalability. The PoC, in its current form, was designed and tested with a limited number of participants. This setup ensured that the system could function efficiently during controlled, small-scale testing. However, the DNP is a large organisation with thousands of employees spread across the country. The swarming platform requires synchronous, real-time interaction from participants, which poses a significant strain on the system's infrastructure when scaled up to large numbers of users. In larger groups, maintaining participation becomes challenging due to delays in communication, latency, and the difficulty of synchronising the inputs of many participants simultaneously.

Additionally, the current data management architecture poses another limitation. The PoC employs a relatively simple data structure, which may not be sufficient for handling the volume of data that would be generated across the DNP. As the number of users grows, the amount of data generated will increase as well. The current system is not optimised for this level of data processing. This could lead to potential delays in data retrieval and analysis.

Ideally, the ranking system should reflect principles from the leaky integrate-and-fire (LIF) model in neuroscience (Usher & Mcclelland, 2001), which suggests that information accumulates until a threshold is met, prompting action. Just as neurons integrate signals over time to assess significance, an optimal PoC would allow ideas to emerge based on their relative importance and ongoing participant engagement, with the most relevant topics dynamically surfacing through repeated prioritization. However, our current solution does not implement a decay mechanism for fitness scores, which limits the system's responsiveness to changes in topic relevance. Without this decay, rankings may become skewed toward older or frequently swarmed topics, potentially overshadowing newer, more relevant ideas.

Another limitation involves authentication and authorisation mechanisms. Currently, the PoC lacks user authentication protocols, which poses risks for both security and privacy. Ensuring secure access is of importance in a government organisation like the DNP. The platform risks unauthorised access without an authorisation framework. This could undermine the integrity of decision-making processes.

Inclusivity and accessibility represent another area where the current PoC falls short. Although the platform strives to ensure that all participants can contribute equally, certain aspects of the UI limit the accessibility of the system. For instance, the UI does not fully consider accessibility for individuals with visual impairments, such as colour blindness. This design limits the platform's effectiveness for certain users, preventing them from fully engaging in the decision-making process. The lack of accessibility not only reduces user satisfaction but can also compromise the platform's ability to represent a truly inclusive decision-making process.

Lastly, bias remains a persistent challenge. While anonymity and warning systems were implemented to mitigate the influence of biases, these measures cannot completely eliminate the potential for bias in group decision-making. Cognitive biases, such as confirmation bias, anchoring, and groupthink, are deeply integrated in human decision-making and can still influence the outcomes of swarms. In a hierarchical organisation like the DNP, where power dynamics can shape interactions, certain biases may persist even with the introduction of mitigating technologies. Without additional measures to monitor this, the platform's results may not fully reflect the collective intelligence of its participants.

9.3. Future Research and Development

The limitations identified in the solution not only highlight the current shortcomings but also lay the foundation for future research and development. Given the 10-week timeframe of this project, certain aspects of the platform could not be fully explored or researched to the necessary extent.

- **Envisioned capabilities:** As shown in Chapter 7, the mockup enables users to filter and join swarms based on specific topics of interest, which could be beneficial. Future research could explore a tag system that allows users to categorise swarms by subject matter. In the end, this would enable participants to contribute to areas where they have the most expertise
- **Scalability:** The solution was developed and tested on small groups. To support the full-scale operation across the DNP, both technical and operational improvements are required. Research could focus on how to support more participants and improve processing power. Additionally, the ability to run multiple parallel swarms could be important when scaling up. Research should focus on solutions aiming to maintain system performance while allowing real-time participation from dozens of users.
- **Database optimisation:** The current solution architecture is not optimised for handling large-scale data inputs. As the number of swarms and participants grows, a more scalable database solution will be necessary. Research should focus on database systems that can handle large-scale data storage, efficient retrieval, and real-time updates.
- **Authentication and authorisation:** As noted in Section 9.2, the current platform lacks an authentication and authorisation framework. Future research could focus on developing a secure system that ensures only authorised employees can access the platform. Exploring technologies such as Multi-Factor Authentication (MFA) might help in securing the platform.
- **Decay of fitness scores:** Looking into the addition of a decay mechanism for fitness

scores is important. Such a system would make our solution more adaptable and responsive, keeping the ranking of PoIs up to date with ongoing interactions. This would involve allowing fitness scores to gradually decrease, capturing the natural decline in relevance as time passes without interaction. This would create a more adaptive system that better aligns with natural decision-making models observed in nature, such as those seen in bees. Future research could help improve how well our PoC supports decision-making, allowing it to adjust to changes in how actively participants engage with different topics and how relevant those topics remain over time.

- **Mobile application:** Extending the platform to mobile devices could make it more accessible for users. It would allow users to join swarms from anywhere, contributing to real-time collaboration. Research could explore how to develop and optimise the platform for mobile devices.
- **Engagement, Gamification, and UI:** Research should focus more on understanding how different UI designs and sensory inputs could influence the experience for all users, ensuring that everyone can engage in the swarming process. The current UI relies heavily on visual elements, which may not be inclusive for users with disabilities, such as those who are colour blind or visually impaired. Additionally, to gamify the platform more, alternative methods, such as auditory signals could be explored.
- **Checking for existing information:** Currently, a PoI in the new bucket is moved to the old bucket once it has been selected for a swarm five times. Future work could involve verifying if the PoI (or a similar one) already exists in the old bucket before transferring it. If it does not, the PoI can be moved directly; otherwise, a strategy could be developed to merge the two scores, assigning a new, updated score to the PoI.
- **Content moderation:** Currently, when adding a new PoI, there are no restrictions on the content, allowing users to submit any information. To maintain quality, ensure accuracy, and foster a respectful environment, a moderation mechanism should be implemented to prevent the addition of PoIs that may be offensive, harmful, or inappropriate. This would help protect users and uphold the platform's standards, making it a safer and more reliable resource.
- **Organisational adoption:** Since this research was focused on the technical development of the platform, future research should focus on how to facilitate organisation adoption of the swarming platform. Understanding how technologies are adopted within organisations and its employees like the DNP is important to its success.
- **Bias:** While the platform addresses bias with certain features, more research is needed to effectively address this. Future research could explore more advanced methods for bias detection and mitigation in the decision-making process.

9.4. Integration Recommendations for the Company

9.4.1. Way of Working

To integrate the swarming platform, we recommend a phased approach that aligns with the current workflows of the policy advisors. In the early stages of implementation, the platform could be introduced during the regular meetings of the policy advisors already conduct. Currently, the meetings rely on traditional methods such as discussions and the use of post-it notes to capture and organise ideas. By integrating the platform into these existing structures, the transition can be phased.

In the early phase, the platform would serve as an enhancement to the discussions already happening. Instead of using post-it notes, policy advisors would start their meetings with submitting and ranking ideas directly through the platform. This would allow for more efficient meetings, ensuring the topics are collaboratively addressed.

As policy advisors become more accustomed to using the platform, its potential to replace physical meetings may become evident. Once familiar with the system, advisors could shift from needing to gather in a single location to participate swarms remotely. This would allow for more flexibility, as participants could contribute from their desks or from home. The only requirement would be that the policy advisors are available in the swarming process simultaneously. The synchronous approach remains essential for ensuring real-time input, but the physical location becomes less critical. Over time, this transition could lead to more efficient and flexible workflows.

Ultimately, the platform can promote a more inclusive, efficient, and dynamic way of working. In addition, it could reduce the need for in-person meetings while maintaining the collaborative benefits of group decision-making.

9.4.2. Technical Integration Considerations

The successful technical integration of our solution depends on the existing IT infrastructure of the DNP; however, specific details regarding this infrastructure were unavailable. Given this, we propose a flexible deployment option to accommodate various configurations.

Currently, the DNP is developing a method for efficient data storage, which essentially operates as a knowledge graph, where nodes represent entities and edges denote the relationships between them. While this structure enhances data storage, the question of how to leverage it and gain insights from it still remains unanswered.

We propose that our solution be introduced as a standalone service that can operate as an independent server within the DNP's digital ecosystem. This architectural design offers flexibility for several reasons. Firstly, it can integrate with any of the internal databases, allowing for easy data exchange and validation. Secondly, the standalone nature of our service means it can be scaled or modified independently, enabling quicker adaptations to future technological advancements or changes in organisational needs.

Our service would provide a crucial mechanism for validating incoming information, preventing the system from being spammed with irrelevant data. Furthermore, it would facilitate the evaluation of existing data through a mechanism we refer to as the ”old bucket,” where users can rank and validate existing information. This dual approach ensures that both new and existing data maintain quality and relevance.

9.5. Interdisciplinarity and Teamwork

The interdisciplinary composition of the team played an important role in shaping the project. With a team comprising members from various academic backgrounds, each discipline contributed to the project’s development. Systems engineering provided a structured framework, while the technical expertise from computer science guided the development and implementation of the ASI model. Business administration helped ground the work in practical realities, considering organisational needs and stakeholder engagement.

This diversity of expertise also introduced challenges. Differences in priorities and perspectives occasionally led to conflicting ideas. These competing priorities required careful negotiation and regular dialogue, sometimes adding complexity to the project.

Despite these challenges, the interdisciplinary nature of the team ultimately proved beneficial. Frequent discussions allowed us to address issues as they arose, creating a collaborative environment where each member’s strengths could be used. This process required time and patience but led to a well-rounded solution that was technically sound and tailored to the DNP’s context.

In reflection, while interdisciplinary teamwork introduced friction at times, it also enriched our project by pushing us to consider a wide range of factors. By navigating and balancing different perspectives, we developed a solution that leverages the full skill set of our team. This experience highlights the value of diverse viewpoints. It illustrates how interdisciplinary collaboration can improve both the process and the outcomes, even when it requires navigating complex team dynamics.

10

Conclusion

In response to the current issues faced by the Dutch National Police, this study researched how Artificial Swarming Intelligence could be used to enable collective intelligence in its decision-making processes. We successfully answered the research questions guiding our study. First, we investigated ways to adapt swarming algorithms to support emergent behaviour within a decentralised decision-making system. It became clear that adapting these algorithms involved more than simply applying existing models; it required tailoring the swarm dynamics to fit the specific needs of the Dutch National Police.

Another crucial focus in our project was engaging and empowering users to actively contribute to information sharing within this system. The Proof of Concept was designed to prioritise usability and inclusivity, enabling users to engage in swarming sessions without feeling influenced by hierarchical roles or biases. The interactive design took inspiration from nature, allowing individual officers to evaluate and rank pieces of information collectively. This decentralised approach empowered users to engage meaningfully with the platform, contributing their perspectives to shape decisions equitably and collaboratively.

Finally, integrating and optimising the Artificial Swarming Intelligence-based system within the Dutch National Police's existing framework remains a long-term goal. The study highlighted several recommendations to guide the system's adoption, emphasising the need for technical scalability, user accessibility, and structured guidance for new users. Overcoming challenges related to scalability and addressing biases in swarming decisions will be essential in transforming the Proof of Concept into a fully operational platform. Future research should explore these points to support the platform's continuous improvement and facilitate a more adaptive and responsive decision-making environment within the Dutch National Police. Through this integration, Artificial Swarming Intelligence has the potential to enhance the collective intelligence of the organisation, improving decision-making processes while fostering a culture of shared responsibility.

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A

Appendix A

Artificial Swarming Algorithms Overview

Algorithm	Inspiration	Functions	Strengths	Best Used For
Artificial Fish Swarm (AFS)	Fish swarming behaviour	Mimics fish behaviour focusing on preying, swarming, and following. Strong at optimizing global solutions	Fast convergence, fewer parameters, strong global optimization	Optimization in engineering, feature selection, continuous problems
Bacterial Foraging Optimization (BFO)	Bacterial chemotaxis (E. coli movement)	Optimizes by simulating chemotaxis (movement toward food), reproduction, and elimination	Effective in global optimization, simulates biological processes	Computational biology, pattern recognition, neural networks
Artificial Bee Colony (ABC)	Honeybee foraging behaviour	Optimizes by simulating foraging behaviour of honeybees, balancing exploration and exploitation	Strong exploration-exploitation balance, easy to implement	Multivariate optimization, scheduling, feature selection, engineering design
Particle Swarm Optimization (PSO)	Bird flocking/Fish schooling	Adjusts particle velocity and position based on individual and group success	Simple, fast, adaptable to various problems	Optimization in machine learning, engineering design, resource allocation
Ant Colony Optimization (ACO)	Ant foraging behaviour	Simulates pheromone-laying behaviour of ants to find optimal paths	Good for routing, scheduling, adaptive learning	Routing, scheduling, network optimization, combinatorial problems

Table A.1: Comparison of Swarm Intelligence Algorithms based on Tang (2021) Tang et al., 2021

B

Appendix B

Survey questions

Below, survey questions used to evaluate the Proof of Concept can be found.

- **What is your age group?**
  - 18 or under
  - 18 to 24
  - 25 to 34
  - 35 to 44
  - 45 to 54
  - 55 to 64
  - 65 or over
- **I felt comfortable indicating my opinion**
  - Strongly disagree
  - Somewhat disagree
  - Neither agree nor disagree
  - Somewhat agree
  - Strongly agree

- **I felt that I had influence on the decision outcome**
  - Strongly disagree
  - Somewhat disagree
  - Neither agree nor disagree
  - Somewhat agree
  - Strongly agree
- **I felt pressure to change my opinion**
  - Strongly disagree
  - Somewhat disagree
  - Neither agree nor disagree
  - Somewhat agree
  - Strongly agree
- **I am satisfied with the decision process**
  - Strongly disagree
  - Somewhat disagree
  - Neither agree nor disagree
  - Somewhat agree
  - Strongly agree
- **I find the tool easy to use**
  - Strongly disagree
  - Somewhat disagree
  - Neither agree nor disagree
  - Somewhat agree
  - Strongly agree
- **I find the tool clear and understandable**
  - Strongly disagree
  - Somewhat disagree
  - Neither agree nor disagree
  - Somewhat agree
  - Strongly agree

- **If not clear, what can be improved? (Not mandatory)**
- **I felt that something in the design was out of place**
  - Strongly disagree
  - Somewhat disagree
  - Neither agree nor disagree
  - Somewhat agree
  - Strongly agree
- **If you could improve one aspect of the tool, what would it be? (Not mandatory)**
- **Do you have any further comments/recommendations? (Not mandatory)**

Participant Survey Responses

Below, raw survey data on open questions from regular user evaluations can be found.

- **”If not clear, what can be improved”**
  - ”It doesn’t look very pretty, a lot of the screen is empty and blue”.
  - ”The UIUX of the website could be a bit more enhanced otherwise the programme was fairly easy to understand”.
  - ”When you are testing this with police officers, sit next to them and see how they are interacting with the tool. If they experience any “blocks” ask them questions. Be curious about their experience. These observations will help you refine your app’s user experience”.
- **”If you could improve one aspect of the tool, what would it be and why?”**
  - ”The red dots”
  - ”I think it is preferable to communicate during the making of a decision”.
  - ”The design”
  - ”The UIUX”
  - ”Sharing of the link process”.
  - ”The red cursor. It was too chaotic in my opinion”.
- **”Do you have any further comments/recommendations?”**
  - ”Needs to be prettier/clearer in the future”.
  - ”Very good tool. Important to think of use cases that will make an impact in various scenarios”.
  - ”Add sounds or music”.

Below, raw survey data on closed questions from regular user evaluations can be found. In the figures, the questions are as follows:

Figure B.1: Question numbers and their corresponding question

Number	Question
$Q1$	*”What is your age?”*
$Q2$	*”I felt comfortable indicating my opinion”*
$Q3$	*”I felt that I had influence on the decision outcome”*
$Q4$	*”I felt pressure to change my opinion”*
$Q5$	*”I am satisfied with the decision process”*
$Q6$	*”I find the tool easy to use”*
$Q7$	*”I find the tool clear and understandable”*
$Q8$	*”I felt that something in the design was out of place”*

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
18 to 24	Somewhat agree	Strongly agree	Somewhat agree	Somewhat agree	Strongly agree	Somewhat agree	Somewhat agree
18 to 24	Somewhat agree	Somewhat agree	Neither agree nor disagree	Somewhat agree	Somewhat agree	Somewhat agree	Somewhat agree
18 to 24	Somewhat agree	Neither agree nor disagree	Strongly Disagree	Somewhat agree	Strongly agree	Strongly agree	Somewhat disagree
18 to 24	Strongly agree	Strongly agree	Somewhat agree	Neither agree nor disagree	Strongly agree	Strongly agree	Somewhat agree
18 to 24	Strongly agree	Somewhat agree	Neither agree nor disagree	Strongly agree	Somewhat agree	Somewhat agree	Neither agree nor disagree
18 to 24	Strongly agree	Strongly agree	Somewhat disagree	Strongly agree	Strongly agree	Strongly agree	Somewhat agree
18 to 24	Somewhat agree	Strongly agree	Neither agree nor disagree	Somewhat agree	Strongly agree	Somewhat agree	Neither agree nor disagree
18 to 24	Strongly agree	Somewhat agree	Strongly Disagree	Somewhat agree	Strongly agree	Somewhat agree	Strongly Disagree
18 to 24	Strongly Disagree	Somewhat agree	Somewhat disagree	Neither agree nor disagree	Neither agree nor disagree	Neither agree nor disagree	Neither agree nor disagree
18 to 24	Somewhat agree	Somewhat disagree	Somewhat agree	Somewhat disagree	Strongly agree	Strongly agree	Strongly Disagree
18 to 24	Somewhat agree	Strongly agree	Somewhat disagree	Strongly agree	Somewhat agree	Somewhat agree	Somewhat disagree
18 to 24	Somewhat disagree	Somewhat disagree	Somewhat agree	Neither agree nor disagree	Somewhat agree	Somewhat agree	Somewhat disagree
18 to 24	Strongly agree	Somewhat agree	Strongly Disagree	Strongly agree	Somewhat agree	Somewhat agree	Somewhat disagree
18 to 24	Somewhat agree	Somewhat disagree	Somewhat agree	Somewhat disagree	Strongly agree	Strongly agree	Somewhat disagree
18 to 24	Somewhat disagree	Somewhat disagree	Somewhat agree	Neither agree nor disagree	Strongly agree	Strongly agree	Strongly Disagree
18 to 24	Strongly agree	Strongly agree	Somewhat disagree	Strongly agree	Strongly agree	Strongly agree	Somewhat disagree
18 to 24	Strongly agree	Somewhat agree	Somewhat agree	Somewhat disagree	Strongly agree	Strongly agree	Strongly Disagree

Table B.1: Summary of Participant Responses

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
25 to 34	Strongly agree	Somewhat agree	Somewhat agree	Somewhat agree	Strongly agree	Strongly agree	Somewhat disagree
45 to 54	Strongly agree	Strongly agree	Somewhat disagree	Strongly agree	Strongly agree	Strongly agree	Strongly Disagree
18 to 24	Strongly agree	Somewhat agree	Strongly Disagree	Neither agree nor disagree	Strongly agree	Strongly agree	Somewhat disagree
18 to 24	Strongly agree	Somewhat agree	Somewhat agree	Neither agree nor disagree	Strongly agree	Strongly agree	Strongly Disagree
25 to 34	Somewhat agree	Somewhat disagree	Somewhat agree	Somewhat agree	Strongly agree	Strongly agree	Somewhat disagree
18 to 24	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Neither agree nor disagree	Strongly agree	Somewhat agree	Somewhat agree
55 to 64	Strongly agree	Strongly agree	Strongly agree	Strongly agree	Strongly agree	Somewhat agree	Neither agree nor disagree
45 to 54	Strongly agree	Somewhat agree	Strongly Disagree	Strongly agree	Strongly agree	Strongly agree	Strongly Disagree
25 to 34	Strongly agree	Somewhat agree	Strongly Disagree	Strongly agree	Somewhat agree	Somewhat agree	Somewhat agree
45 to 54	Strongly agree	Strongly agree	Strongly Disagree	Strongly agree	Strongly agree	Strongly agree	Somewhat disagree
45 to 54	Somewhat agree	Somewhat disagree	Somewhat agree	Somewhat disagree	Somewhat agree	Strongly agree	Somewhat disagree
18 to 24	Strongly agree	Strongly agree	Strongly Disagree	Somewhat disagree	Somewhat agree	Strongly agree	Somewhat agree
18 to 24	Somewhat agree	Somewhat disagree	Somewhat agree	Somewhat disagree	Strongly agree	Strongly agree	Somewhat disagree
18 to 24	Somewhat disagree	Somewhat disagree	Somewhat agree	Neither agree nor disagree	Strongly agree	Strongly agree	Strongly Disagree
18 to 24	Strongly agree	Strongly agree	Somewhat disagree	Strongly agree	Strongly agree	Strongly agree	Somewhat disagree
18 to 24	Strongly agree	Somewhat agree	Somewhat agree	Somewhat disagree	Strongly agree	Strongly agree	Strongly Disagree

Table B.2: Summary of Participant Responses

C

Appendix C

Overview of Mockup

The Figures C.1 to C.20 visualise the integral envisioned mockup.

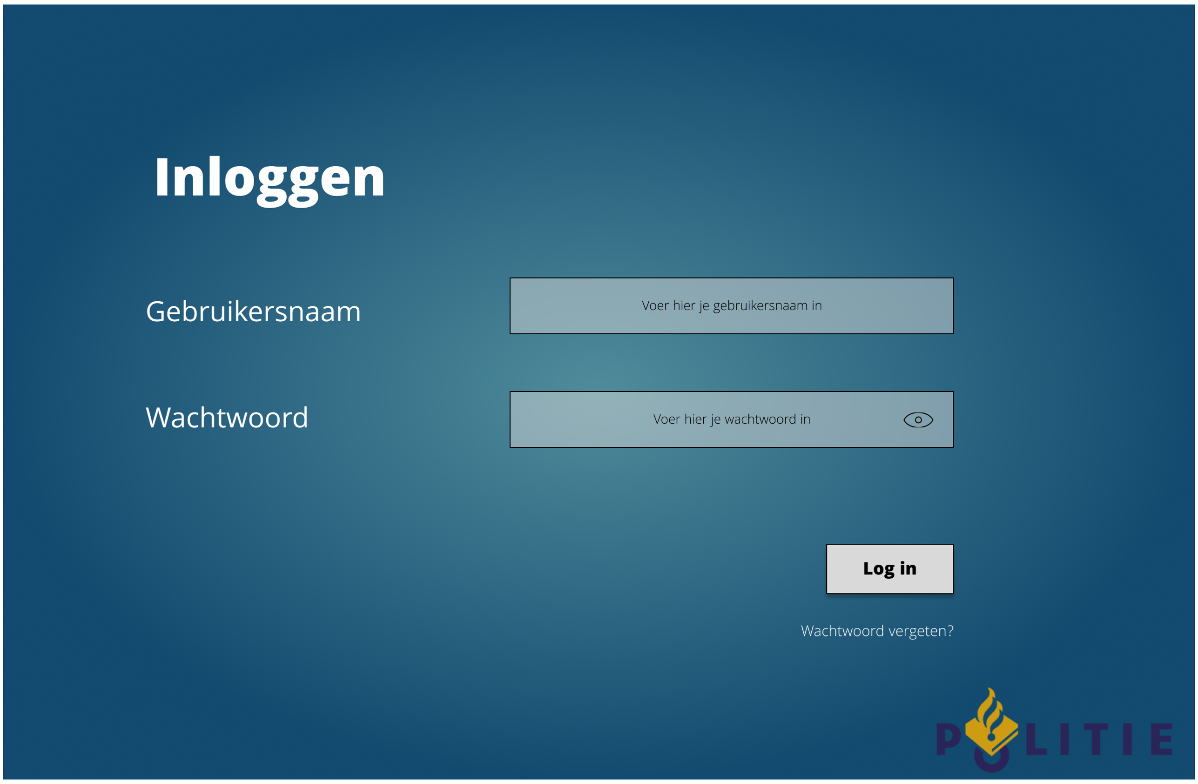

Figure C.1: Mockup Log In Page

Figure C.2: Mockup Homepage

Figure C.3: Mockup Warning Message before Top 10 Leaderboard

Figure C.4: Mockup Top 10 Leaderboard

Figure C.5: Mockup Step-By-Step Explanation

Figure C.6: Mockup Step-By-Step Explanation

Figure C.7: Mockup Step-By-Step Explanation

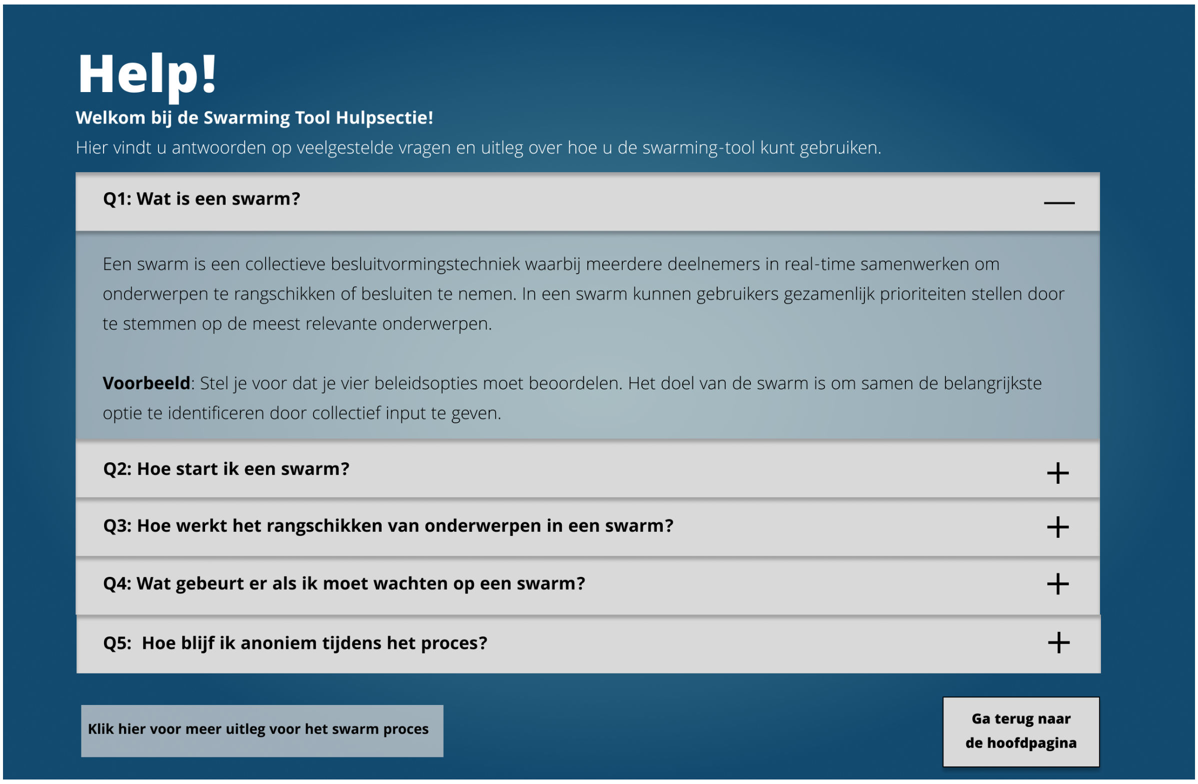

Figure C.8: Mockup Frequently Asked Questions

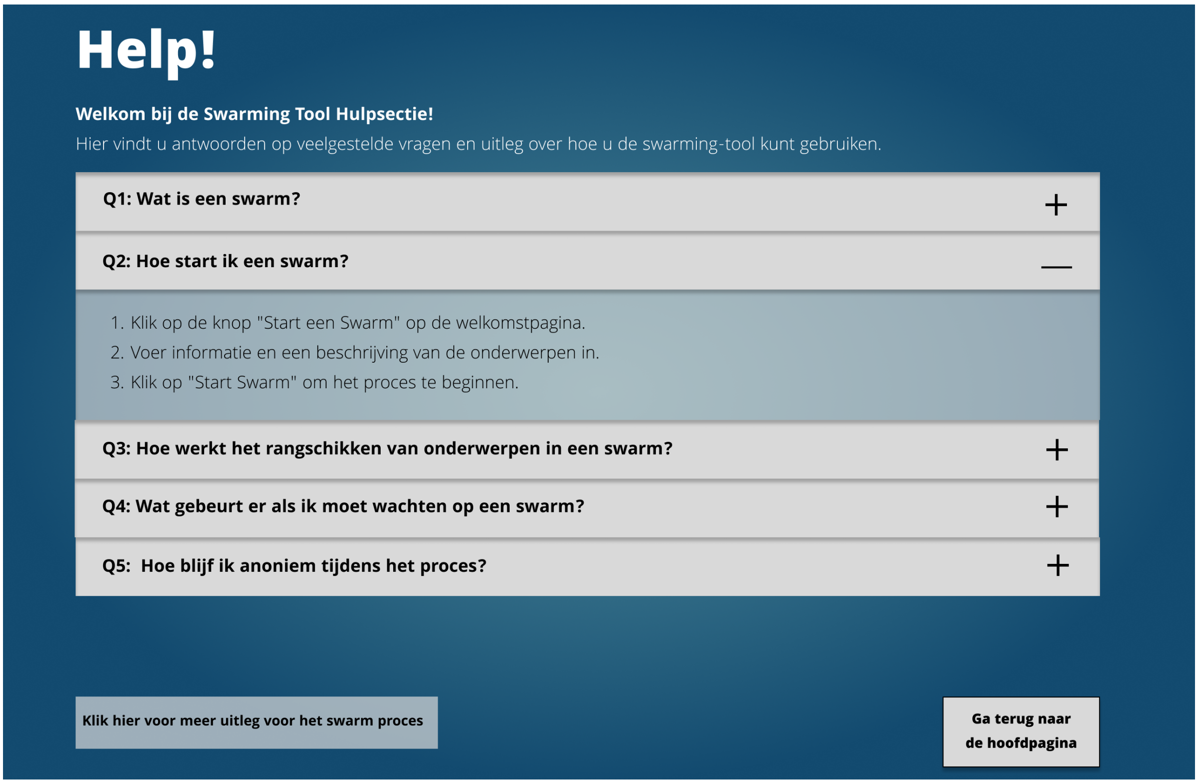

Figure C.9: Mockup Frequently Asked Questions

Figure C.10: Mockup Frequently Asked Questions

Figure C.11: Mockup Frequently Asked Questions

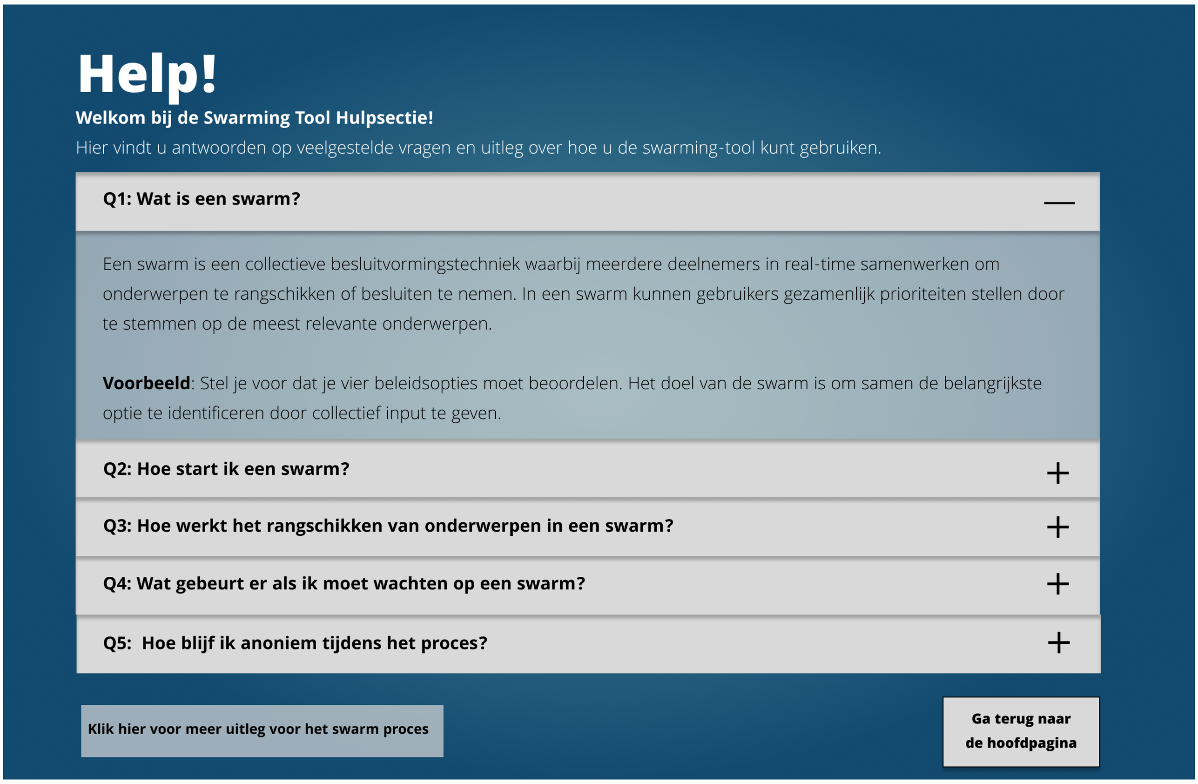

Figure C.12: Mockup Frequently Asked Questions

Figure C.13: Mockup Active Swarms

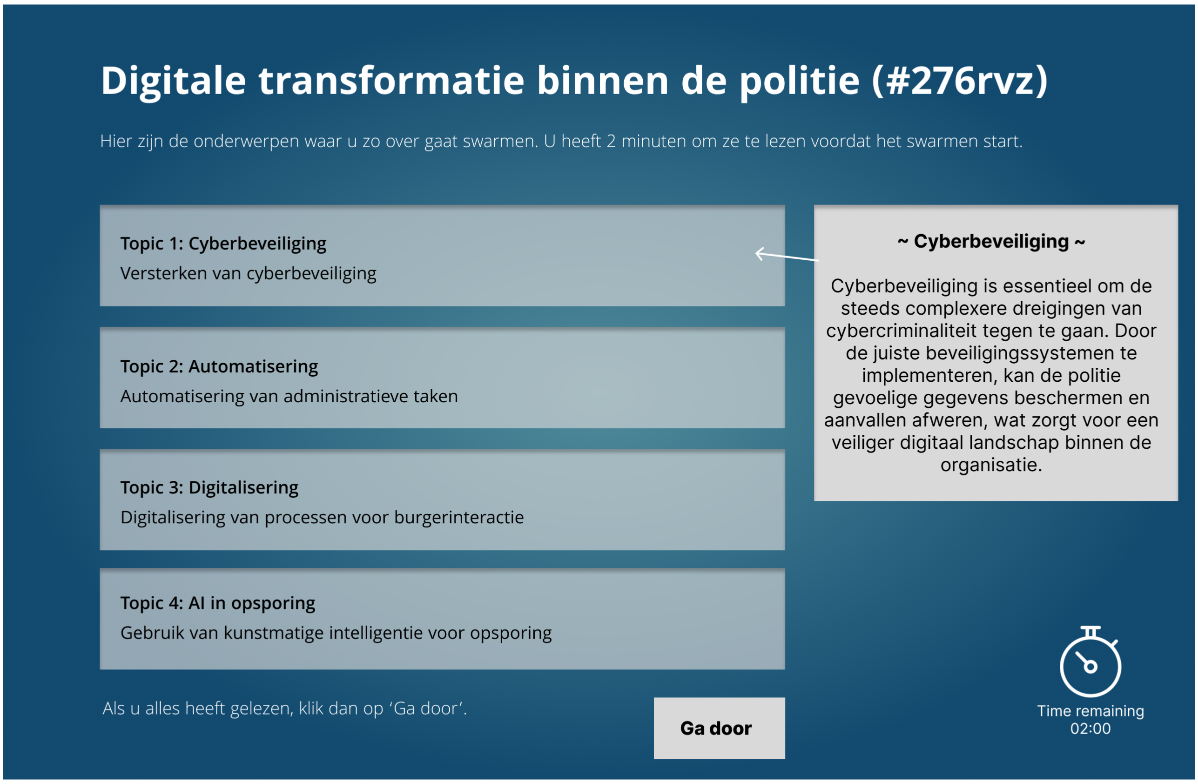

Figure C.14: Mockup Information about Active Swarms

Figure C.15: Mockup Results of Closed Swarms, seen in Active Swarms

Figure C.16: Mockup Waitin Room before Swarming Process

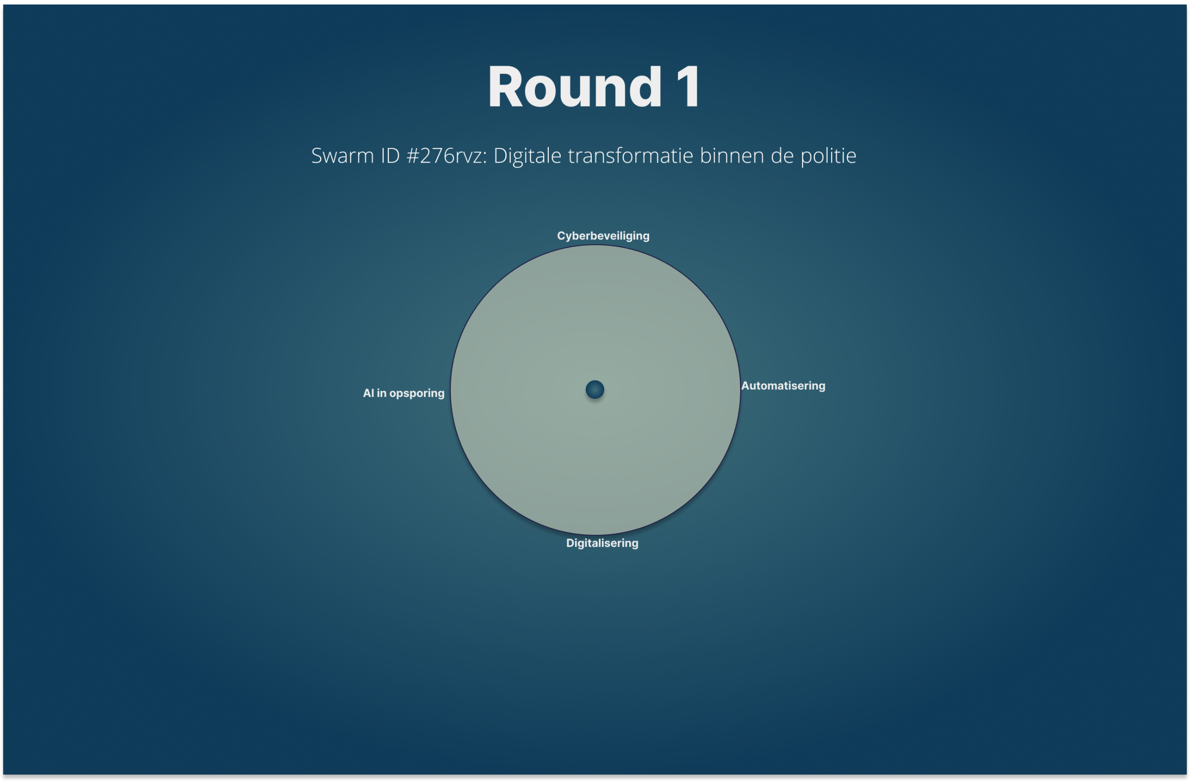

Figure C.17: Mockup Round 1 of Swarming Process

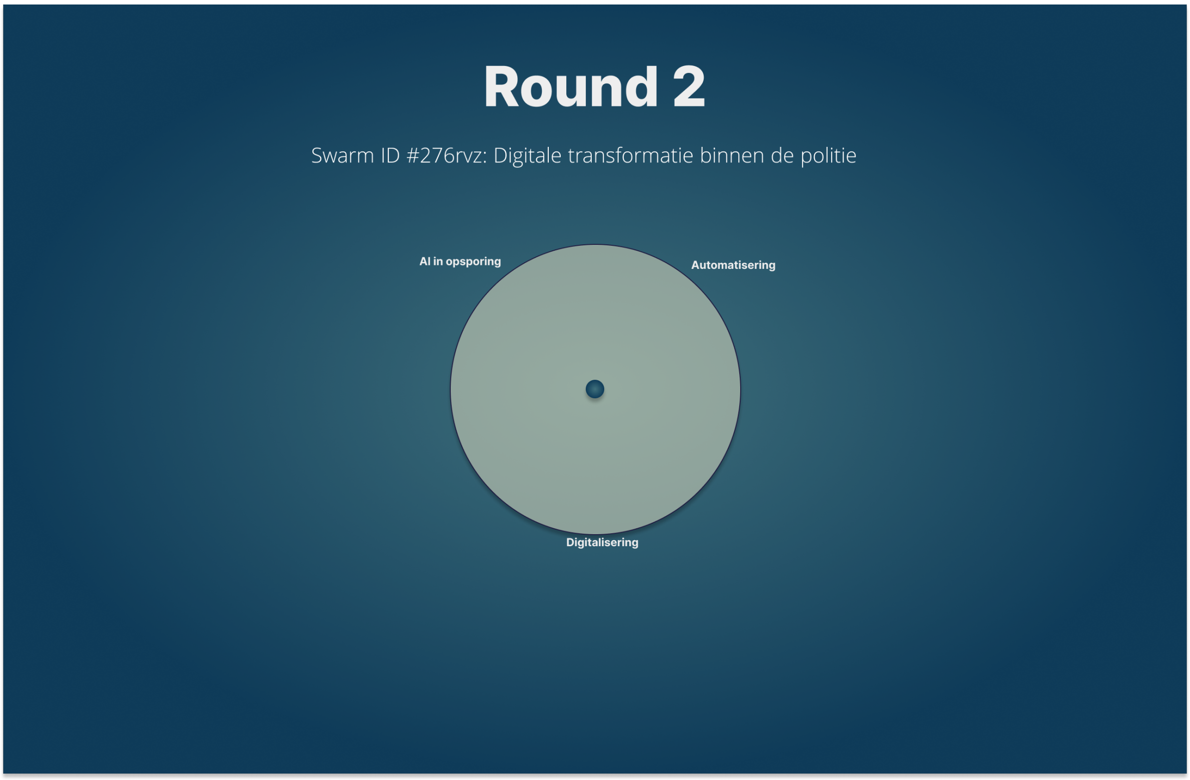

Figure C.18: Mockup Round 2 of Swarming Process

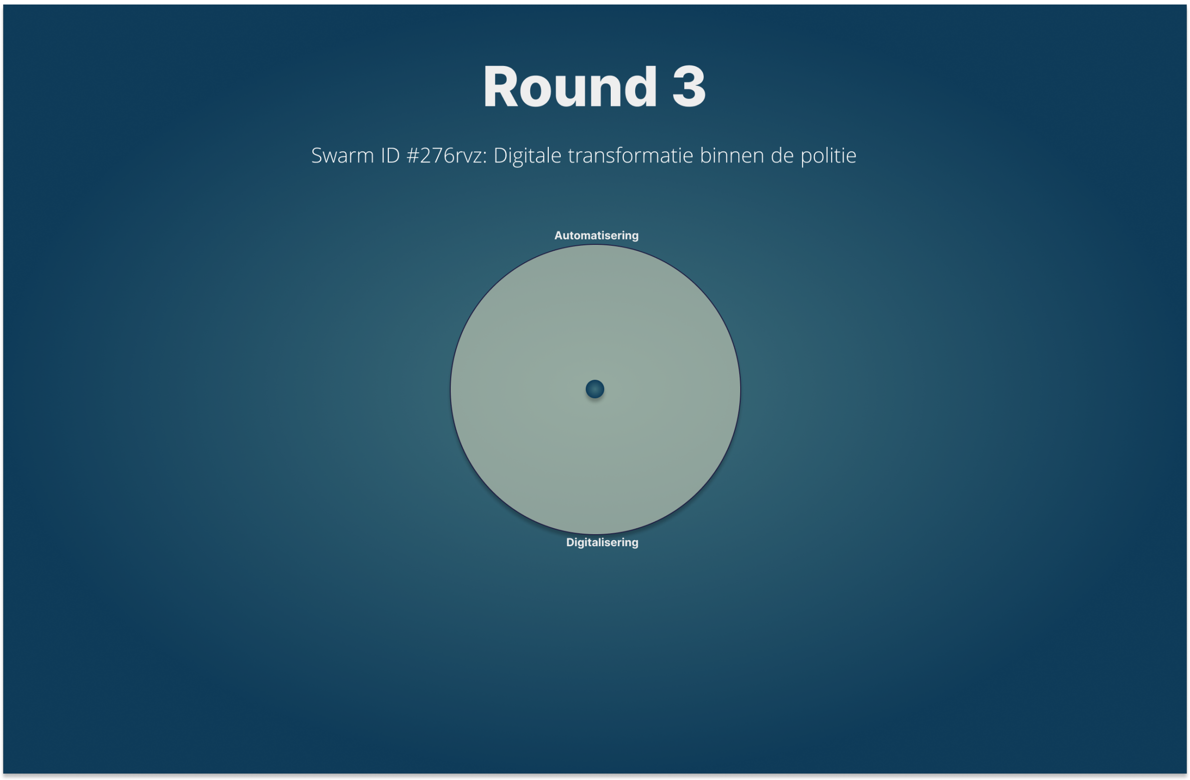

Figure C.19: Mockup Round 3 of Swarming Process

Figure C.20: Mockup Results after Swarming Session