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Developing an Integrated Model of Resilience and System Dynamics for NPP Accident

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ABSTRACT

The Fukushima Daiichi nuclear power plant (FDNPP) accident highlights the role of resilience and system dynamics in maintaining the safety of nuclear power plants (NPP). A brief literature review is conducted regarding the FDNPP accident, and an integrated model of resilience and system dynamics (IMRSD) for an NPP accident is proposed. This IMRSD is developed based on four key elements of resilience: anticipating, monitoring, responding, and learning. These elements are influenced by thirteen factors. The identified factors in the proposed model are requisite imagination regarding expected initiating event, the organizational safety culture, the proper human resource with adequate training, the requisite interpretation regarding the progress of the event, the monitoring procedures during the accident, the proper support from the human resources, the proper system to notice the developments of the accident, the adequate resources, the responding procedures, the availability of flexibility of responses, the trained personnel for emergency responses, experiences from the past events and responses, proper modeling of accident and analyzing natural hazard. Responding is found as the most vital element for effective resilience in the event of an NPP accident. Decision-makers of operating management at an NPP can consider the identified factors and how they interact with various elements to ensure the safety of NPPs.

Keywords

FDNPP Accident, IMRSD, Resilience, Severe Accident, System Dynamics.

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1. Introduction

When a nuclear power plant (NPP) experiences a severe accident, radioactive material is released, causing significant core degradation (IAEA, 2008). The earthquake and the ensuing tsunami caused the catastrophic accident at the Fukushima Daiichi nuclear power plant (FDNPP). The FDNPP accident revealed multifaceted issues related to ensuring the safety of complex socio-technical systems (Yoshizawa et al., 2016). The research on the lessons of the FDNPP accident is still ongoing from different perspectives and views. To ensure safety during an NPP accident, the resilience and system dynamics (Williams, 2002; Hollnagel and Fujita, 2013) approaches can be used.

A computer simulation modelling technique called system dynamics is used to frame, comprehend, and discuss complex problems in a complex system (Radzicki and Taylor, 1997; Azar, 2012). A qualitative and quantitative tool for developing inter-relations, such as cause-effect relations, non-linear behaviour, and dynamic changes for a complex project, is system dynamics, which includes causal loop and feedback loop diagrams (Williams, 2002). While feedback loops are closed chains of cause-effect links that can generate additional actions, casual loops in a system dynamics model illustrate the relationships between various causes of a system (Wang et al., 2005; Hossen et al., 2016). The complexity of system dynamics must be handled properly to ensure the safety of an NPP during accident conditions (Kamanja and Jonghyun, 2014).

Resilience systems require four key elements: anticipating developments, threats, and opportunities; responding swiftly and efficiently to both expected and unexpected circumstances; monitoring system performance and critical developments; and learning from past experiences, both successful and unsuccessful (Hollnagel and Fujita, 2013; Hollnagel et al., 2010). These four elements interact with one another rather than existing independently of each other. Through study and practice, one can enhance the ability to anticipate and respond (Yoshizawa et al., 2016). Examining the interaction between these four elements and other factors that boost resilience in the event of an NPP operation and accident is helpful.

A brief literature review on the FDNPP accident from the perspectives of resilience and the system dynamics approach is appropriate. The development of an integrated model by applying the approach of resilience and system dynamics during NPP operation and accident conditions is useful to ensure the safety. The main objectives of this study are to analyse the FDNPP accident from the perspectives of resilience and system dynamics approaches, and to develop an integrated model using these approaches during an NPP accident qualitatively.

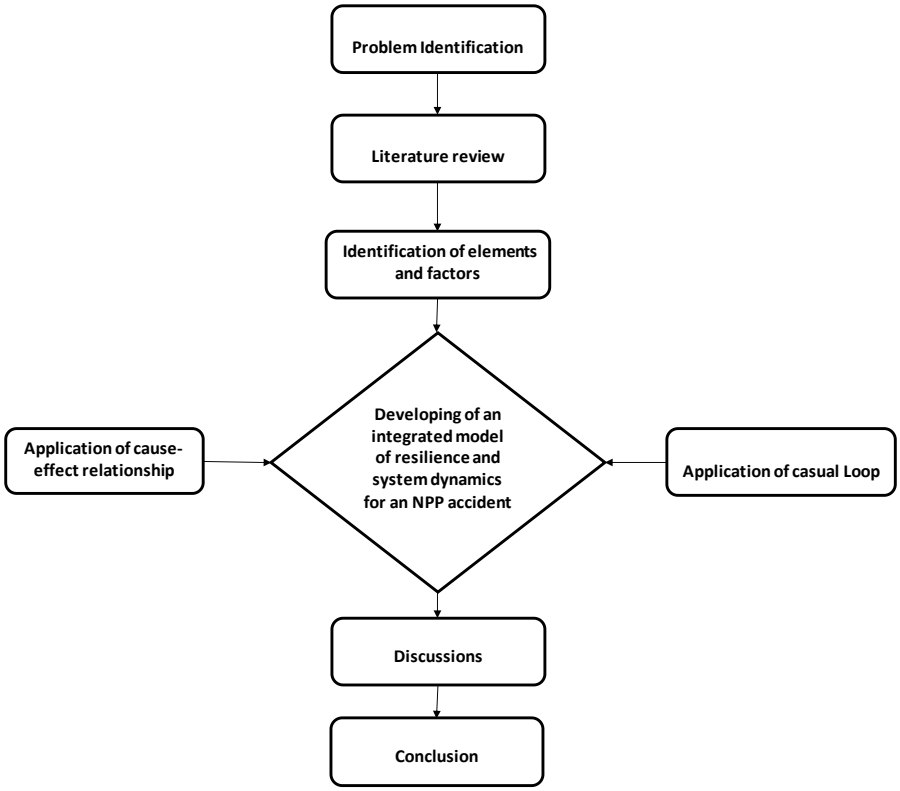

Figure 1. Research methodology

The research framework of this study is shown in Figure 1. As shown in Figure 1, the research problem is identified first, which is the investigation of the resilience and system dynamics during NPP operation and accident conditions. Secondly, a brief literature review of the FDNPP accident is provided from the perspective of resilience and system dynamics approaches. Thirdly, elements and factors affecting the resilience and system dynamics are identified. Fourthly, an integrated model by applying the approach of resilience and system dynamics during NPP operation and accident conditions is developed using cause-effect relationships and causal loop qualitatively. Finally, the study concluded by discussing the importance of the developed model to ensure the safety of NPP and signalling future research.

2. Literature review

The FDNPP site was designed based on the tsunami during Chile's earthquake in 1960, and the tsunami height was considered as 3.122 m above the Onahama Port (OP) level according to the 1966 approval for the establishment of FDNPP. Tsunami height for the FDNPP site was reviewed in 2002 and 2009 as 5.7 m and 6.1 m above the OP level, respectively, and measures were taken to raise the pump elevation and make buildings watertight (TEPCO, 2012; IAEA, 2015).

The FDNPP site had six boiling water reactors. The devastating earthquake occurred on March 11, 2011, at 14:46, with a magnitude of 9.0 (JMA, 2013). Units 1, 2, and 3 of the FDNPP were operational, while units 4, 5, and 6 were shut down. With a range of intense pulses and aftershocks, the earthquake lasted for over two minutes (IAEA, 2015). All operating reactors were automatically shut down, and the basic safety function to control the reactivity was sustained just after the earthquake. The earthquake caused the FDNPP to lose all of its off-site electric power supply, and emergency diesel generators were activated to provide power and ensure reactor safety (TEPCO, 2012; IAEA, 2015).

Subsequently, a massive tsunami wave arrived at the FDNPP site. The design-based tsunami height at the FDNPP site failed due to tsunami-induced flooding, which was nearly 11.5 to 15.5 meters above the OP level. In addition to damaging the emergency diesel generators, which resulted in the loss of on-site AC power, the tsunami-induced flooding damaged the cooling seawater pumps and motors, causing the ultimate heat sink to fail, and it flooded the on-site DC batteries and power panels, resulting in a loss of DC power in FDNPP (TEPCO, 2012). Operating EDGs were shut down, and numerous power panels were flooded. As a result, FDNPP units 1, 2, 3, 4, and 5 lost the AC power and these units experienced a station black out (SBO) scenario except unit 6, with its one remaining air cooled EDG supplied emergency AC power (IAEA, 2015). All AC-powered cooling functions were lost, and flooding of the cooling seawater pumps rendered the reactor unable to transfer decay heat to seawater. Core cooling functions, which were designed to operate without an AC power source, were sequentially shut down at FDNPP units 1, 2, and 3 due to the DC power outage (TEPCO, 2012).

In FDNPP, the extended SBO events lasted longer than nine days in units 1 and 2, and fourteen days in units 3 and 4. Reactors in units 1, 2, and 3 suffered damage as a result of the fuel overheating and melting because NPPs were unable to manage the extended power outages and plant heat removal. The radioactive material contained in the primary containment vessels was released into the environment after the reactor pressure vessels in those units were damaged, causing radioactive material to leak from the reactors. This resulted in radiological contamination of the surrounding environment and exposure to radiological hazards for on-site workers and local residents (IAEA, 2015).

The earthquake and the following tsunami caused the loss of AC and DC power, with multiple failures of safety systems, and a severe accident occurred in all three operating reactors in FDNPP (IAEA, 2015; Mizokami and Kumagai 2015; Kim et al., 2016). The cascade of engineering and regulatory failures can be considered as the reason of the FDNPP accident

(Synolakis and Kânoğlu, 2015). The Fukushima Daiichi accident was a result of a combination of earthquake, tsunami, and human factors, such as inadequate plant design, failure of backup systems, and insufficient safety measures.

The resilience engineering applications can be related to industrial systems, focusing on the effects of socio-technical factors, multi-disaster situations, design optimisation, and restoration strategies (Pawar et al., 2021). Resilience engineering involves multifactorial, multilevel and multidimensional aspects for successful outcomes for a complex system (Pillay, 2017). Critical infrastructure systems can be considered as resilient if it has the ability to imagine, protect and resist disruptions, absorb adverse effects, adapt to new conditions and changes and recover from disruptions (Mottahedi et al., 2021). The modelling of the effect of extreme events on multiple interdependent critical infrastructure systems is useful for improving their resilience (Wang et al., 2024). Resilience is a distinguishing aspect of a socio-technical system (Hollnagel and Fujita, 2013). A system's resilience is defined as its capacity to withstand a disruptive event, adjust to mitigate possible repercussions, and recover (Adjetey-Bahun et al., 2016). The ability of hardware, software, and organizational systems to adapt to changing circumstances, lessen the likelihood and severity of failures or losses, and react appropriately after the fact is known as system resilience (Jackson, 2007). Resilience is a characteristic that results from the interactions between the hardware, software, and people that comprise the system (Cilliers, 1998). The capacity of a system to bounce back from both anticipated and unforeseen disruptive events is known as resilience (Abimbola, Khan, 2019).

Resilience engineering is a relatively new approach to safety management in NPPs, which can deal with complexity under pressure or disturbance to succeed (Kim et al., 2018). A resilience engineering approach can be applied in design, operation, and maintenance in the response and recovery of accidents for high-impact low-probability events to ensure nuclear safety (Yan et al., 2023). As demonstrated by the nuclear accidents at Three Mile Island, Chernobyl, and Fukushima, NPP is a complex system where disaster risk is real and requires resilience to both internal and external challenges (Hollnagel, 2014). Thus, the resilience of NPPs can be referred to as their capacity to endure and bounce back from a variety of events, such as natural disasters, technological malfunctions, and human error, by maintaining safety and lowering risks to the environment or public health.

System dynamics is capable of capturing the reciprocal and temporal causal relationships in a complex system (Fang et al., 2018). A conceptual model of system dynamics is capable of managing nuclear safety in an operational organisation of an NPP on the basis of the human,

technology, organisation, and environment framework (Acuña et al., 2023). A system of systems management framework can be applied for the emergency recovery of the Fukushima Daiichi nuclear disaster (Gunawan et al., 2017). The dynamic response to possible emergencies in a NPP was analysed on the basis of the evolutionary change of an emergency plan in light of the organisational learning, innovation and risk communication (Quadros et al., 2022). The application of a combined approach of resilience and system dynamics during NPP operation and accident conditions can be valuable for ensuring safety.

3. Model development using resilience and system dynamics approach for an NPP accident

Vensim computer software tool (Ventana Systems, 2007) was used to develop a qualitative integrated model using resilience and system dynamics approach for an NPP accident from the perspective of the FDNPP accident. In this study, the model was qualitatively formulated using key components of the resilience system, namely, anticipating, monitoring, responding, and learning, with other dominating factors.

Due to the occurrence of the earthquake and tsunami, the flooding led to the failure of the design basis for the Tsunami height at the FDNPP site. In addition to damaging the EDGs and cooling seawater pumps and motors, which resulted in the loss of the ultimate heat sink, the flooding also inundated the on-site DC batteries and power panels, causing a loss of DC power in the FDNPP (TEPCO, 2012). As a result, the plant lost its ability to cool. It implies that the failure of anticipating the required design basis Tsunami height, as well as the loss of all AC and DC power, caused the FDNPP accident.

Anticipating possible outcomes is essential for identifying and managing undesirable occurrences (Lundberg and Johansson, 2015). The ability to anticipate possible obstacles or systemic changes by identifying risks and opportunities early on enables better preparation and adaptation. In a resilient system, anticipating means being aware of what to expect or having the ability to foresee future opportunities, threats, and developments, such as possible disruptions or shifting operating conditions (Hollnagel and Fujita, 2013). The anticipation largely depends on requisite imagination, which is the ability to foresee future problems (Westrum, 2006). Prescription, human resource, human machine interface, training, safety culture, and previous experience can contribute to anticipating the resilient system (Kamanja and Jonghyun, 2014). Anticipating characterizes the measures that are in place before the occurrence of an initiating event in order to ensure that there is preparedness for it. The NPP

operation procedures, operator training, organizational culture, human resources, and human–system interfaces are all part of anticipating (Kim, 2018). Thus, the requisite imagination regarding the expected initiating event, the organisational safety culture, and the proper human resources with adequate training can positively affect the anticipation. The proper anticipation can positively impact the prevention of the occurrence of an NPP accident.

Due to the prolonged power outage, the Fukushima Daiichi NPPs lost most of their safety systems, including instrumentation and control systems, which made it extremely difficult to respond to the accident (Yang, 2014). Operators were unable to monitor critical plant parameters, such as the reactor's water level, temperature, and pressure, because of the loss of on-site and off-site power during the FDNPP accident. The plant status of key systems and components used for core cooling could not also be confirmed due to the loss of displays of monitoring instruments and various inoperable lamps of the main control room during the FDNPP accident (IAEA, 2015). It indicates that the failure of the monitoring of the status of important thermal-hydraulics parameters and the status of the key systems and components in FDNPP was occurred.

The monitoring in a resilient system looks for or monitors what could seriously affect the performance of the system positively or negatively (Hollnagel, 2015). Appropriate anticipation serves as a guide for monitoring, which is the surveillance of important system parameters and events. Anticipating is a prerequisite for establishing modes of monitoring in advance of signs for the onset of events (Lundberg and Johansson, 2015). The requisite interpretation is the ability to see the facts of an accident and to accept that it happened and to coordinate a process of adaptation in response to the emerging events (Lundberg and Johansson, 2015; Lundberg and Johansson 2006). For emergency response organization of a nuclear power plant, monitoring procedures, information, and support are immediate contributing factors of monitoring capability (Lee et al., 2022). Monitoring must cover the changes in the system and environment (Hollnagel and Fujita, 2013). Thus, the requisite interpretation regarding the progress of the event, the monitoring procedures during the accident, the proper support from the human resource, and the proper system to notice the developments of the accident can positively affect the monitoring. Proper monitoring and respective actions can prevent the progression of an NPP accident.

In the case of the FDNPP accident, the failure to anticipate and monitor led to a failure to respond to the control of abnormal operation and a failure to detect using control, limiting, and protection systems, as well as other surveillance features.

Because of the prolonged station blackout, operators were unable to successfully operate the safety systems during the FDNPP accident (Yang, 2014). In the FDNPP accident, plant instrumentation was lost or severely reduced, and operating the safety systems for cooling the reactor cores became extremely challenging (Pellegrini et al., 2015). During the FDNPP accident, the failure to protect the critical safety equipment at the plant from flooding has occurred (National Research Council, 2014). In the case of the FDNPP accident, the failure to anticipate and monitor resulted in the failure to respond to the control of abnormal operation and the failure to detect using control, limiting, and protection systems as well as other surveillance features.

In a resilient system, responding means knowing what to do or being able to react to opportunities, disruptions, and regular and irregular variability by either activating pre-programmed responses or changing the way things are done (Hollnagel, 2015). In order to effectively respond to a problem, there must be adequate resources together with the capability to coordinate those resources in a meaningful way to deal with the progress of the problem (Lundberg and Johansson, 2015). Knowledge and competence are prerequisites for making decisions on how to respond, but to make such decisions, learning from successes is also important (Yoshizawa et al., 2016). Anticipating is a prerequisite for establishing modes of response in advance of events, and monitoring is necessary to detect problems and remain in control of a situation (Lundberg and Johansson, 2015). The availability of necessary resources is required to respond in a resilient system (Hollnagel, 2014). For emergency response organization of a nuclear power plant, responding procedures, performance, staffing, adaptability, and tools and equipment are immediate contributing factors of responding capability (Lee et al., 2022). Thus, adequate resources, the responding procedures, the availability of flexibility of responses, and trained personnel for emergency responses can positively affect the response during an NPP accident. The proper responding and responses can prevent the occurrence of any worst situation during an NPP accident.

Evidence of massive tsunamis flooding the area in the past had not received sufficient attention, and the tsunami hazard analysis appeared to contain methodological errors in determining the maximum likely tsunami height at Fukushima Daiichi (Synolakis and Kânoğlu, 2015). Steps that could have prevented the FDNPP accident, namely, protecting emergency power supplies, including diesel generators and batteries; establishing watertight connections between emergency power supplies and key safety systems; and enhancing the protection of seawater pumps (Acton and Hibbs, 2012).

Experience-based learning, specifically the ability to draw the appropriate lessons from both successes and failures for a resilient system (Hollnagel, 2015). An accident is an exceptional source of insight into future events (Lundberg and Johansson 2006). For emergency response organisation of a nuclear power plant, training and experience dissemination are immediate contributing factors of learning capability (Lee et al., 2022). Overconfidence in anticipating what might go wrong limited the ability to monitor and respond and to learn, hence impeding the development of resilience (Hollnagel and Fujita, 2013). Thus, the experiences from the past events and responses, proper modelling of accidents and analysing natural hazards, and organisational safety culture can positively impact the learning capability of an NPP accident. The proper learning can positively impacts the safe operation of the plant during an accident. The integrated model of resilience and system dynamics (IMRSD) during NPP accident conditions is shown in Figure 2. The positive '+' sign shown in Figure 2 represents a positive effect of one factor on the incidence of another factor, contributing to effective resilience.

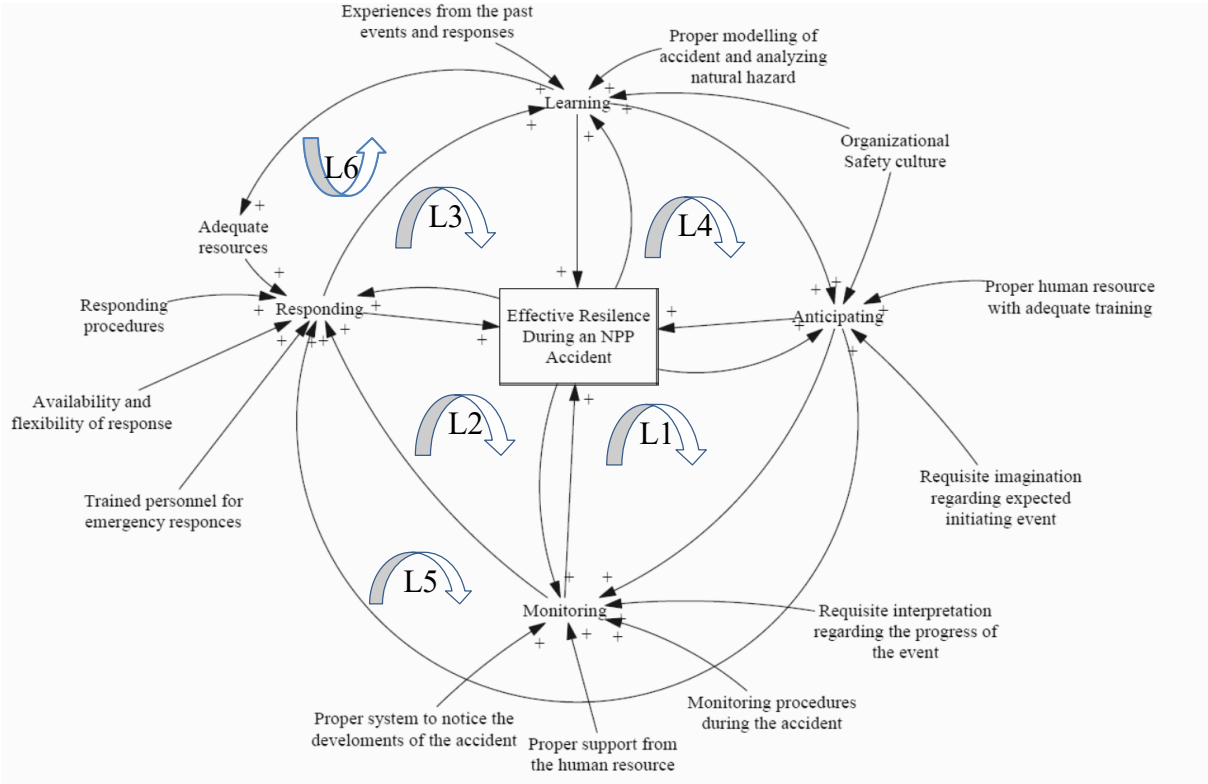

Figure 2. Integrated resilience and system dynamics model of an NPP accident

The proposed IMSRD is formulated of four elements, namely, anticipating, monitoring, responding and learning, which can positively impact the resilience during an NPP accident. The anticipation can be impacted by element learning and by three factors, namely, requisite imagination regarding the expected initiating event, the organisational safety culture, and the proper human resources with adequate training. The monitoring can be impacted by element

anticipating and by four factors, namely, the requisite interpretation regarding the progress of the event, the monitoring procedures during the accident, the proper support from the human resource, and the proper system to notice the developments of the accident. The response can be impacted by two elements, learning and anticipating, and by four factors, namely, adequate resources, the responding procedures, the availability of flexibility of responses, and trained personnel for emergency responses. The learning can be impacted by the element responding and by three factors, namely, experiences from past events and responses, proper modelling of accidents and analysing natural hazards, and organisational safety culture.

From the proposed IMRSD, it can be observed that the response is a critical element for effective resilience. The response is directly affected by the anticipation, monitoring, and learning with other factors, namely, adequate resources, the response procedures, the availability of flexibility of responses, and trained personnel for emergency responses. The factor organisational safety culture can positively impact two elements of learning and anticipating in the proposed model. The factor of adequate resources is created through learning and affects the element responding. It can be considered that responding and monitoring are more influential elements than learning and anticipating during the accident of an NPP.

The effective resilience for NPP accident conditions is comprised of four elements and thirteen factors according to the developed IMRSD. If the effective resilience occurs during an NPP accident, it will positively impact four elements and six causal loops can be directly observed in Figure 2. Anticipating has a positive impact on monitoring, which ultimately enhances the effective resilience of the system, and this in turn positively impacts the anticipating process again. A positive causal loop L1 is generated by it. Monitoring positively impacts responding, which ultimately boosts effective resilience in the system, and this, in turn, positively impacts the monitoring again. It creates a positive causal loop L2. Responding has positive impacts on learning, which ultimately boosts effective resilience positively in the system, and it will positively impact the responding again by generating a causal loop L3. Learning has a positive impact on monitoring, which ultimately boosts effective resilience in the system. This, in turn, positively impacts the system, and the system's learning is further enhanced by generating a causal loop L4. Anticipating also impacts responding, which ultimately boosts the effective resilience positively in the system, and it impacts anticipating again by generating a causal loop L5. Learning positively impacts adequate resources, which ultimately boosts the response, and it will impact the learning again, generating a causal loop

L6. Besides, by the combination of two or more loops in the model, more new loops can also be formed in the developed model.

Figure 2 illustrates the positive relationship between the factor and the element of effective resilience. However, the elements may also be adversely affected by these factors, which will ultimately have a negative impact on the model's resilience. Consequently, ineffective resilience for an NPP accident condition can occur due to the negative relationship between the factor and the element of the developed model.

4. Discussions

The developed IMRSD is a generalised qualitative model for NPP operation management and accident conditions to enhance the safety of NPP. The proposed model can increase the understanding of the dynamics of the operational safety management of an NPP. It may be possible to decrease risk during the normal operation of NPP and during the accident condition by implementing the elements and factors of the developed model.

The safety philosophy of an operating nuclear power plant (NPP) is grounded in principles of diversity, redundancy, and defence in depth (Clayton, Poore, 2015). It is recommended to consider the system resilience during the design of NPP to ensure the safety. Besides, operators and technical personnel must be trained and aware of the four elements of resilience, namely, anticipating, monitoring, responding and learning. Improving the resilience of NPPs requires a multi-faceted approach, encompassing physical, operational, digital, environmental, and human factors. Maintaining and improving resilience for NPP requires ongoing investment, technological innovation, and a robust regulatory framework. The resilience of an NPP depends on the robustness of its design, the effectiveness of its safety systems, and the response of its operators under accident conditions. System dynamics during an NPP accident are interconnected procedures that occur within the NPP and its various safety systems in response to an event.

Nuclear safety encompasses more than just preventing accidents; it involves the development of systems that can adapt and improve over time. By integrating the four elements of resilience, anticipating, monitoring, responding, and learning, into nuclear operations according to the suggested model, the nuclear industry can move towards ensuring the safe and sustainable operation of NPP in the future. The operating management of an NPP can visualise the identified factors and their interaction with elements according to the suggested model for safe operation and accident management. It is expected that the suggested model can enable

managers to enhance operational safety and to ensure more resilient and efficient plant performance.

Although the model can identify causal relationships and feedback loops within a system, it cannot provide numerical predictions of failures of factors and elements during an NPP accident. Thus, the proposed qualitative model does not provide specific numerical output and the exact required time between elements and factors during an NPP accident, which is a limitation of the developed model. Besides, the model considers only thirteen factors, but external factors beyond the control of the NPP operating organisation are not considered in the suggested model, which is another limitation.

The proposed model has not been implemented yet in any specific NPP accident. In further studies, the implementation of the suggested model to a specific NPP accident can be performed. Furthermore, the developed model can be further enriched by incorporating additional factors and adopting a quantitative approach to ensure the safe operation of NPP.

5. Conclusion

In this study, an integrated model of resilience and system dynamics during an NPP accident is proposed from the perspective of the FDNPP accident. The proposed IMRSD is formulated based on four elements and thirteen key factors to ensure the safety of NPPs. The conceptual model is developed qualitatively.

The traditional four elements — anticipating, monitoring, responding, and learning —are positively impacted by the thirteen factors according to the model. The identified factors in the proposed model are namely, requisite imagination regarding expected initiating event, the organizational safety culture, the proper human resource with adequate training, the requisite interpretation regarding the progress of the event, the monitoring procedures during the accident, the proper support from the human resource, the proper system to notice the developments of the accident, the adequate resources, the responding procedures, the availability of flexibility of responses, the trained personnel for emergency responses, experiences from the past events and responses, proper modelling of accident and analysing natural hazard. The response can be considered as the critical element for effective resilience during an NPP accident.

Combining resilience and system dynamics for an NPP accident is an innovative approach to enhancing the safety and long-term sustainability of NPPs. Decision-makers of the operating

management of an NPP can consider the identified factors and their interaction with elements in the suggested model to ensure the safety during an NPP accident.

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Improving Healthcare Service Quality: A System Dynamics Approach to Managing Visit Times and Reducing Error Rates

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ABSTRACT

This study explores the application of system dynamics modelling to enhance service quality in healthcare systems. Healthcare environments are inherently complex, requiring adaptive strategies to address challenges such as fluctuating patient demands, work pressure, reduced visit times, and error generation in physician prescriptions. Through simulation-based analysis, we evaluated the impact of various policies, including adjustments to patient arrival rates and human resource hire/quit rate. Our findings indicate that reducing patient arrival rates effectively stabilises work pressure and minimises error generation, but it may conflict with organisational accessibility goals. Increasing human resources, particularly experienced employees, emerges as a sustainable alternative, enhancing service capacity and reducing errors. A dual strategy combining an increased hire fraction of experienced employees with retention-focused policies preventing the employee quit rate yields the most promising results. This approach improves employee efficiency, reduces error probabilities, aligns visit times with standards, and boosts profitability. The study underscores the importance of balancing workforce optimization with system costs to achieve long-term improvements in service quality. Simulation-based decision-making offers healthcare administrators a robust framework for evaluating the cascading effects of policy changes. By integrating dynamic modelling into management practices, healthcare systems can achieve enhanced operational performance, improved patient satisfaction, and sustainable service quality outcomes..

Keywords

System Dynamics, Error Generation, Visit Time, Healthcare Service Quality, Patient Arrival Rate, Human Resource Efficiency.

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1. Introduction

In healthcare systems, the quality of service is a multifaceted concept that significantly impacts patient outcomes and overall system efficiency. The World Health Organisation (WHO) defines quality of care as the degree to which health services increase the likelihood of achieving desired health outcomes, emphasising the importance of effectiveness, safety, and patient-centredness in delivering healthcare services (Fatima et al., 2018). This perspective emphasises that service quality is not merely about meeting standards but also involves ensuring that services are tailored to meet the individual needs and preferences of each patient. The quality of service is a critical factor that influences patient satisfaction and overall health outcomes (Younis, 2024; Coutinho et al., 2020).

Hence, healthcare administrators must implement robust policy-making strategies that focus on optimising service delivery without compromising quality. It includes training physicians in time management while maintaining thoroughness in patient interactions, as well as continuous monitoring of service quality metrics to identify areas for improvement (Begun et al., 2011; Adekugbe, 2024; Arabov et al., 2024). Ultimately, improving service quality in healthcare systems requires a holistic approach that integrates evidence-based practices with an understanding of the unique challenges faced by healthcare providers.

The quality of service encompasses various dimensions, including the time taken for patient visits, which can significantly affect both the efficiency of care delivery and the probability of errors made by healthcare providers. The complexities surrounding these issues are increasingly recognised in contemporary healthcare research (Younis, 2024; Coutinho et al., 2020).

A systematic review highlights that service quality in healthcare is inherently multidimensional, with factors such as tangibility, responsiveness, reliability, assurance, and empathy being essential for enhancing patient satisfaction. These dimensions are crucial as they directly relate to how patients perceive their interactions with healthcare providers and the overall care they receive (Singh and Prasher, 2019).

Healthcare systems and hospitals often face challenges in accurately forecasting the time required for patient care, which can result in numerous negative effects, starting with a fundamental inability to accommodate individual patient variability (Charan et al., 2024). Due to the complexity of system dynamics models arising from interdependencies, interactions, feedback loops, and nonlinear relationships interactive simulations offer a valuable way to explore various scenarios, policies, and decisions, making it possible to gain deeper insights into the behaviour of complex systems (Ebtekar et al., 2024). System Dynamics (SD) Modeling

provides invaluable insights into understanding the dynamic complexity present in healthcare systems due to the interconnections between factors including health behaviours, environmental and socio-economic conditions, human service delivery infrastructures, medical innovations, health and social policy, disease progression and outcomes, and other health-related determinants, as these change about one another over time (Charan et al., 2024). The goal of applying SD models in healthcare is to highlight innovative approaches—such as stakeholder-engaged approaches—to simulation modelling, data analysis, and data use that enhance our understanding of the behaviour of complex systems, predict responses to policy interventions, and translate findings and discussions into actionable insights (Zabell et al., 2021).

SD models are mathematical representations based on causal feedback loops, with simulation at the core of their methodology. When the structure of a system is accurately modelled, the simulation results can reliably forecast its behaviour. Vensim is a commonly used tool for performing these simulations. The concept of system dynamics was introduced in the mid-1950s by Jay Forrester, a professor at the Massachusetts Institute of Technology, as an innovative approach to improving organizational performance. Researchers argue that the human mind struggles to understand the behaviour of social systems through simple linear thinking. Therefore, analyzing such systems requires the use of nonlinear, multi-loop feedback models. Through dynamic simulation, experts were able to uncover the underlying causes of operational issues at General Electric (Madady Nia et al., 2024).

SD models offer the potential to improve healthcare systems by enabling real-time adjustments to physician schedules and workloads, thereby enhancing efficiency and patient satisfaction. By using these models, healthcare providers can better align their clinical schedules with accurate time estimates for different diagnoses and procedures, leading to more efficient and patient-centred care (Musa et al., 2024). SD modelling involves the continual updating and monitoring of clinical prediction models. This method enables models to adapt over time as new data becomes available, ensuring their predictions remain accurate and relevant in the context of evolving health system dynamics. These models integrate information from multiple sources, such as patient history and ongoing health status, to provide more comprehensive and accurate predictions regarding physician visit times (Jenkins et al., 2021). Accurate simulation of health service challenges relies on several best practices designed to ensure realistic and effective modelling of complex healthcare environments. One critical approach involves the integration of simulation activities co-designed and delivered by a team of simulation experts

in partnership with health service units, specifically targeting quality and safety goals (Rose et al., 2018).

The integration of dynamic systems into healthcare management facilitates a more comprehensive understanding of the interdependencies within healtcare clinical environments. An effectively designed simulation scenario offers a realistic and immersive experience, fostering critical thinking, teamwork, and problem-solving among participants. As highlighted by Wolstenholme (1993), this approach enables decision-makers to visualise how various factors, such as staffing levels, patient inflow, and appointment durations, interact over time, leading to more informed policy-making strategies aimed at improving service delivery. SD modelling offers valuable tools for understanding and addressing these complexities. By simulating various scenarios within healthcare systems, stakeholders can identify how changes in scheduling practices or resource allocation impact visit times and overall service quality. For example, studies have shown that implementing dynamic appointment scheduling can significantly improve access times and reduce patient wait times, ultimately enhancing service quality. Such approaches allow for flexibility in managing fluctuating patient loads while ensuring that healthcare providers can maintain in adequate interaction times with patients (Ala et al., 2019).

In Primary Health Care (PHC), maintaining sufficient visit times is vital for ensuring patient safety and satisfaction. Key variables in SD models of physician visit times typically include patient arrival times, consultation durations, and scheduling strategies (Kyarisiima et al., 2024). Extending visit times can lead to increased patient waiting times and longer working hours for physicians. The discrepancies between expected and actual service times can create a "death spiral" effect within healthcare settings. This phenomenon occurs when reduced interaction times lead to rushed assessments, resulting in misdiagnoses and compromised patient safety. The implications of this are significant; as service quality declines, patient trust erodes, further exacerbating the challenges faced by healthcare providers (Alizadeh-Zoeram et al., 2019).

Simulation can be a practical tool for quantifying these impacts and guiding decision-making. The use of simulation not only enhances medical and nursing education by improving knowledge, skills, and behaviour but also supports patient safety and risk management. It helps healthcare professionals identify and correct potential sources of error, thereby improving safety and clinical outcomes (Makhni and Hennekes, 2023). Recent studies have highlighted the complexities associated with managing visit times, particularly in dynamic healthcare

environments where patient demand and provider availability fluctuate (Joseph et al., 2024; Alnajjar, 2024).

Experimental studies have sought to determine how varying the visit time of outpatient clinical encounters affects the quality of healthcare. These studies manipulate visit times to assess their impact on several dimensions of care quality, including effectiveness, efficiency, timeliness, safety, equity, patient-centeredness, and patient satisfaction (Araujo et al., 2020; Younquoi et al., 2023; Farooqi et al., 2024). A systematic review by Hajebrahimi et al. (2019) emphasizes that insufficient consultation time not only affects the accuracy of diagnoses but also diminishes patient satisfaction and trust in healthcare services. This finding is typically recommended for outpatient consultations. When actual visit times fall below this standard, it can create a cycle of rushed appointments and heightened risks of errors, leading to a phenomenon described as a "death spiral" in service quality. Specifically, the study emphasises that when physicians adhere to standard visit times, there is a notable reduction in the potential for errors during consultations. Conversely, when actual visit times fall short of the standards, it can lead to increased error rates and a decline in service quality (Hajebrahimi et al., 2019). A study by Swathi and Barkur (2023) underscores the importance of integrating patient-centred approaches into service delivery models, which can help mitigate the complexities associated with time management in clinical settings. By focusing on the nuances of patient-provider interactions and fostering an environment where adequate time is allocated for each consultation, healthcare organisations can enhance both service quality and patient outcomes. Another study published in BMC Primary Care examined the impact of shorter (15-minute) primary care appointments compared to longer (30-minute) appointments on healthcare utilisation within seven days following the initial appointment. The findings suggested that limiting the time spent with patients when evaluating acute health needs could adversely affect the quality of care and increase subsequent healthcare utilisation, such as ambulatory reassessment, emergency department care, and hospitalisation.

Additionally, an observational study examined the temporal regularity of primary care visits and their impact on patient outcomes. This study used Medicare claims data from 378,862 fee-for-service Medicare beneficiaries who received primary care at federally qualified health centres over four years. The results indicated that more regular primary care visits were associated with better patient outcomes, highlighting the importance of consistent and proactive care.

In summary, understanding the intricacies of service quality in healthcare necessitates a SD approach. Such an approach not only highlights existing problems but also facilitates the development of targeted interventions that enhance both patient care and operational efficiency. This introduction provides an overview of the importance of visit time in healthcare service quality while referencing recent studies that validate these claims within the context of SD modelling.

This study aims to utilise the SD approach to effectively manage various variables, including human resources, patient arrival rate, work pressure, error generation, and visit time, in order to combat the decline in service quality and ultimately enhance the quality of medical services. This study introduces a novel approach by examining the interconnections between key variables in a healthcare service system, analysing how work pressure, visit time, error rates, and workforce hire and quit rates interact dynamically. By modelling these relationships, the research predicts system behaviour over time and highlights the reinforcing feedback loops that sustain inefficiencies and quality erosion. The study demonstrates how increased work pressure reduces visit time, leading to higher error rates, increased rework, and a continuous rise in patient quantity. To address this, managers may adjust human resource levels, considering the balance between rookie and experienced employees. While hiring increases efficiency over time, a high workforce quit rate can negatively impact overall system performance, worsening the problem.

Furthermore, this research evaluates various policy interventions, including workforce hiring and reduction strategies, as well as patient intake management, to mitigate work pressure and enhance service quality. By simulating these dynamics, the study offers valuable insights into the long-term effects of policy decisions, enabling managers to design strategies that enhance efficiency, control costs, and maintain service quality in healthcare systems.

The study is structured as follows: It begins with the development of a conceptual model based on a dynamic hypothesis and a causal loop diagram. Next, the relationships among variables are represented through a stock-and-flow diagram. Finally, the completed model is applied in a healthcare clinic, where the impact of various human resources policies and employees' hiring and exit rates on service quality is examined. The study identifies and recommends effective policies to overcome the decline in quality.

2. Methodology

In this research, a system is considered based on the Alizadeh-Zoeram et al (2019) model. To

gain a clear understanding of the developed model, it is applied in a hospital clinic setting with their data. The analysis examines explicitlythe physicians working during one of the clinic's shifts. The primary concern identified in this clinic relates to the behaviour of visit time per service. According to the clinic's standards, the standard duration for each patient visit is approximately 18 minutes. However, the actual time per service falls short of this standard due to work pressure. While this discrepancy might appear minor, the SD approach aims to demonstrate that this seemingly simple issue involves significant complexities. So, the system experiences a "death spiral," where the time allocated for each service an essential indicator of service quality—continually decreases. Addressing this problem through policy-making introduces additional layers of complexity.

To study the system dynamically, the following four main steps are implemented using the Vensim DSS V6.4 software environment.

3. Modelling problem: Dynamic hypothesis and causal loop diagram

The dynamic hypothesis outlines the system's framework and explains its evolving behaviour over time (Madady Nia et al., 2024). In this study, the dynamic hypothesis related to service quality, with a focus on patient visit time, is finalised after incorporating insights from the literature and expert feedback. The hypothesis is as follows:

In a healthcare service system, when work pressure increases, the visit time per service for each person falls below the desired level. It triggers two primary responses:

Employees (physicians) attempt to address the situation by reducing the visit time spent per service below the standard level. This adjustment increases the rate of task completion and increases the patient's quit rate. However, shortening service time (patient visit time) increases the likelihood of error generation, leading to more rework. This rework amplifies the rework rate and further increases work pressure (a reinforcing loop).

The reduction in visit time compared to the standard time, along with the rise in errors (such as prescription mistakes), signals a decline in system quality. To address this issue, known as the 'death spiral of quality,' managers may decide to adjust their human resources and productivity to address the problem, thereby attempting to mitigate work pressure and quality erosion.

Therefore, managers may increase hiring rates to match the desired level of human resources, thereby improving human resource efficiency. If the workforce is categorised into two groups—rookies and experienced employees—with differing input/output rates in efficiency, over time,

rookies gain experience, and their efficiency improves. This dynamic increases the total efficiency, reducing error generation and, subsequently, work pressure.

Conversely, hiring new employees (rookies) while experienced employees leave the system can lower overall efficiency. This reduction increases the probability of errors, leads to increased rework, and expands the error backlog, thereby exacerbating work pressure. On the other hand, hiring experienced and rookie employees imposes costs on the system, and consequently, profit decreases.

The outlined relationships in the dynamic hypothesis are represented in detail through a causal loop diagram (Figure 1). Arrows illustrate the relationships between variables, with positive (+) or negative (–) signs assigned to indicate polarity. A positive relationship means that the cause and effect move in the same direction, while a negative relationship indicates the opposite.

As shown in the figure below, two reinforcing loops exist in the causal loop diagram. The larger loop, labelled as the **reinforcing loop W/E,** demonstrates that as the number of patients increases, work pressure rises, leading to shorter visit times. It, in turn, results in an increase in prescription errors, ultimately causing a rise in the rework due to patients returning for corrections, which further increases the number of patients. The smaller loop, labelled as **reinforcing loop P/E**, illustrates that when the number of patients increases, their outflow also grows, which again contributes to higher error generation and rework.

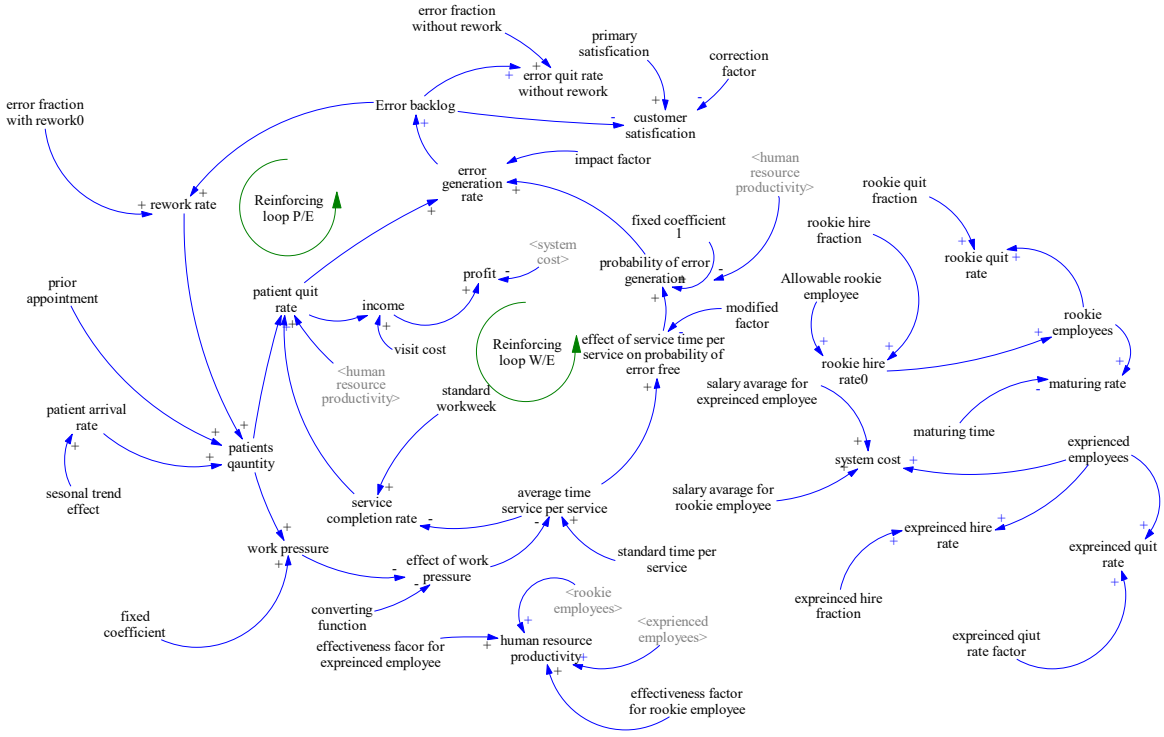

Figure 1. Causal loop diagram

4. Stock and flow diagram

The stock/flow diagram is divided into two main parts: the human resources subsystem and the patient quantity and error generation subsystem, shown in Figure 2. Also, detail is described as follows:

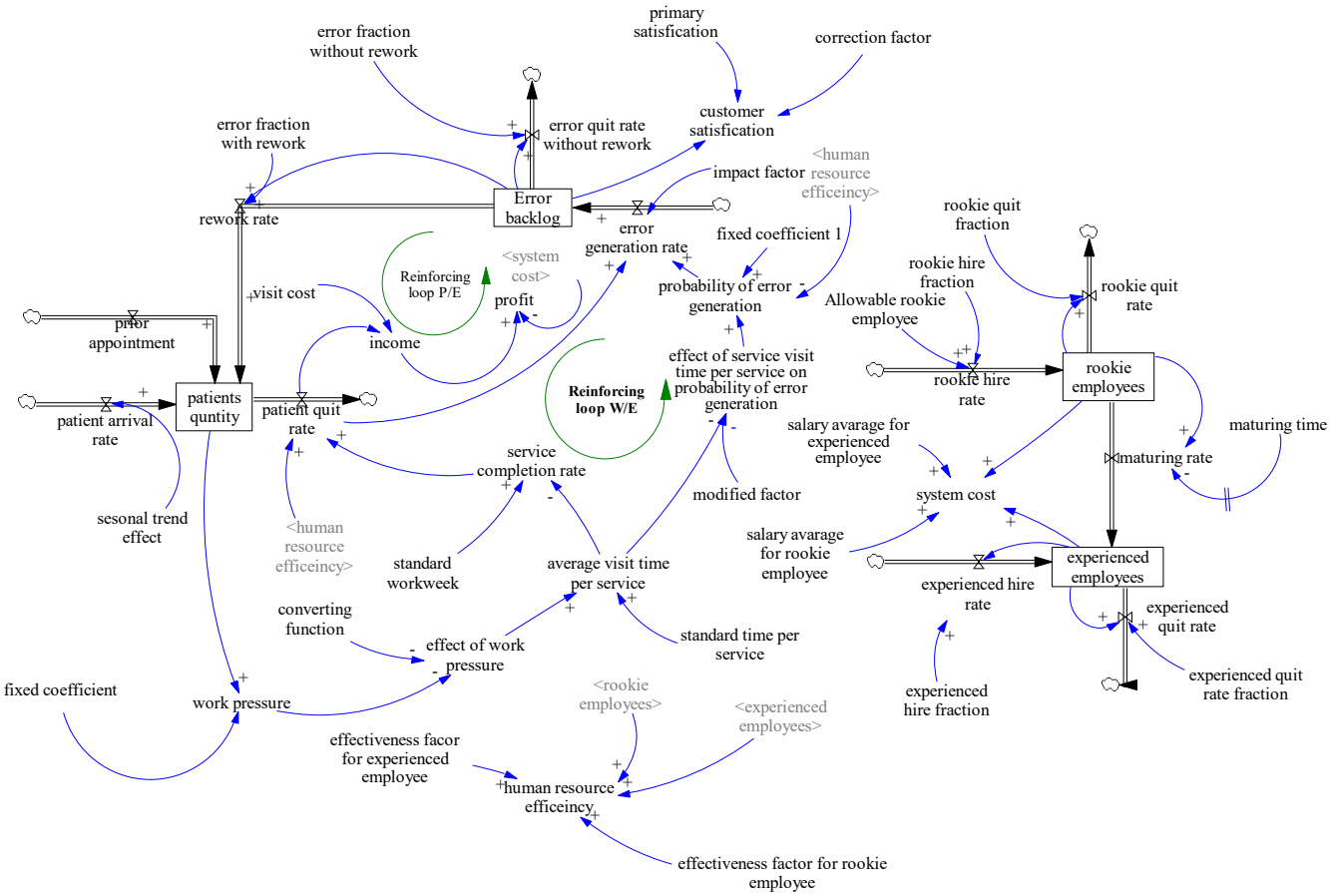

Figure 2. Stock and flow diagram

4.1.1. Human resources subsystem

The first part focuses on the human resources dynamics, as shown on the right side of Figure 2. The workforce is categorized into two groups: rookie employees and experienced employees. The total number of employees is the sum of these two groups. Over time, as rookies gain experience, they are converted into the experienced category, increasing the number of experienced employees. Both groups can quit the system, and new employees must be hired. So, the hire rate can balance rookie and experienced level variables. Efficiency levels differ between rookies and experienced employees due to their varying expertise. Consequently, an effectiveness factor is assigned to each group, and the human resource efficiency variable is determined by multiplying the number of employees by their respective efficiency rates and other related variables.

In this subsystem:

- **Rookie employees' rates** are modelled as a stock variable. Their level changes based on input (hiring) and output (quitting) rates, which employ integral operators.
- The **number of rookies** increases according to the hiring rate and decreases due to their quitting rate. After a specific period (referred to as the **maturing time**), rookies are converted into the experienced employee category. The maturing rate acts as an output for rookies and an input for experienced employees.

4.1.2. Patient quantity and error generation subsystem:

The second part of the diagram, presented on the left side of Figure 2, examines aspects related to patient quantity and error generation. This subsystem highlights the key dynamics that impact service delivery and quality. A critical factor in this model is the reduction in visit time compared to standard expectations, which, along with errors in task execution, contributes to an accumulation of errors. Rework is required to address these errors; however, not all errors are detectable or necessitate correction. The patient entry to the clinic is defined as a stock variable, with the rework rate serving as the input, patient arrival rate and prior appointment as inputs, and patient quit rate as the output. The patient quit rate is also added back to the error backlog by error generation. Error generation is introduced as an indicator of service quality erosion.

The connection between patient quantity and error generation with Human Resources subsystems occurs with the human resource efficiency variable. Because this variable is influenced by the number of rookies and experienced employees and can impact the probability of error generation. Work pressure is calculated as the ratio of patient quantity, which can influence the average visit time variable by the effect of the work pressure variable. Typically, reducing the visit time per service increases the error generation variable. Ultimately, the visit time variable can impact the probability of error generation through the effect of visit time on the service variable. The service completion rate, which can be influenced by the average visit time per service and standard workweek, can impact the patient's quit rate.

5. Validation test

Once the model is developed, its structure is validated based on expert feedback. The model's behaviour is further assessed using a sensitivity analysis, which examines how the model responds to changes in parameter values. This test is typically performed by analysing the model's sensitivity to variations in parameters. By adjusting these parameters, the consistency and logic of the model's behaviour are scrutinised and confirmed.

To validate the model, the sensitivity of work pressure to the patient arrival rate is analysed, as shown in Figure 3. In the left diagram, the model's behaviour is compared under two scenarios: increasing the patient arrival rate by 1.1 (test 1) and reducing it to 0.9 (test 2). As anticipated, work pressure and error backlog variables increase with the higher patient arrival rate and lower with the reduced patient arrival rate. Additionally, the average visit time per service variable increases with higher input (patient arrival rate) and decreases with lower one.

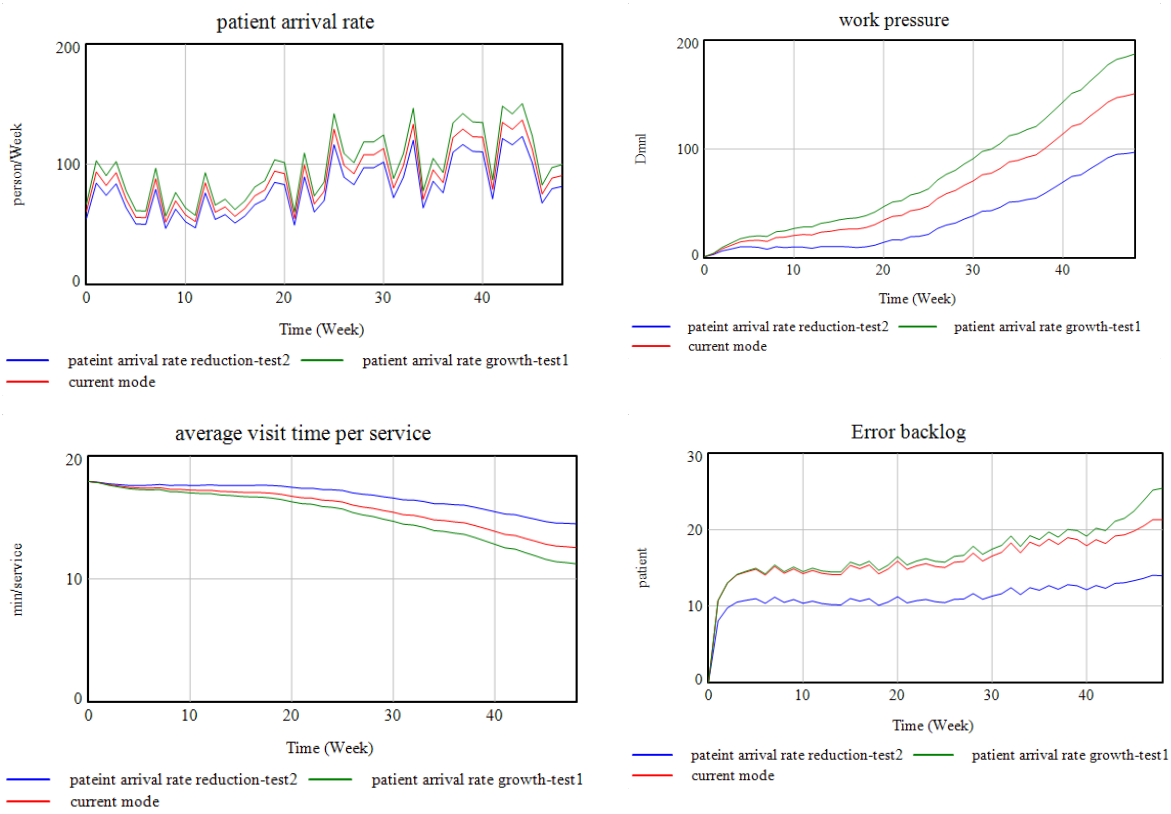

Figure 3. Validation test (patient arrival rate)

In Figure 4, the sensitivity of work pressure to human resource service is evaluated. Results are compared by reducing the rookie hire fraction to 0.5 (test-1), increasing it to 0.5 (test-1), and then increasing it by 0.9 (test-2) against the original value (0.8). As observed, increasing the fraction of rookie hires leads to a higher rookie hire rate, which in turn reduces work pressure and error backlog and increases the average visit time per service. Conversely, decreasing the rookie hire fraction leads to an increase in work pressure and error backlog, as well as a reduction in the average visit service variable.

Therefore, it can be demonstrated that our model is reliable and can be applied to subsequent analyses.

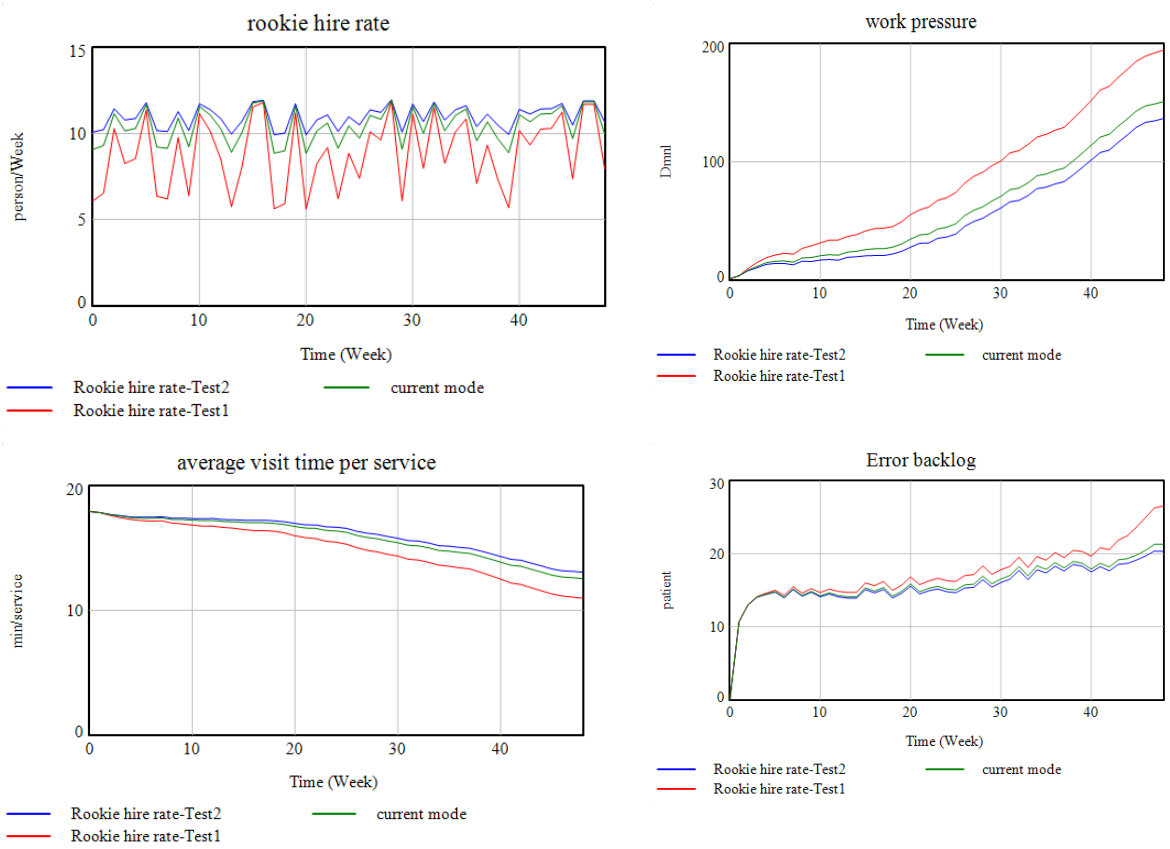

Figure 4. Validation test (rookie hire rate)

The next step after validation is simulation and model behaviour analysis based on different policies on a real-world case study described in the paper of Alizadeh-Zoeram et al., (2019), which are provided in the following sections.

6. Simulation and policy evaluation

The subsequent sections provide a detailed discussion of the three simulation models and their influence on the system behaviour.

6.1. No change in exogenous variables (Base mode)

When the primary exogenous variables such as demand (patient arrival rate) and human resources (rookie & experienced employees) are considered, external constraints like macro-level policies, cost limitations, or financial considerations may prevent any adjustments. Consequently, these variables are assumed to be the current operational state variables.

Simulation results for base mode, depicted in Figure-5.

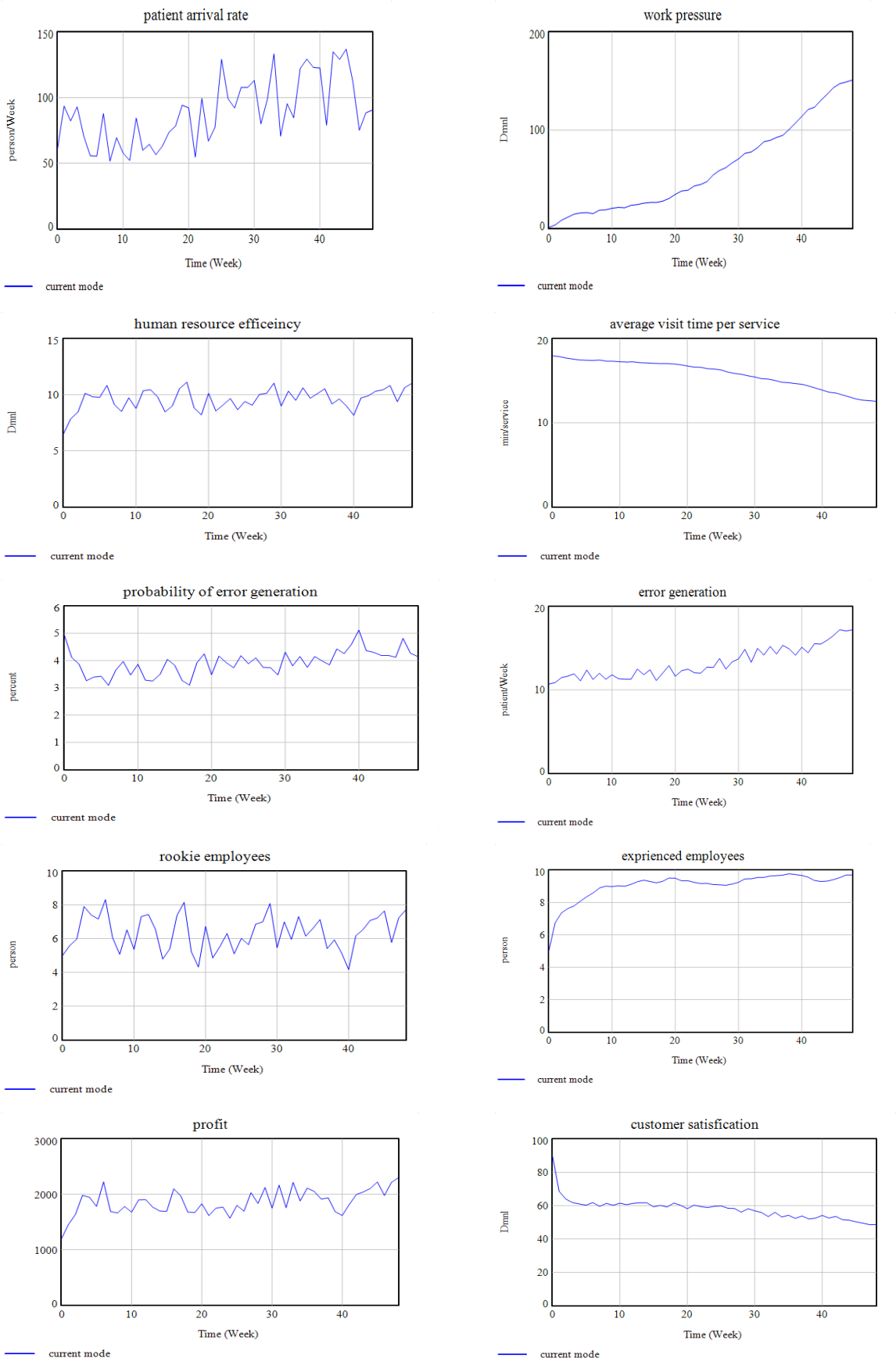

Figure 5. Simulation of base mode

As shown in Figure 5, the patient arrival rate in the healthcare system ranges from 50 to 150 patients per week. Due to the seasonal trend effect, the number of patients increases in the second half of the year compared to the first half. Thus, work pressure increases as the number of patients grows. Under these conditions, physicians respond to the increased pressure by reducing visit times below the standard 18 minutes. Additionally, human resource efficiency, which here refers to the maximum capacity of the physicians, fluctuates around the value of 10.

Furthermore, the number of rookie employees in the clinic varies between 4 and 8 people per week due to the rate of rookie hires and the rate of quit hires. To balance work pressure, with a maturing rate that is affected by the maturing time (the time required for rookies to be converted into experienced employees) and the experienced hire rate, the value of experienced employees in the clinic increases at a moderate rate of 10 people per week. However, customer satisfaction, initially set at a base value of 100, has decreased significantly to around 55 due to increased work pressure, reduced visit times, and higher rates of visit errors. Additionally, the clinic's total profit varies around $2,000 per week, based on the patient quit rate (patients that physicians service).

With the increase in the number of patients in the second half of the year, which leads to a growth in work pressure and a reduction in visit times by physicians, the probability of error generation rises from approximately 10 to 20 per cent, and the error generation rate per week shows an upward trend.

It indicates signs of service quality decline caused by causal and feedback interactions within a dynamic system, often referred to as quality death spirals. To address these spirals, two broad strategies can be implemented. The first involves reducing the patient arrival rate, while the second focuses on increasing the number of human resources. Both approaches aim to alleviate work pressure and, consequently, reduce the rate of error generation. These strategies are elaborated in the subsequent sections.

6.2. Reducing the patient arrival rate

Reducing the patient arrival rate (i.e., limiting patient check-ins) helps lower the patient volume, resulting in reduced work pressure. The extent of reduction needed to achieve suitable work pressure can be determined through trial and error, varying patient arrival rates, and analysing simulation results. In the Base Mode, patient arrival rates vary in the range U (100, 200) -(following a uniform function)- However, in this scenario, they are converted to U (100, 110) to produce favourable outcomes. As illustrated in Figure 6, this approach significantly reduces

the patient quantity and, consequently, work pressure. This reduction leads to stabilising the visit time per service variable at approximately 13 minutes, and the probability of error generation is diminished due to the reduction in work pressure.

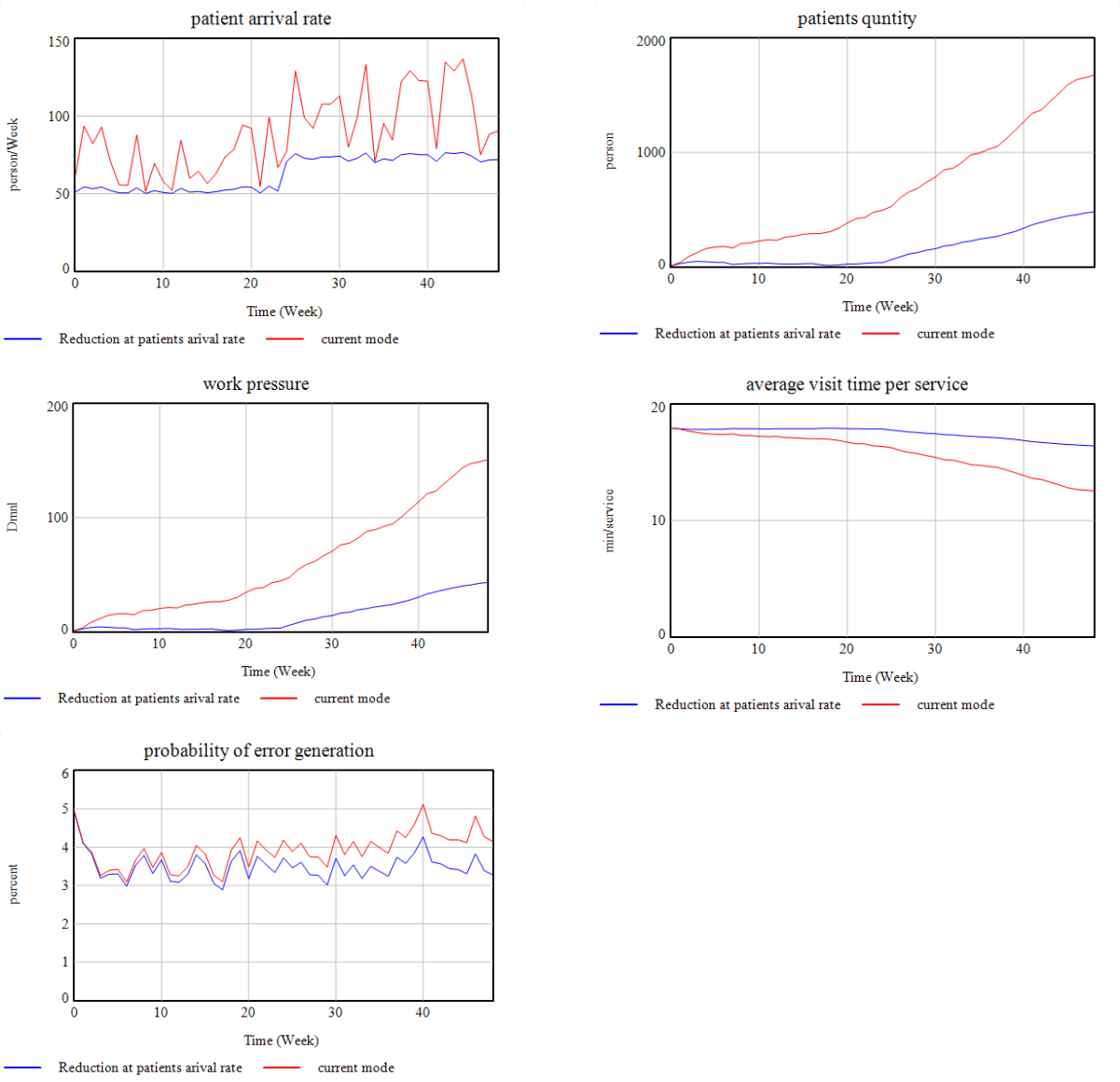

Figure 6. Reducing the patient arrival rate

Additionally, implementing this reduction in patient check-ins may conflict with broader organizational policies, making this strategy challenging to apply. Consequently, alternative measures, such as increasing human resources, may be required to address human resource efficiency shortfalls and enhance service quality. The effectiveness of this policy is examined in the next scenario.

6.3. Increasing human resources

In this scenario, we aim to boost service capacity to enhance human resource efficiency.

However, excessively increasing the number of employees can lead to underutilisation of human resources and incur unnecessary costs. Therefore, it is essential to strike a balance in increasing human resources to minimise error generation while managing system costs. As shown in Figure 7, when the fraction of experienced hires increases from 0.05 to 0.3, the number of experienced employees rises from approximately 10 to 16. Consequently, the probability of error generation decreases to around 3%. Additionally, the visit time per service variable reduces, while customer satisfaction declines in comparison with the Base Mode. In the second policy, by increasing the number of physicians, the profit variable rises to between $ 2,500 and $ 3,000 per week, representing growth compared to the current mode. Therefore, it can be a suitable policy to execute in the healthcare system.

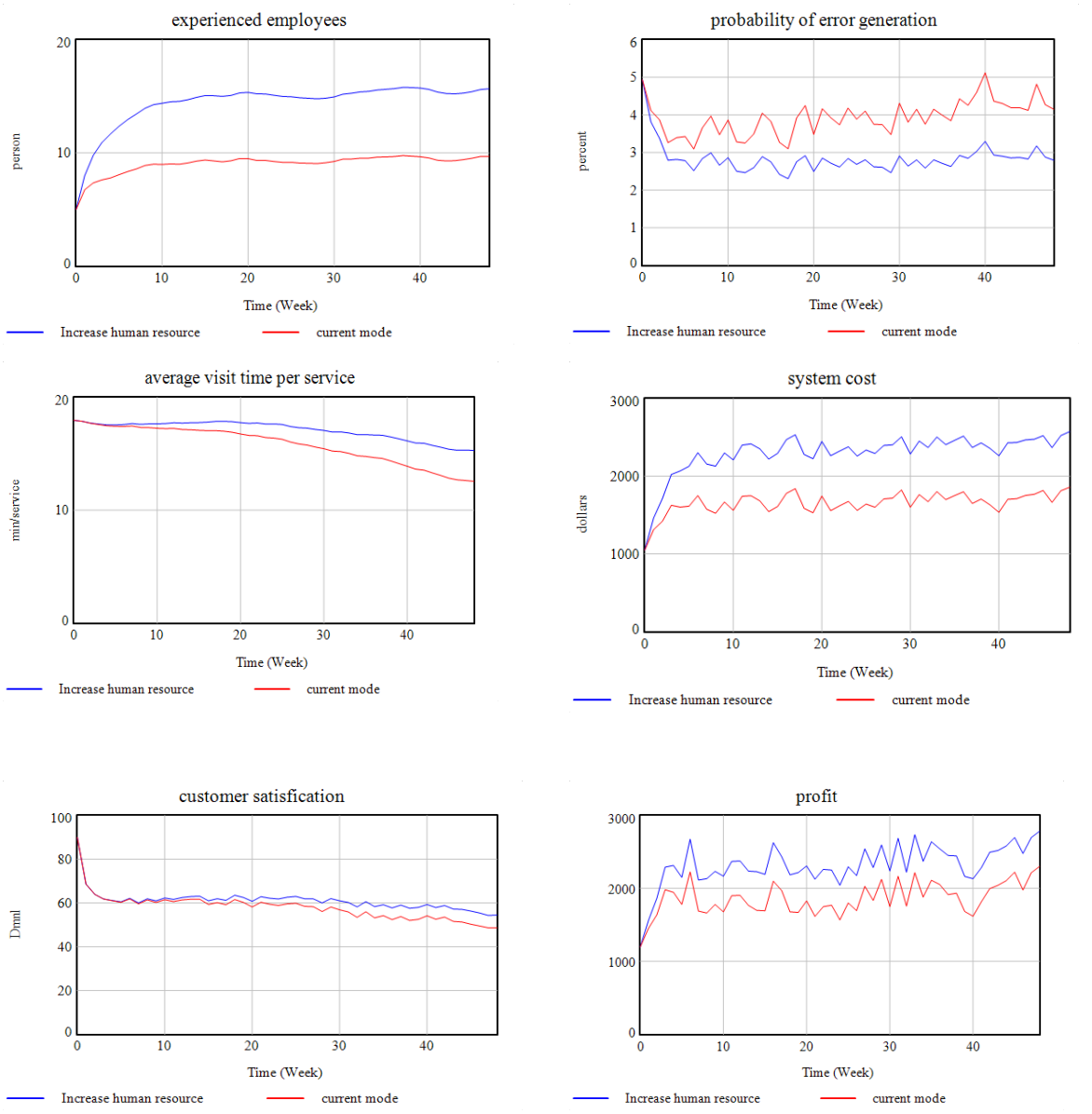

Figure 7. experienced hire fraction growth

6.4. Increasing human resources:

We can design an alternative scenario that appears to have better outcomes than the previous one. For this purpose, in addition to increasing the experienced hire fraction from 0.05 to 0.3, we can implement policies to reduce the experienced quit rate. To achieve this, the experienced quit rate fraction has been reduced by 0.1, and the effects of this scenario are shown in Figure 8.

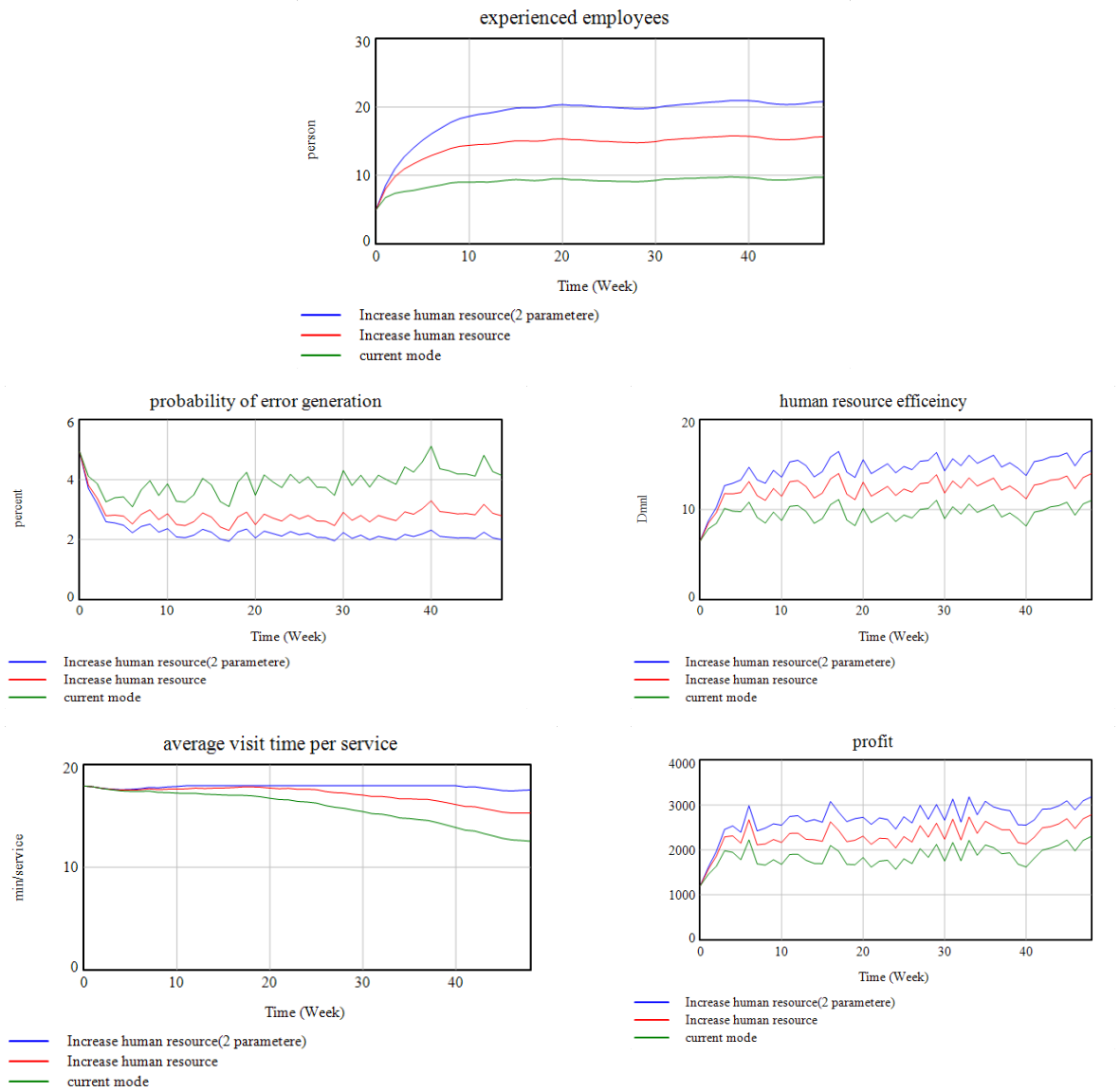

Figure 8. experienced hire fraction growth & the experienced quit rate fraction

As observed, with the increase in these two rates, the number of experienced employees in the clinic rises to approximately 20 persons. Also, the human resource efficiency has improved compared to previous scenarios, and consequently, the error probability has decreased by 2%. Additionally, the average visit time is approximately the standard time, around 17 minutes and 30 seconds. Furthermore, the clinic's profit has increased compared to previous scenarios due

to improvements in human resource efficiency and a reduction in the error generation rate. These findings suggest that targeted adjustments to hiring and retention policies can effectively address service quality challenges while boosting operational outcomes.

7. Managerial insights

Efficient management of human resources and the implementation of strategic hiring and retention policies are critical for enhancing service quality and ensuring operational efficiency in healthcare systems. Given the complexities and dynamic nature of healthcare environments, achieving a balance between maintaining adequate levels of employees (physicians) and optimising levels of employees (physicians) and optimising profit is essential. These efforts not only help alleviate work pressure and reduce the likelihood of error generation but also contribute to enhancing patient satisfaction and overall system performance. The following analysis as examining patient arrival rates and modifying hiring and retention policies, to address challenges in human resource efficiency and service capacity. Some managerial insights based on numerical results are as follows:

7.1. Strategic reduction of patient arrival rates

Lowering patient arrival rates effectively reduces work pressure and stabilises visit times, as demonstrated by the reduction in patient quantity and error generation probability in this scenario.

Trial-and-error analysis and simulation modelling are essential to determine the optimal patient arrival range, ensuring system stability while balancing broader organisational policies.

However, restricting patient check-ins may conflict with overarching policies or accessibility goals for patients, making it a short-term or situational strategy rather than a universal solution.

7.2. Balancing human resource allocation

Increasing human resources addresses service capacity gaps and reduces work pressure, thereby enhancing employee efficiency and lowering the probability of error generation.

It is crucial to avoid overstaffing, which can lead to underutilization and unnecessary costs. Optimal staff allocation should strike a balance between system costs, efficiency, and quality.

As shown in the scenario, increasing the experienced hire fraction boosts the number of skilled employees, reduces error rates to approximately 3%, and contributes to improved service quality.

7.3. Retention strategies to boost efficiency

Implementing retention-focused policies, such as reducing the quit rate among experienced staff, significantly impacts service quality. As shown, lowering the quit rate leads to an increased number of experienced employees and improved workforce efficiency.

Retention strategies can reduce training costs associated with replacing experienced employees and stabilize service quality by maintaining a skilled workforce.

7.4. Improved outcomes through targeted policies

The combined strategy of increasing the proportion of experienced hires and reducing the quit rate yields the best results, with the number of experienced employees rising to 20, error probabilities decreasing by 2%, and average visit times aligning with the target of 17.5 minutes.

This dual approach also enhances the clinic's profitability, with weekly profits surpassing those of previous scenarios, emphasising the importance of integrated hiring and retention strategies.

7.5. Impact on service quality and patient satisfaction

A balanced approach to managing patient arrivals, employee efficiency, and employee levels directly influences service quality. Reduced errors and stabilized visit times contribute to improved patient satisfaction.

However, fluctuations in visit times and satisfaction in certain scenarios underscore the need for continuous monitoring and adjustments to policies to achieve sustainable improvements.

7.6. Policy recommendations

Policymakers should integrate simulation-based decision-making to test various scenarios, allowing them to evaluate the impact of changes on service capacity, costs, and quality metrics.

A holistic approach combining resource improvement, patient management, and retention strategies is essential to achieve long-term operational and quality goals in healthcare systems.

8. Conclusion

This research emphasises the crucial role of SD modelling in improving service quality within healthcare environments. By simulating various scenarios, it highlights how strategic changes in patient arrival rates, workforce allocation, and retention policies can profoundly affect service capacity, employee efficiency, visit time, error generation reduction, and patient

satisfaction. The study reveals the interconnected nature of healthcare systems, where decisions can cascade, influencing work pressure, error rates, and financial outcomes. While reducing patient arrivals helps stabilise work pressure and minimise errors, this method may conflict with broader organisational objectives, necessitating alternative strategies. Enhancing human resources and optimising allocation presents a sustainable solution, balancing efficiency with organisational costs. Policies such as increasing experienced hire rates and improving employee retention enhance workforce capability, and elevate service quality. A dual strategy hiring experienced employees and reducing their quit rates—produces the best outcomes, including higher levels of experienced employees, adherence to standard visit times, lower error rates, and improved efficiency. These changes improve patient trust and satisfaction. The study underscores the value of integrating simulation-based decision-making into healthcare management. Through dynamic modelling, administrators can address challenges, optimise human resource use, and drive sustainable improvements. These findings support evidence-based policy-making, enabling healthcare systems to navigate complexities and achieve enduring excellence in patient care.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix

Formulas and Details in Stock and Flow Diagram.

Rookie Employees = INTEG (Rookie Hire Rate – Maturing Rate – Rookie Quit Rate, Initial Stock, Initial Value)	1
Rookie hire rate=rookie employees*rookie quit fraction	2
Rookie Hire Rate = Random Uniform (Allowable rookie employee*rookie hire fraction,12, 2)	3
Maturing Rate = DELAY1(rookie employees, maturing time)	4
System cost=Salary average for experienced employee*experienced employees+ rookie employees*salary average for rookie employee	5
Experienced Employees = INTEG (experienced hire rate+ maturing rate-experienced quit rate, Initial Value)	6
Experienced Hire Rate = experienced hire fraction*experienced employees	7
Experienced Quit Rate = Experienced Employees × Experienced Quit Fraction	8
Human Resources efficiency = rookie employees*effectiveness factor for experienced employee+ effectiveness factor for rookie employee*experienced employees	9
Service Completion Rate = standard workweek*fixed coefficient0/average visit time per service	10
Work Pressure = patients' quantity*fixed coefficient	11
Average visit time per service = Standard time per service*Effect of work pressure	12
Patient Quit Rate = Human resource efficiency*LN (service completion rate) *Random Uniform (13,15, 1) * a	13
Error Backlog = INTEG (error generation rate-error quit rate without rework-rework rate, Initial Value)	14
Rework Rate = Error backlog*error fraction with rework	15
Error Generation Rate = probability of error generation*(patient quit rate) *impact factor	16
Probability of Error Generation = Effect of service visit time per service on probability of error generation*fixed coefficient 1/ human resource efficiency	17
Patient arrival rate =Random Uniform (100,200,0.5) *Seasonal trend effect*0.9	18
Patients' quantity =patient arrival rate+prior appointment+rework rate-patient quit rate	19
Income = Visit cost*Patient quit rate	20
Customer satisfaction =Primary satisfaction- (Correction factor (Error backlog)	21
Seasonal trend effect =0.5+0.2*Pulse Train (24,24, 24, 50)	22
Profit= Income-b*system cost	23
Effect of service visit time per service on probability of error generation = Modified factor (Average visit time per service)	24

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Designing a Digital Advertising Model Using the Integration of Soft Systems Methodology and Critical Systems Heuristics

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ABSTRACT

This study presents a novel, systems thinking-based approach to designing a comprehensive digital advertising model, addressing the field's complex and ill-structured challenges. Unlike prior research focused on singular aspects, this study integrates multiple worldviews—financial sustainability, technological innovation, market dominance, and project management—to create a holistic framework. A key contribution is the integration of Soft Systems Methodology (SSM) and Critical Systems Heuristics (CSH), which enables a deeper understanding of systemic and ethical dimensions, reconciles diverse stakeholder perspectives, and identifies leverage points for effective interventions. Employing an action research methodology, the model is iteratively refined through real-world implementation. The study expands on foundational digital advertising research by incorporating strategic, tactical, and operational dimensions, situating ad performance metrics within a broader organizational context. It addresses gaps in earlier research, particularly in campaign planning and execution, while considering technical, social, and political implications. Consumer perspectives and concerns about intrusive advertising are also integrated alongside data-driven and behavioural advertising research. The resulting model provides a comprehensive framework for understanding and addressing consumer needs, offering practitioners a tool to develop coherent and effective advertising strategies. By integrating SSM and CSH, this research highlights its unique contribution. This papeer provides a robust methodological foundation for tackling systemic and ethical challenges in digital advertising while advancing theoretical understanding and practical application.

Keywords

Digital advertising model; Digital marketing; Soft systems methodology; Systemic framework; Critical systems heuristics.

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1. Introduction

The digital landscape has fundamentally reshaped the marketing industry, particularly through the ever-evolving world of digital advertising. In today's hyper-connected environment, businesses of all sizes recognize the immense potential of digital marketing to reach target audiences, engage customers, and ultimately drive growth. Among the most prominent strategies in modern marketing is digital marketing (Chaffey, 2015; Chaffey and Ellis-Chadwick, 2019; Chaffey and Smith, 2022). Digital marketing involves promoting products or services using digital technologies, like mobile phones, display advertising, and other digital media. The development of digital marketing since the 1990s and 2000s has revolutionised how brands and businesses utilise technology for marketing purposes. Digital platforms are increasingly being integrated into marketing plans and everyday life. As people use digital devices instead of visiting physical stores, digital marketing campaigns have become more common and effective (Desai, 2019). This shift has significantly altered how companies engage with consumers, requiring a deeper understanding of evolving consumer behaviours behaviourand digital touchpoints. Therefore, the rapid pace of digitalization requires innovative methods to influence customer behaviour (Lingqvist et al., 2015). From social media platforms (Hanafizadeh et al. 2012; Mehrabioun, 2024) to search engines, the channels for digital advertising are vast and dynamic, offering unparalleled targeting capabilities and real-time data insights. However, navigating this complex ecosystem requires a deep understanding of the diverse stakeholders involved, each with distinct mindsets and priorities (Mehrabioun, 2024; Hanafizadeh et al., 2017). Digital advertising, a crucial branch of digital marketing, can be defined as using online channels to deliver targeted promotional messages to potential customers (Gupta and Nair, 2021). From banner ads on websites to sponsored content on social media, these messages aim to influence behaviour and ultimately drive conversions (Chaffey and Smith, 2022). The statistics paint a compelling picture: In 2023 alone, global digital advertising spending is projected to reach a staggering $626.86 billion (Cramer-Flood, 2023), highlighting its immense economic impact. As competition intensifies in an increasingly saturated digital space, crafting impactful advertising campaigns has become more complex, requiring data-driven strategies and consumer-centric approaches.

In this context, SSM emerges as a powerful approach for navigating the complexities of designing digital advertising models. SSM's focus on human-centred design, stakeholder engagement, and iterative development (Checkland, 1999; 2000; Checkland and Poulter, 2006; Hanafizadeh and Mehrabioun, 2022) makes it uniquely suited to address the dynamic and

multifaceted nature of the digital advertising landscape. Despite its potential, the application of SSM in designing digital advertising models remains largely underexplored. While numerous studies have investigated various aspects of digital advertising (Aiolfi et al., 2021; Aslam and Karjaluoto, 2017; Cheng et al., 2009; Gordon et al., 2021; Sundar et al., 2017), a critical gap exists in understanding how SSM can be leveraged to create effective and sustainable advertising models in the context of diverse stakeholders and ever-evolving technologies. This research aims to bridge this gap by demonstrating the value of SSM in designing a digital advertising model that balances the needs of advertisers, platforms, and consumers, paving the way for more effective and ethical advertising practices in the digital age. Consequently, a comprehensive and holistic approach is essential. To address this need, this study leverages systems thinking principles to develop an integrated digital advertising model. Furthermore, it seeks to enhance the intervention by applying CSH questions to uncover underlying assumptions and ethical considerations (Hart and Paucar-Caceres, 2014; Ulrich, 2005; Mohammadi, 2024). CSH offers a set of reflective questions that help uncover underlying assumptions, values, and ethical considerations within systems. By applying CSH, the study aims to enhance the ethical dimension of digital advertising practices, ensuring that decisions are not only effective but also morally sound. Accordingly, this study tries to meet three purposes. 1) It intends to offer a systemic approach based on systems thinking to the design of the digital advertising model; 2) It seeks to consider the application of SSM in digital advertising aspects and improve its intervention using CSH questions; 3) Provides a theoretical foundation for current research in digital advertising studies. Given that SSM is an action research investigation (Checkland, 2011; Checkland and Holwell, 1998), this research was conducted within a specific context to ensure practical relevance. As such, a leading Iranian digital advertising agency, referred to as Company X, was chosen as the case study for this investigation. The following questions guided the research:RQ1: How a combination of SSM and CSH questions can be employed in the design of a digital advertising model for X company?

The methodology of this study has been carefully structured to not only answer the aforementioned research question but also to develop a comprehensive, purpose-driven model applicable to digital advertising design. This investigation primarily aims to illuminate the essential activities and prerequisites for constructing the model. It is important to note that, although the study focuses on model design, it does not extend to the implementation phase of the model.

2. Theoretical background

2.1. Digital advertising

Digital advertising is commonly linked with and often used synonymously with online advertising or Internet advertising. The association reflects their shared use of digital technologies and web-based platforms for delivering promotional content to target audiences. Digital advertising offers unique advantages, including measurability, cost-effectiveness, and the ability to reach a global audience (Lamberton and Stephen, 2016). As the digital landscape continues to evolve, so too does the definition and scope of digital advertising. Recent trends have seen the integration of artificial intelligence, machine learning, and big data analytics in digital advertising strategies, enabling more sophisticated audience targeting and personalisation (Kumar et al., 2019). Additionally, the rise of programmatic advertising and native advertising has further blurred the lines between traditional and digital advertising formats (Malthouse et al., 2018).

2.2. Digital advertising as an ill-structured problem

Research on digital advertising indicates that the challenges in this field are often ill-structured and highly complex, characterized by ambiguity and interdependent factors. These problems typically involve stakeholder perspectives, evolving technologies, and dynamic market conditions, making them difficult to define and address using conventional, linear approaches. The problematic situation arises from the constant evolution of technology, algorithms, and consumer behaviour, rendering traditional advertising models obsolete. Conflicting worldviews among advertisers, marketers, and consumers further contribute to the complexity, as divergent perspectives on privacy, ethics, and the impact of targeted advertising create challenges in finding common ground. The digital advertising ecosystem operates as a complex system of activities involving numerous stakeholders, each with distinct goals, interests, and priorities. The interconnectedness of these systems adds layers of complexity, making it difficult to address issues comprehensively. Purposeful holons, representing autonomous entities within the advertising process, introduce variability and unpredictability, adding to the ill-structured nature of the problem. Learning through inquiry processes becomes imperative in navigating this complexity, requiring continuous adaptation and exploration of innovative solutions.

2.3. Soft Systems methodology

SSM emerged from a critical realisation in the 1970s: traditional "hard" systems thinking, with

its focus on rigid optimisation and control, would not suffice for tackling the complex realities of social and organisational problems (Zarezadeh, 2024). These problems, characterised by their complexity, ill-defined nature, and diverse stakeholder perspectives, demanded a new approach – one that is human-centred. SSM is not a rigid, step-by-step manual; it is a journey of exploration and learning. At its core, SSM embodies a fundamental shift from the reductionist lens of "hard" systems to a holistic understanding of the "epistemological chasm" separating the observer and the observed (Checkland and Holwell, 1998). This chasm necessitates a methodological approach that is not merely prescriptive but dialogical, engaging stakeholders in a collaborative process of inquiry and understanding (Checkland, 1999). Through its iterative seven-stage framework, SSM equips practitioners to navigate complex issues with a focus on context (Flood and Romm, 1996), guiding them through problem exploration, conceptual modelling, and reflective action to drive meaningful solutions.

Checkland proposed two distinct "modes" of SSM – Mode 1 and Mode 2 – each catering to different epistemological stances (Checkland, 2000; Hanafizadeh et al., 2021). Mode 1 navigates the seven stages with a pragmatic focus on generating actionable solutions. While Mode 2 fosters critical reflection and learning journeys (Checkland and Holwell, 1998). This dialectical tension between pragmatism and emancipation ensures that SSM remains a relevant tool for both problem-solving and organizational transformation. SSM's ontological resonance with action research (Flood and Romm, 1996; Ranjbar Fordoei et al., 2023) further strengthens its transformative potential (Faezirad and Khoshnevisan, 2023). Both approaches champion praxis-oriented inquiry (Schön, 1983), where knowledge production (Lather, 1991) is inextricably intertwined with social change (Freire, 1970). This cyclical dance between action, reflection, and learning empowers stakeholders to become agents of change (Checkland and Holwell, 1998) and navigate the complexities of their sociocultural tapestry.

However, SSM is not without its critiques. Its reliance on skilled facilitators and its time-consuming nature can pose practical challenges, particularly in resource-constrained environments (Mingers and Taylor, 1992). Additionally, the abstract nature of its conceptual models can sometimes feel disconnected from the tangible realities of implementation (Mingers, 1984; Jackson, 2003). Despite these limitations, SSM's enduring value lies in its unwavering focus on human-centeredness. It enables stakeholders to engage actively in addressing issues, cultivating a sense of ownership and dedication to the resulting solutions.

2.4. Critical systems heuristics (CSH)

CSH stands as an influential framework in the realm of critical systems thinking, offering a

comprehensive and incisive approach to comprehending and addressing complex societal issues. Rooted deeply in the ethos of democratic and participatory planning (Ulrich and Reynolds, 2010), CSH fundamentally challenges traditional methodologies by highlighting the inherent biases and limitations within the concept of 'improvement.' Its overarching objective is to instil a critical consciousness among individuals, disrupting prevalent technocratic planning paradigms.

At its core, CSH operates on a dual-fronted mission: first, it aims to empower decision-makers, planners (Reynolds, 2008), and experts by fostering self-reflection and a democratic mindset concerning the pursuit of progress (Ulrich, 2005). Simultaneously, it endeavours to equip ordinary individuals—those outside the traditional power structures of decision-making—with the necessary critical competencies. These skills empower them to engage meaningfully in planning processes, thereby transcending their dependency on the goodwill and abilities of established authorities. By emphasising critical consciousness, CSH seeks to subvert the conventional understanding of 'improvement,' urging a deeper evaluation of societal interventions and policies. Its goal is to bridge the gap between those who dictate decisions and those affected by them, advocating for inclusive and participatory approaches to planning (Ulrich and Reynolds, 2010).

3. Literature review

3.1. A Review of digital advertising studies

Empirical studies exploring the efficacy of digital advertising strategies have offered valuable insights into audience engagement, platform effectiveness, and campaign performance metrics. For instance, Silva et al. (2020) conducted a mixed-method study assessing the impact of targeted social media advertising on conversion rates, revealing significant improvements in engagement and sales metrics when comparing Business-to-Business (B2B) and Business-to-Consumer (B2C) companies. Similarly, Setyani et al. (2019) shed light on the nuanced factors influencing consumer perceptions and behaviour in response to digital ads, emphasising the importance of personalised content and contextual relevance. Building on these findings, Gao et al. (2023) examined the role of Artificial Intelligence (AI) in optimising digital advertising campaigns. Their research demonstrated that AI-driven ad placement and content customisation resulted in higher click-through rates and improved Return On Investment (ROI) across various digital platforms. Likewise, Adeleye et al. (2024) investigated the potential of big data analytics in improving the accuracy of audience targeting, demonstrating that data-driven segmentation

strategies significantly surpassed traditional demographic-based methods in engagement and conversion metrics.

Lee and Cho (2020) provide a foundational definition of digital advertising, identifying key trends and proposing management strategies for future campaigns. Building on this, Taylor (2009) discusses factors contributing to the Internet's rise as a major advertising medium; however, the study lacks a comprehensive analysis of the challenges in new media advertising. Expanding the scope, Chen et al. (2016) offer a holistic survey of the digital advertising ecosystem, covering technical, social, and political implications. This broad approach is complemented by more focused studies, such as Cheng et al. (2009), who compare attitudes towards different types of interactive digital advertising and identify three key attitudinal forms: informative, entertaining, and irritating. Delving into the technological aspects, Bruce et al. (2017) present a dynamic model measuring the effects of ad formats, content, and targeting on performance over time. In a similar vein, Gordon et al. (2021) examine market inefficiencies in digital advertising, including ad effectiveness measurement and fraud, offering valuable insights into the challenges faced by practitioners.

Consumer perspectives are well-represented in the literature, with Truong and Simmons (2010) linking perceived consumer intrusiveness with strategic marketing implications. Further enriching this consumer-centric approach, Aiolfi et al. (2021) offer insights into factors influencing data-driven digital advertising and online behavioural advertising. The evolution of digital advertising practices is captured by Truong et al. (2010), who identify five key trends, including permission-based advertising and increased personalisation. Complementing this practical perspective, Stewart et al. (2018) contribute to the theoretical understanding of consumer responses to digital advertising by developing a framework based on the affect transfer hypothesis. While these studies collectively provide a comprehensive overview of digital advertising, some gaps remain. Truong and Simmons (2010) note a lack of focused work on the intrusive aspects of digital advertising, while Gordon et al. (2021) primarily focus on the current state of digital advertising, potentially overlooking some practical aspects of campaign planning and execution.

Therefore, this current research distinguishes itself as a pioneering study that not only adopts a holistic perspective but also systematically addresses digital advertising as a comprehensive system. Specifically, it prioritises a meticulous examination of inputs, outputs, and processes in the design of digital advertisements while also incorporating a pragmatic and systems-thinking approach to involve diverse stakeholders.

3.2. A Review of SSM and CSH combination

The combination of SSM and CSH has been explored in the literature as a powerful approach to addressing complex, multi-stakeholder problems, particularly those characterised by asymmetric power relations and conflicting perspectives. SSM offers a structured framework for understanding and addressing problematic situations through systemic thinking, enabling practitioners to model and reflect on systems conceptions about real-world scenarios. However, SSM's focus on systemic modelling and comparison with perceived situations can sometimes overlook the critical examination of the assumptions and boundaries that shape these perceptions. It is where CSH complements SSM by introducing a critical dimension, interrogating the underlying assumptions and values that define how problems are framed and addressed. Both SSM and CSH share a foundational understanding of systems as conceptual tools for learning about reality rather than as direct representations of reality itself. However, they differ in how they operationalise this understanding. SSM encourages practitioners to reflect on their systems conceptions and compare them with the perceived real-world situation to identify feasible interventions.

In contrast, CSH takes a step further by problematising the "perceived situation" itself, challenging the assumptions and boundaries that underpin it. This critical approach allows practitioners to see through their assumptions and recognise that the distinction between "system" and "situation" is not a rigid opposition but rather a continuum between two poles of contrasting proximity to reality (Torun and Torlak, 2023; Venter and Goede, 2017; Ravasan et al., 2018). While SSM provides practical tools for modelling and intervention, CSH ensures that these interventions are critically informed, addressing power dynamics and challenging dominant perspectives. Together, they develop a more robust methodology for addressing complex problems, striking a balance between systemic reflection and critical boundary critique. This integration underscores the value of combining SSM and CSH, offering a nuanced and comprehensive approach to understanding and addressing real-world challenges.

One of the key reasons for combining SSM and CSH is their ability to address asymmetric power relations, which are often present in complex problem situations. Setianto et al. (2014) argue that CSH is particularly useful in complementing SSM by explicitly addressing power imbalances. CSH's focus on boundary critique enables the identification and questioning of the assumptions and values that underpin different perspectives, ensuring that the voices of less powerful stakeholders are not marginalised. It is particularly relevant in cases where more powerful stakeholders, such as government or industry representatives, dominate the discourse.

Hart and Paucar-Caceres (2014) demonstrate this in their evaluation of an SSM intervention in a mining case study in Peru. They highlight that while SSM provides mechanisms for capturing diverse perspectives, CSH's boundary critique ensures that these perspectives are not overshadowed by the demands of more powerful actors for harder, data-driven research. While SSM is an effective approach for capturing and exploring different perspectives, it often lacks the critical dimension needed to challenge the assumptions that underpin these perspectives. CSH addresses this gap by employing boundary critique, a process that makes transparent the assumptions and values that shape how problems are defined and addressed (Hutcheson et al., 2024). It is particularly important in coercive problem situations, where SSM's lack of grounding in social theory can limit its effectiveness. Torun and Torlak (2023) advocate for CSH as a favourable alternative to SSM in such contexts, as it directly considers problems through the lenses of control and legitimacy.

The integration of SSM and CSH has been demonstrated in various practical applications. For example, Petkov et al. (2007) describe a process in which multiple perspectives were developed through stakeholder groups performing CATWOE analysis (a core component of SSM) and answering the CSH's Boundary Judgment Questions. This combined approach ensures that both the systemic structure of the problem and the critical assumptions underlying it are addressed. Additionally, Pinzon-Salcedo (2023) highlights how CSH's lack of attention to managing complexity can be addressed by integrating it with methodologies such as interactive planning and SSM. This integration enables a more holistic approach to problem-solving, striking a balance between critical reflection and practical action.

4. Research methodology

The process begins with the "Finding-out" phase, which involves a thorough exploration of the environment and organisational context. This phase includes "Environmental Analysis" to identify external factors influencing the system, followed by "Organisational Analysis" (comprising Analysis 1, 2, and 3) to examine internal structures, processes, and stakeholders. A Rich Picture is then designed to visually represent the complex interrelationships within the system. The "Finding-out Statement" is developed after the researcher gains a deep understanding of the problem situation through the application of the 12 CSH questions. These questions are used to explore both the current state and the desired state of the system, thereby enriching the analysts' understanding of the problem context. The 12 CSH questions enable the researcher to examine the problem from multiple perspectives, identify contradictions and conflicts, and provide a comprehensive view of the existing and ideal conditions of the system.

In the next step, the “Root Definitions” phase is undertaken to articulate the core purpose and boundaries of the system under study. It is followed by “Defining Performance Measures”, which establishes criteria for evaluating the system's effectiveness. The “Definition Enrichment” phase further refines the understanding of the system by incorporating additional perspectives and insights. Subsequently, the “Building Purposeful Activity System” phase focuses on designing a conceptual model that aligns with the system's objectives. It leads to the “Building Consensus Model” phase, where stakeholders collaborate to validate and refine the proposed model. Finally, the "Debate and Discussion" phase provides an opportunity for stakeholders to engage in critical evaluation, provide feedback, and build consensus, ensuring the robustness and applicability of the findings. The research methodology steps are outlined in Figure 1.

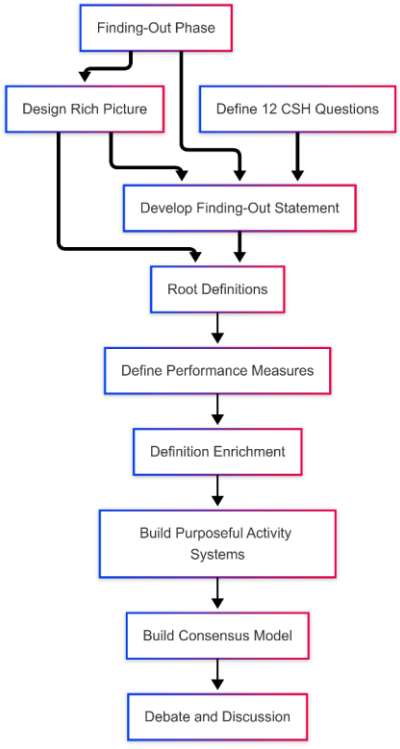

Figure 1. Research methodology steps

4.1. Findings

In the process of designing digital advertising, the finding-out phase entails four key steps. Firstly, in step 1, an analysis of the digital advertising landscape is conducted to identify external factors influencing its development. This analysis draws upon existing research and literature relevant to digital advertising models. Secondly, in step 2, an examination of internal organisational dynamics is carried out. Data for this internal analysis were collected through interventions in problem situations and detailed interviews with various stakeholders, including

managers, experts, and customers of X company, who were selected through snowball sampling due to their involvement in the technical or business aspects of digital advertising development. A total of 14 in-depth interviews were conducted, providing substantial qualitative data, which was then analysed using ATLAS.ti 9 software. The data analysis process explores the relationships between codes and interview concepts. More details about the interviews are provided in Appendix 1, where one sample interview is summarised, and another sample interview is summarised in Appendix 2. In addition, step 3 involves creating a comprehensive overview or 'rich picture' based on the analysis of both internal and external data. Finally, in step 4, the findings from the finding-out phase are synthesised into a statement based on CSH boundary questions and the analysis of internal and external factors influencing the development of digital advertising strategies.

4.1.1. Environmental analysis

To design digital advertising plans, an environmental analysis was conducted to investigate various factors influencing the digital advertising landscape for X company. This analysis encompassed social, economic, political, legal, and technological dimensions, providing a holistic understanding of the contextual influences on digital advertising practices.

Social: In the context of social analysis, the analysis indicates significant shifts in customer needs and preferences regarding digital advertising services. Unlike traditional advertising approaches, which uniformly present products and services, the digital advertising paradigm tailors its offerings to meet diverse customer needs. This shift has necessitated partnerships with new stakeholders who were not traditionally involved in conventional advertising models. Additionally, social analysis revealed substantial shifts in the preferences and demands of gamers for digital entertainment services.

Technological: To strengthen its market presence, Company X is actively developing a comprehensive digital advertising strategy. The rapidly evolving technological landscape has significantly influenced the gaming sector, and this influence extends directly into the domain of mobile applications. Acknowledging the transformative influence of these advancements, Company X is strategically positioning itself to harness their potential. Within this dynamic environment, social networks have become essential platforms for launching new games, a perspective that Company X actively embraces and leverages. By utilizing these networks as a primary channel for advertising, the company is well-positioned to establish a strategic alliance that not only boosts visibility but also enables the identification of potential issues. This

approach is a user-focused strategy, underscoring its commitment to a user-centric advertising approach, ensuring a seamless and engaging experience for its audience.

Economic: Company X is strategically positioned to enhance its market presence through a comprehensive digital advertising plan, seizing opportunities within the dynamic gaming sector. With a keen focus on customised gamification designs for businesses, the company aims to diversify revenue streams and cater to the increasing demand for personalised marketing approaches. Accessing diverse advertising capabilities represents a critical opportunity for Company X, enabling the company to expand its audience reach and enhance market exposure. Additionally, by leveraging targeted advertising, the company seeks to minimiseunoptimisedminimise unoptimised spending, optimising campaigns for greater efficiency and improved return on investment. Nevertheless, the economic environment poses significant challenges, particularly the high costs associated with infrastructure and server maintenance. To address this, Company X must adopt strategic resource management practices and explore cost-effective solutions to mitigate these financial pressures.

4.1.2. Organisational analysis (Analysis 1, 2, 3)

Regarding analysis 1, in the pursuit of creating value, Company X's marketing objectives encompass retargeting users, facilitating easy analysis of data, documenting campaign information and decision propositions, achieving return on investment, intelligently optimising advertising channels, delivering targeted reports, and ensuring proper budget allocation and management. The current state of digital advertising involves executing campaigns based on the organisation's overall strategy and promoting new features or products derived from existing ones. Challenges include a considerable gap between ideation and execution quality, substantial loss and inadequate desired results, lack of documentation and campaign reporting, and the absence of a comprehensible dashboard. Nevertheless, Company X possesses valuable assets, including creative campaign ideas and designs, a shared user base, a relatively agile technical team, and notable capacity in owned and earned media.

Social analysis involves identifying three key dimensions: roles, norms, and values. The roles essential in designing digital advertising at X company include financial analysts, technical experts, marketing strategists, planning managers, and the general marketing directorate. Adherence to norms is crucial within X company's operational framework. It includes the implementation of personalised gamification strategies, efficient utilisation of advertising capacities, and targeted approaches to prevent wastage of advertising expenses. These norms

serve as guiding principles to optimise resources and enhance the effectiveness of marketing endeavours. Complementing these norms are the company's core values, which encompass user retargeting, easy data analysis, targeted reporting, prudent budget allocation, intelligent advertising channel optimisation, and a focus on achieving a return on investment.

Analysis 3, or political analysis, focuses on identifying dominant and influential groups within an organisation. In examining power dynamics, the financial unit prioritises cost-effective customer service and strategic investments, allocating resources toward enhancing customer satisfaction and driving business expansion rather than incurring digital advertising expenditures. Meanwhile, the technical unit, responsible for platform implementation, gains critical insights into marketing requirements and operational activities, ensuring the technical infrastructure supports data extraction and reporting needs. Shareholders, on the other hand, stand to benefit from the platform's success, as digital advertising remains a key revenue driver for many businesses within the ecosystem. However, the potential advantages and spheres of influence regarding the project's success or failure differ across stakeholder roles, shaping their respective priorities and decision-making processes. Financially, success translates to project profitability, diversified revenue streams, and the empowerment to allocate budgets to respective units. For innovation and product development, success entails steering budgets towards development, serving as a notable resume for larger projects. In the marketing domain, success is evident in increased brand recognition, the execution of larger campaigns, enhanced customer experiences, precise targeting of a wider audience, successful campaign tracking and measurement, and better alignment with overall marketing strategies. In essence, the collective success of the project has multifaceted impacts on the financial, technical, and marketing realms, highlighting the importance of effective collaboration and strategic coordination among these units within Company X.

4.1.3. Designing rich picture

A rich picture schematically identifies all information and relationships governing the problem situation, enabling researchers to gain an in-depth understanding of the issue. After analysing internal and external dimensions, it is crucial to identify the stakeholders and their concerns using the rich picture (Figure 2). This rich picture presents the key stakeholders, activities, and four dominant worldviews within a digital advertising company. It highlights areas of alignment and conflict—marked with red Xs—between goals such as market expansion, user experience, financial sustainability, and project management.

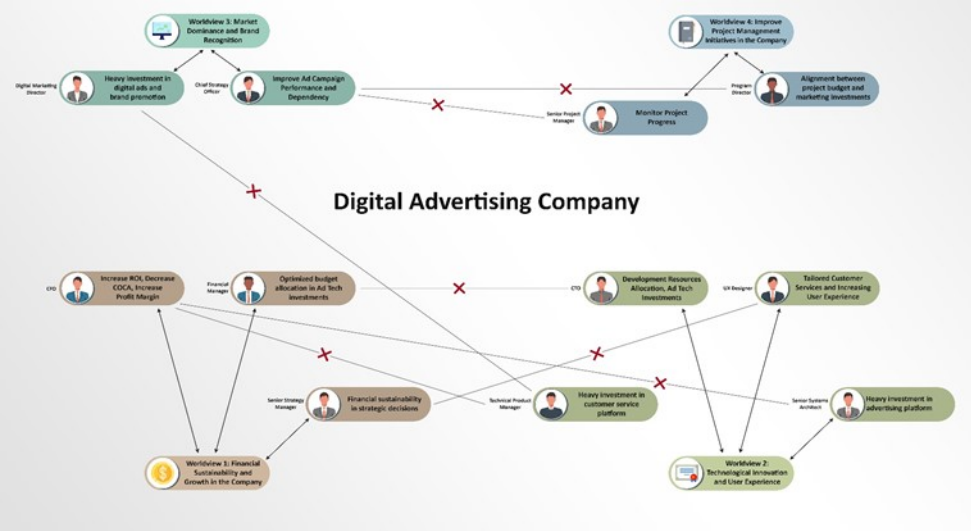

Figure 2. Rich picture of digital advertising company

4.1.4. Finding-out statement

Using CSH boundary questions can be a highly effective technique for uncovering underlying issues and generating insightful findings. CSH boundary questions facilitate a holistic examination of diverse perspectives and stakeholder interests, fostering a collaborative environment for problem-solving (Ulrich, 2005). Through this process, valuable insights emerge, leading to informed decisions and innovative solutions that address the root causes of complex issues. Thus, employing CSH boundary questions as a technique not only facilitates the discovery of pertinent information but also promotes deeper understanding and more effective problem resolution. In the fourth step, a focus group session was convened to gather ideas and formulate the findings statement. Representatives from the financial, technical, marketing, and planning departments, as well as the planning manager, participated in the session. Pre-determined questions guided the discussion, which took place in September 2023. Fifteen participants attended the meeting, which lasted over three hours and involved data collection through recording. Prior to the meeting, respondents received the questions, which were presented during the session via PowerPoint slides. The author reviewed the recorded data to extract answers to each question. Based on the meeting results, a findings statement document was prepared. This document, along with the results, was sent to each participant for confirmation, requesting verbatim validation of quotes and their interpretations. The findings related to answers to the key questions are summarised in Table 1.

Table 1. Results of CSH boundary questions (‘Is’ mode)

No	Question	Financial analysts	Technical experts	Marketing strategists	Planning managers
1	Who is the customer?	Stakeholders impacted by the project outcomes (internal and external), Senior management and leadership team	Target consumers and potential customers, Existing customer base	Clients/advertisers seeking effective digital advertising platforms, End-users/consumers of digital advertising experiences	Shareholders, investors, Senior management team
2	What is the purpose of this idea?	Evaluate financial viability and potential return on investment	Assess technical feasibility and alignment with existing systems	Develop strategies to promote and market the idea effectively	Determine how the idea fits into overall organizational goals
3	What is the criterion for improvement/success?	Increase revenue generation and profitability	Ensure seamless integration and user satisfaction	Enhance brand visibility and market share	Achieve project objectives within specified timelines and budget
4	Who is the decision-maker?	Chief Financial Officer or Finance Department	Chief Technology Officer or Technical Team	Chief Marketing Officer or Marketing Department	Project Manager or Planning Department
5	What resources are controlled by the decision-maker?	Budget allocation and financial resources	Technological infrastructure and development resources	Marketing budget and promotional resources	Project timeline and human resources
6	What are the conditions outside the decision environment that lead to project success?	Economic trends, market demand, and competitive landscape	Technological advancements and industry standards	Social media trends, consumer behaviour, and cultural influences	Regulatory requirements, organizational priorities, and market dynamics
7	Who is considered a professional or an expert?	Certified financial analysts and economists	Experienced software developers and IT specialists	Marketing strategists and branding experts	Project management professionals and strategic planners
8	What specialities are used?	Financial analysis, risk assessment, and investment strategies	Software development, coding languages, and system architecture	Market research, consumer psychology, and advertising techniques	Strategic planning, resource allocation, and project management
9	Who guarantees success?	Ensuring financial viability and profitability	Ensuring technical functionality and user satisfaction	Ensuring effective promotion and market penetration	Ensuring project completion within scope and objectives
10	Who is the lawyer/representative of the people who are affected but not involved?	Financial regulators and compliance officers	User experience designers and quality assurance professionals	Public relations specialists and customer service representatives	Legal advisors and risk management experts
11	What guarantees the release of affected people?	Compliance with financial regulations and ethical standards	User-friendly interfaces and efficient technical support	Transparent communication and responsiveness to customer feedback	Clear project communication and stakeholder engagement
12	What is the worldview?	Financial sustainability and growth mindset	Technological advancement and innovation	Market orientation and customer-centric approach	Strategic planning and adaptive management

Table 2. Results of CSH boundary questions ('Ought' mode)

No	Question	Financial Analysts	Technical Experts	Marketing Strategists	Planning Managers
1	Who should be the customer?	Stakeholders impacted by the project outcomes (internal and external), Senior management and leadership team	Target consumers and potential customers, Existing customer base	Clients/advertisers seeking effective digital advertising platforms, End-users/consumers of digital advertising experiences	Shareholders, investors, Senior management team
2	What ought to be the purpose of this idea?	Evaluate financial viability and potential return on investment	Deliver a seamless, user-centric advertising experience through advanced technological infrastructure and innovative software solutions	Establish market dominance and increase brand recognition through innovative marketing strategies and consumer insights	Achieve project objectives within specified timelines and budgets while integrating regulatory requirements and organizational priorities
3	What ought to be the criterion for improvement/success?	ROI of campaigns, COCA (Cost of Customer Acquisition), and profit margins	Ensure seamless integration and user satisfaction	Enhance brand visibility, market share, and campaign performance	Timely project completion, adherence to budget, regulatory compliance, and alignment with organizational goals
4	Who ought to be the decision-maker?	Chief Financial Officer or Finance Department	Chief Technology Officer or Technical Team	Chief Marketing Officer or Marketing Department	Project Manager or Planning Department
5	What resources ought to be controlled by the decision-maker?	Budget allocation and financial resources	Development resources, IT infrastructure, and software tools for implementing advanced solutions	Marketing budget and promotional resources	Project timelines, human resources, budgets, risk management tools, and stakeholder expectations influencing project execution
6	What ought to be the conditions outside the decision environment that lead to project success?	Market trends, consumer behaviour, technological advancements, and competitive dynamics	Technological advancements and industry standards	Social media trends, consumer behaviour, and cultural influences	Regulatory requirements, organizational priorities, and market dynamics
7	Who ought to be considered a professional or an expert?	Financial analysts, digital marketing specialists, and data scientists	Software developers, IT specialists, and UX/UI designers with expertise in cutting-edge technologies	Marketing strategists and branding experts	Project management professionals and strategic planners
8	What specialties ought to be used?	Financial analysis, digital marketing strategies, and data-driven decision-making	Software development, coding languages, and system architecture	Market research, consumer psychology, social media marketing, customer relationship management and advertising techniques	Strategic planning, resource allocation, and project management
9	Who ought to be responsible for guaranteeing success?	Ensuring financial viability and profitability	Ensuring technical functionality and user satisfaction	Ensuring effective promotion and market penetration	Ensuring project completion within scope and objectives
10	Who ought to be the lawyer/representative of the people who are affected but not involved?	Compliance officer or ethical advisor ensuring ethical and legal standards	User experience designers and quality assurance professionals	Public relations specialists and customer service representatives	Legal advisors and risk management experts
11	What ought to guarantee the release of affected people?	Compliance with financial regulations and ethical standards	User-friendly interfaces and efficient technical support	Transparent communication and responsiveness to customer feedback	Clear project communication and stakeholder engagement
12	What should be the worldview?	Financial sustainability and growth mindset	Technological advancement and innovation	Market orientation and customer-centric approach	Strategic planning and adaptive management

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The comparison between the "is" mode (current state, Table 1) and the "ought" mode (ideal state, Table 2) across the four worldviews reveals both alignment and discrepancies, highlighting areas for improvement. For financial analysts, the "is" mode focuses on financial viability and revenue generation, which the CFO controls, while the "ought" mode emphasises a data-driven approach that incorporates ROI, COCA, and profit margins alongside ethical standards. This shift calls for greater integration of digital marketing strategies and financial sustainability. For technical experts, the "is" mode centres on technical feasibility and system integration, led by the CTO, whereas the "ought" mode prioritises a seamless, user-centric advertising experience through advanced technologies and UX/UI design. This transition highlights the importance of aligning technical efforts with user satisfaction and innovation. Marketing strategists operating in the "is" mode aim for market penetration under the guidance of the CMO, while those in the "ought" mode seek market dominance through innovative strategies, consumer insights, and transparent communication. This shift underscores the importance of a consumer-centric, data-driven approach for achieving long-term brand success. For planning managers, the "is" mode focuses on aligning projects with organisational goals managed by project managers. In contrast, the "ought" mode adopts a holistic approach, integrating regulatory requirements, market dynamics, and adaptive management principles to achieve a comprehensive understanding. It suggests a need for a more strategic, compliance-oriented mindset.

4.2. Root definitions

During the finding-out phase, a variety of distinct viewpoints emerged, each offering unique perspectives on the issue under examination. In the subsequent fifth step, a precise of the root definition was carefully outlined for each of these identified viewpoints, offering clarity and guidance in understanding their foundational principles. Through the analysis of qualitative data from interviews (detailed in Appendices 1 and 2) and active engagement by researchers in addressing the problem, four distinct worldviews were identified, each playing a crucial role in shaping the approach to resolving the identified issues. The following four worldviews were discerned:

The first worldview: Financial sustainability and growth mindset

The purpose of this worldview is to ensure the financial sustainability and growth of the organisation through diligent financial management and strategic decision-making. It entails evaluating financial viability and potential return on investment to enhance revenue generation

and profitability. The primary decision-maker within this worldview is the Chief Financial Officer, responsible for budget allocation and efficient utilisation of financial resources for digital campaigns, which could create some obstacles for digital advertising. Key factors considered include the return on investment (ROI) of campaigns, the COCA index, and profit margins. Ultimately, the focus lies on achieving financial sustainability and fostering a growth mindset within the organisation.

The second worldview: Technological innovation and seamless user experience

The second worldview in a digital advertising company is defined by its commitment to delivering a seamless and user-centric advertising experience through advanced technological infrastructure and innovative software solutions. Assessing the technical feasibility and alignment with existing systems involves evaluating the company's current technological capabilities, development resources, and adherence to industry standards. This assessment encompasses analysing the proficiency of software developers and IT specialists, ensuring compatibility with emerging technological advancements, and prioritising user satisfaction through user-friendly interfaces and efficient technical support. By leveraging experienced professionals and staying abreast of industry trends, the company aims to integrate cutting-edge technologies seamlessly and enhance user satisfaction in its advertising endeavours.

The third worldview: Technological innovation and seamless user experience

The third worldview aims to establish market dominance and increase brand recognition through a comprehensive marketing strategy leveraging consumer behaviour insights, innovative advertising techniques, and responsive customer service. By conducting thorough market research, implementing cutting-edge advertising methods, and staying current with social media trends, the company can effectively promote its brand and expand its market share. Collaborating with marketing experts, prioritising customer satisfaction, and maintaining transparent communication with consumers are essential components of this approach. By adopting a market-oriented approach and continuously monitoring performance, the company can ensure effective promotion, market penetration, and sustained growth in a competitive landscape.

The fourth worldview: Technological innovation and seamless user experience

The fourth worldview is a holistic approach to project management and strategic planning that integrates regulatory requirements, organisational priorities, and market dynamics to achieve project objectives within specified timelines and budgets. It involves coordinating project timelines and human resources, guided by strategic planning and adaptive management

principles. The Fourth Worldview is facilitated by project management professionals and strategic planners who ensure clear communication of project objectives and effective engagement with stakeholders. It encompasses resource allocation, risk management, and legal advisory to ensure project completion within scope and objectives, aligning with overall organisational goals.

After formulating the root definitions, PQR analysis is employed to further delineate each of them. This analysis is detailed in Table 3.

Table 3. PQR Analysis

Worldview	PQR analysis
First worldview	P: Implement diligent financial management and strategic decision-making practices. Q: Assess budget allocation, ROI of campaigns, and resource utilization for digital campaigns. R: Ensure financial sustainability and foster growth within the organization.
Second worldview	P: Deliver a seamless and user-centric advertising experience through advanced technological infrastructure and innovative software solutions. Q: Assess the technical feasibility, evaluate current technological capabilities, and prioritize user satisfaction through user-friendly interfaces and efficient technical support. R: Enhance user satisfaction, ensure compatibility with emerging technological advancements, and stay competitive in the digital advertising industry.
Third worldview	P: Establish market dominance and increase brand recognition through a comprehensive marketing strategy. Q: Utilize consumer behaviour insights, innovative advertising techniques, and responsive customer service. R: Ensure effective promotion, market penetration, and sustained growth in a competitive landscape.
Fourth worldview	P: Integrate regulatory requirements, organizational priorities, and market dynamics. Q: Coordinate project timeline and human resources using strategic planning and adaptive management. R: Ensure project completion within scope and objectives, aligning with overall organizational goals.

5. Step 6: Defining performance measures

Once the root definitions are established, it becomes essential to develop criteria for evaluating the performance of each worldview. These criteria are categorized as follows:

1. Criteria to assess whether the transformation T is achieving its intended outcomes (efficacy).
2. Criteria to assess whether the transformation is achieved using minimal resources (efficiency).
3. Criteria to assess whether the transformation contributes to higher-level or long-term goals (effectiveness).

Details defining the performance assessment criteria for each root definition are provided in Table 4.

Table 4. Performance measures

Performance assessment criteria	First worldview	Second worldview	Third worldview	Fourth worldview
Effectiveness	Year-over-year revenue growth, Increase in market share, Improvements in brand equity and reputation, Sustainable competitive advantage achieved, Long-term profitability and shareholder value creation	Revenue growth from technology-driven advertising solutions, Market share in the ad-tech industry, Industry recognition and awards for technological innovation, Retention of top technical talent and developers, Successful partnerships and integrations with industry leaders	Year-over-year growth in market share, Improvements in brand equity and reputation, Customer retention and loyalty rates, Revenue growth attributed to marketing efforts, Industry awards and recognition for marketing excellence	Year-over-year growth in market share, Improvements in brand equity and reputation, Customer retention and loyalty rates, ROI of completed projects
Efficiency	COCA index, Marketing spend as a percentage of revenue, Operational costs as a percentage of revenue, Budget adherence and variance analysis	Development time and costs for new features and enhancements, code coverage, defect density, Resource utilization and scalability of infrastructure, Time-to-market for new product releases	Cost per acquisition (CPA), Marketing return on investment (MROI), Customer lifetime value (CLV) to customer acquisition cost (CAC) ratio, Time-to-market for new advertising campaigns and initiatives	Project cost performance index (CPI), schedule performance index (SPI), Resource utilization rates (e.g., workforce utilization, equipment utilization), Cycle time for project phases and processes
Efficacy	Return on Investment (ROI) of digital campaigns and marketing initiatives, Revenue growth rate, Profit margins, Customer acquisition and retention rates	Net Promoter Score, Uptime and reliability of advertising platform, Seamless integration with existing client systems, Successful adoption of new technologies and software solutions	Brand awareness and recall metrics, Engagement rates on social media and advertising campaigns, Customer acquisition and conversion rates	Percentage of projects completed within scope, timeline, and budget, Stakeholder satisfaction ratings, Compliance with regulatory requirements and industry standards, Achievement of project objectives and key performance indicators

5.1. Definition enrichment

After conducting the PQR analysis, CATWOE is employed to define the primary attributes of the system and to obtain a precise, enriched characterization of the root definitions (Checkland, 1981). Table 5 presents the details regarding the CATWOE analysis for each worldview (Tayebnia et al., 2023).

Table 5. CATWOE analysis

CATWOE components	First worldview	Second world view	Third worldview	Fourth worldview
Customers (C)	Shareholders, investors, Senior management team	Clients/advertisers seeking effective digital advertising platforms, End-users/consumers of digital advertising experiences	Target consumers and potential customers, existing customer base	Stakeholders impacted by the project outcomes (internal and external), Senior management and leadership team
Actors (A)	Chief Financial Officer (CFO), Finance and accounting teams, Strategic planning and budgeting teams	Software developers and engineers, IT specialists and infrastructure teams, UX designers, Technical support and customer service teams	Marketing teams (digital marketing, social media, etc.), Market research and consumer insights analysts, Advertising and creative teams, Customer service and support teams	Project managers and project management teams, Strategic planners and business analysts, Risk management and legal advisory teams, Subject matter experts and cross-functional teams involved in the project
Transformation Process (T)	Transforming financial resources and data into optimized budget allocations, strategic investment decisions, and financial performance metrics to drive profitability and growth	Transforming technological capabilities, development resources, and user insights into innovative software solutions and seamless advertising experiences	Transforming consumer insights, market research, and creative ideas into innovative advertising campaigns, effective brand promotion strategies, and responsive customer service to drive market dominance and brand recognition	Transforming organizational priorities, market dynamics, and project requirements into well-coordinated project plans, resource allocations, and risk mitigation strategies to achieve project objectives within specified timelines and budgets
Worldview (W)	Strategic planning and adaptive management	Market orientation and customer-centric approach	Technological advancement and innovation	Financial sustainability and growth mindset
Owner (O)	Chief Financial Officer (CFO)	Chief Technology Officer (CTO) or Head of Engineering/IT	Chief Marketing Officer (CMO) or Head of Marketing	Project Sponsor or Senior Project Manager
Environment (E)	Organizational financial policies and regulations, Economic conditions and market trends, Competitive landscape and industry dynamics, Availability of financial resources and investment opportunities, Potential obstacles or limitations in digital advertising campaigns	Industry standards and technological advancements, Compatibility with clients' existing systems and platforms, Availability of skilled technical talent and development resources, User preferences and expectations for digital advertising experiences, Competitive landscape in the ad-tech industry	Consumer trends and preferences, Competitive landscape and market dynamics, Availability of marketing resources and budgets, Advertising regulations and legal compliance, Social media and digital marketing trends and platforms	Regulatory requirements and industry standards, Organizational policies, culture, and structure, Market trends, competition, and customer demands, Availability of skilled project management resources, Budgetary constraints and resource limitations

After conducting the CATWOE analysis, root definitions are formulated for each mindset. Subsequently, these root definitions can be characterised in the following manner:

Root definition 1: Designing a digital advertising plan is a system owned by the shareholders, investors, and the senior management team and is operated by the CFO, finance and accounting teams, as well as strategic planning and budgeting teams. This system transforms financial resources and data into optimised budget allocations, strategic investment decisions, and financial performance metrics. This system aims to drive profitability and growth through

strategic planning and adaptive management, while considering organisational financial policies and regulations, economic conditions and market trends, the competitive landscape and industry dynamics, the availability of financial resources and investment opportunities, and potential obstacles or limitations in digital advertising campaigns.

Root definition 2: Designing a digital advertising plan is a system owned by the CTO or Head of Engineering/IT, and operated by software developers and engineers, IT specialists and infrastructure teams, User Xxperience (UX) designers, and technical support and customer service teams, to transform technological capabilities, development resources, and user insights into innovative software solutions and seamless advertising experiences for clients/advertisers seeking effective digital advertising platforms and end-users/consumers of digital advertising experiences. This system is guided by a market-orientation and customer-centric approach, while considering industry standards, technological advancements, compatibility with clients' existing systems and platforms, availability of skilled technical talent and development resources, user preferences and expectations for digital advertising experiences, and the competitive landscape in the ad-tech industry.

Root definition 3: Designing a digital advertising plan is a system owned by the CMO or Head of Marketing and operated by marketing teams (digital marketing, social media, etc.), market research and consumer insights analysts, advertising and creative teams, and customer service and support teams, to transform consumer insights, market research, and creative ideas into innovative advertising campaigns, effective brand promotion strategies, and responsive customer service for target consumers and potential customers, as well as the existing customer base. This system is guided by a focus on technological advancement and innovation, while considering consumer trends and preferences, the competitive landscape and market dynamics, the availability of marketing resources and budgets, advertising regulations and legal compliance, as well as social media and digital marketing trends and platforms.

Root definition 4: Designing a digital advertising plan is a system owned by the Project Sponsor or Senior Project Manager and operated by project managers and project management teams, strategic planners and business analysts, risk management and legal advisory teams, as well as subject matter experts and cross-functional teams involved in the project. This system transforms organisational priorities, market dynamics, and project requirements into well-coordinated project plans, resource allocations, and risk mitigation strategies to achieve project objectives within specified timelines and budgets, benefiting stakeholders impacted by the project outcomes (both internal and external) as well as senior management and the leadership team. The system is guided by a worldview of financial sustainability and a growth mindset

while considering regulatory requirements and industry standards, organisational policies, culture and structure, market trends, competition, customer demands, the availability of skilled project management resources, and budgetary constraints and resource limitations.

5.2. Building a purposeful activity system

The conceptual models were created by analysing the interview transcripts with representatives of each mindset conducted during the finding-out phase. The development of these conceptual models proceeded as follows:

The researchers, in collaboration with digital advertising experts, thoroughly examined the interview transcripts. Following a detailed review of the interview content, the researchers conducted open coding based on consensus among themselves and the two experts for code naming. This step aimed to ensure consistency between the encoded text and its interpretation (refer to Appendix 1 and Appendix 2 for details on open coding). During the coding process, relationships between codes in the interview transcripts were analysed. For example, if interviewees identified "Analyse Financial Resources" as a prerequisite for "Optimise Budget Allocations," it was categorised accordingly. The conceptual models were tailored to address the concerns of each representative of the respective mindsets. Figures 2-5 depict the conceptual model (human activity system) advocated by proponents of the first mindset. It should be noted that due to space constraints, communication and control processes are not depicted in the conceptual models.

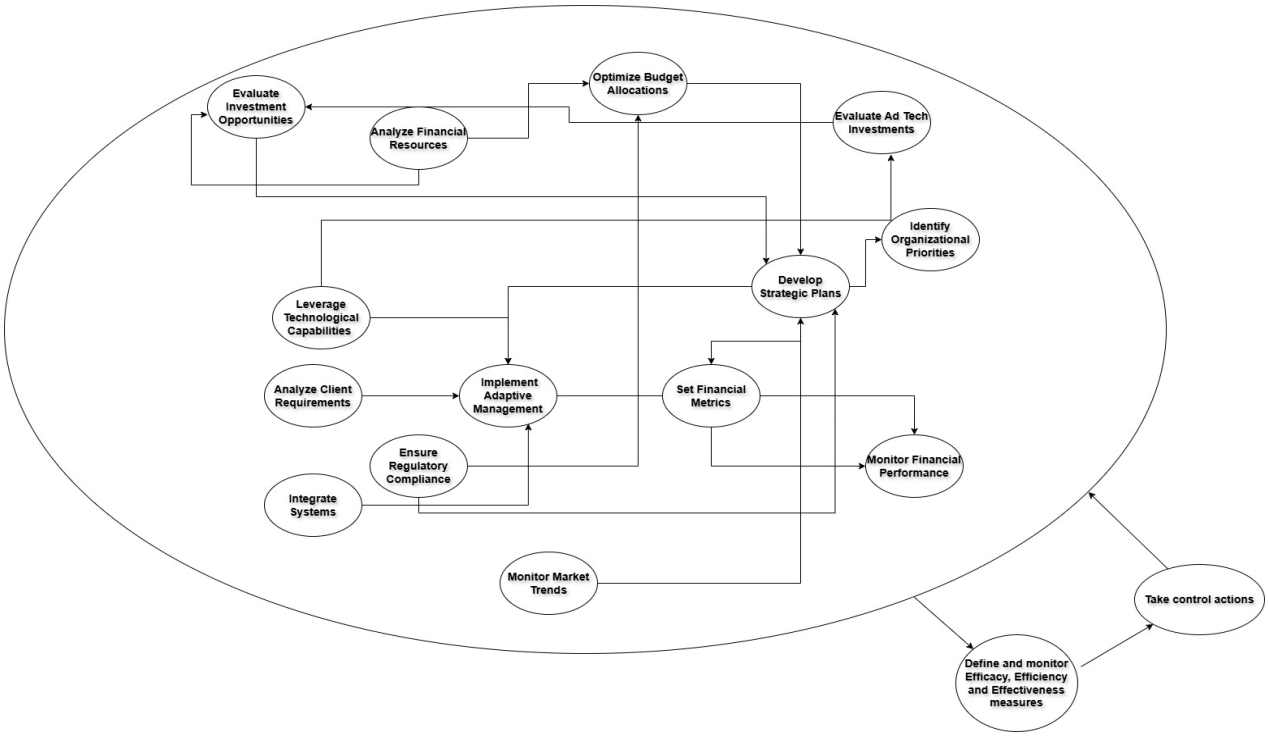

Figure 3. Conceptual model representing the first worldview idea

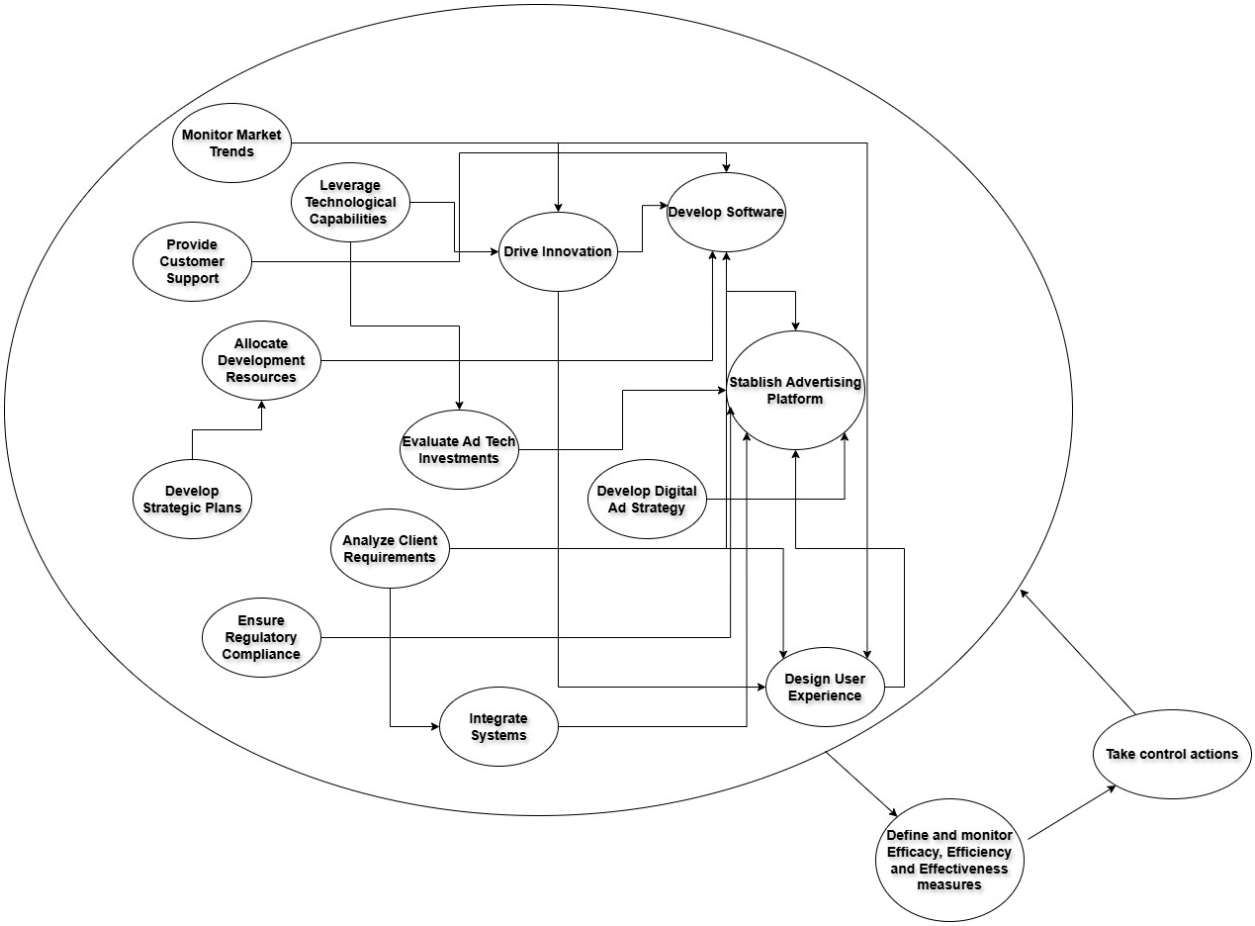

Figure 4. Conceptual model representing the second worldview idea

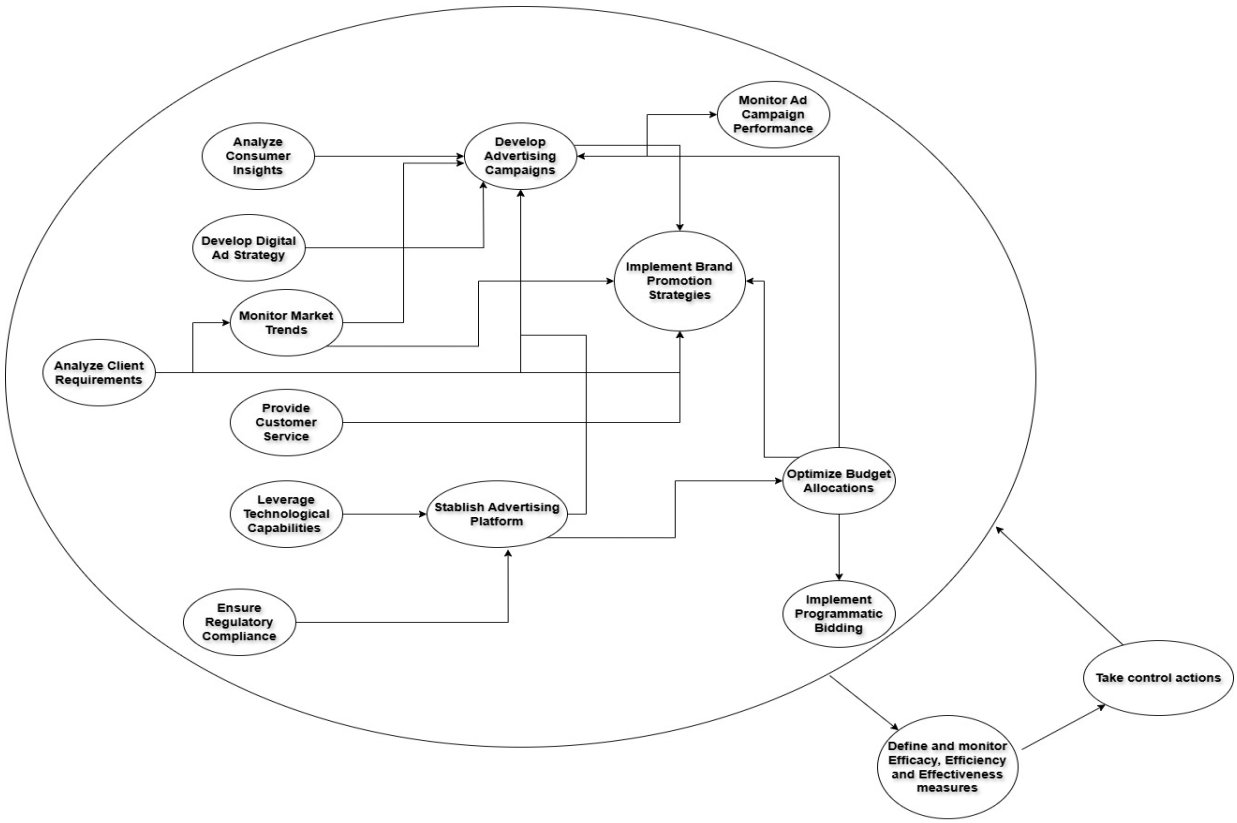

Figure 5. Conceptual model representing the third worldview idea

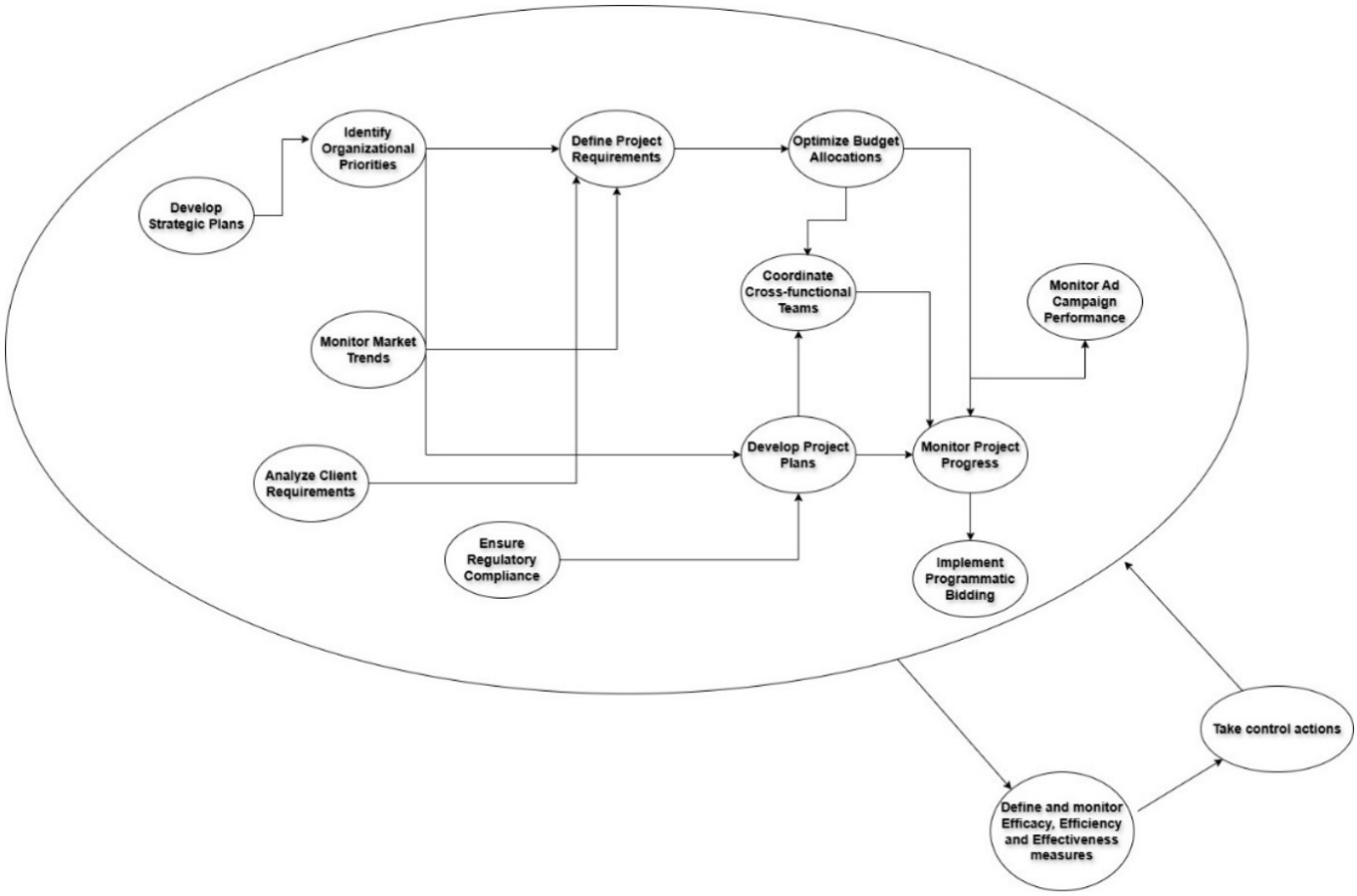

Figure 6. Conceptual model representing the fourth worldview idea

5.3. Building consensus model

After designing mindset-specific activity systems, it's essential to develop a unified model that all perspectives can agree on and defend (Hanafizadeh and Mehrabioun, 2020). Wilson (2001) suggests using the Consensus Primary Task Model (CPTM) for this purpose, which begins by identifying different types of consensus among activities.

Neutral primary task (global consensus): These are activities that contribute to the core nature of digital advertising, regardless of mindset differences. For instance, " Provide Customer Support " is universally applicable across all mindset-based models.

100% consensus: This represents activities that all conceptual models agree on. An example is " Implement data-driven marketing", which is consistent across all mindsets.

Local consensus (consensus by accommodation): These are activities that initially lack general agreement but may reach consensus through discussion.

Table 6 provides an overview of global, 100%, and local consensus activities in designing a digital advertising model.

Table 6. Global, 100% and local consensus

Type of consensus	Activities
Global	Ensure Regulatory Compliance, Provide Customer Support, Monitor Market Trends, Optimize Budget Allocations, Analyze Client Requirements, Analyze Customer Acquisition Costs
100%	Implement data-driven marketing, Align ATL/BTL services
Local	**W1 and W2:** Leverage Technological Capabilities, Integrate Systems, Develop Strategic Plans, Evaluate Ad Tech Investments **W1 and W3:** Leverage Technological Capabilities **W1 and W4:** Develop Strategic Plans, Identify Organisational Priorities, **W2 and W3:** Leverage Technological Capabilities, Develop Digital Ad Strategy **W2 and W4:** Implement Programmatic Bidding, Develop Strategic Plans **W3 and W4:** Monitor Ad Campaign Performance

After identifying activities, a "Tentative Primary-Task Model" was developed. This model is constructed based on the concepts outlined in Table 6 and their relationships, as illustrated in Appendix 3. The next step in the CPTM development involves creating a "Test model" derived from the Tentative Primary-Task Model. This process begins by extracting a root definition from the Tentative Primary-Task Model, which serves as the basis for constructing the Test model.

The text then indicates that a root definition follows, but it's not provided in the excerpt you've shared. This root definition would typically encapsulate the core purpose and components of the system being modelled.

A system owned by senior management and operated by cross-functional teams, including strategic planners, digital marketers, financial analysts, project managers, customer service representatives, and technological experts, to transform organisational priorities, consumer insights, market trends, financial resources, and technological capabilities into optimised digital advertising campaigns and brand promotion strategies. This system aims to achieve project objectives, maximise return on investment, and enhance customer satisfaction through the development and implementation of strategic plans, digital ad strategies, and advertising campaigns. The system functions by analysing client requirements, defining project requirements, developing project plans, and optimising budget allocations while ensuring regulatory compliance and leveraging technological capabilities. It continuously monitors ad campaign performance, project progress, and market trends to implement adaptive strategies and programmatic bidding. Key performance indicators, including return on ad spend, customer acquisition costs, brand awareness metrics, and overall project success rates, measure the success of the system.

Using the previously mentioned root definitions, a Test model was developed, as shown in Appendix 5. Following this, representatives from each mindset were brought together for meetings. The purpose of these gatherings was to scrutinize the root definition and the Test model, aiming to refine the Test model and achieve consensus. These meetings were conducted as unstructured interviews, primarily focusing on critiquing the Test model. Rather than following a predetermined list of questions, the discussions centred on evaluating and improving the Test model.

In total, two meetings were conducted with representatives from various groups: Financial Analysts, Technical Experts, Marketing Strategists, and Planning Managers. The outcome of these meetings revealed specific demands from different units or departments. The text suggests that these demands would be listed next, but they are not included in the excerpt you have provided. This process demonstrates an iterative approach to model development, where initial models are created, tested, and then refined based on input from various stakeholders.

Financial Analysts: According to financial analysts, defining ad spend efficiency metrics and monitoring financial forecasts are critical activities in optimising digital marketing strategies and enhancing financial performance. The definition of ad spend efficiency metrics involves establishing a comprehensive set of measures to accurately evaluate advertising expenditure across digital channels. These metrics typically include CPA, LTV/CAC, and channel-specific performance indicators.

Technical Experts: Technical experts emphasise the importance of establishing RTB infrastructure and developing marketing automation scripts in digital advertising. RTB infrastructure requires integrating both demand and supply side platforms in advertising, and ad exchanges, along with algorithms for rapid bid placement. Marketing automation scripts streamline processes like email marketing and lead scoring, integrating with CRM systems and analytics platforms. Both activities necessitate robust, scalable infrastructure capable of handling real-time data processing.

Marketing Strategists: Marketing strategists emphasize the importance of redefining target audience segmentation in digital advertising. This process involves analyzing diverse data sources to move beyond traditional demographic segmentation, incorporating psychographic and behavioural factors. Advanced analytics and machine learning are used to identify micro-segments with specific needs and behaviours.

Planning Managers: Planning managers emphasise the importance of implementing agile methodologies, setting Objectives and Key Results (OKRs), and monitoring capacity planning in digital advertising strategies. Agile methodologies enable more flexible and responsive

project management, allowing teams to adapt quickly to changing market conditions and campaign performance. OKR setting provides a framework for aligning team efforts with organizational goals, ensuring that advertising initiatives contribute directly to broader business objectives.

After evaluating the Test model, stakeholders refined it by adding multiple activities and removing one. This process resulted in the CPTM. Table 8 details these changes, while Appendix 3 provides a comprehensive view of the CPTM. This iterative approach ensured that the final model incorporated diverse perspectives and addressed stakeholder concerns.

Table 7. Added and removed activities in CPTM

The activities added to the CPTM
Define Ad Spend Efficiency Metrics, Monitor Financial Forecasting, Establish RTB Infrastructure, Develop Marketing Automation Scripts, Implement Agile Methodologies, Implement OKR Setting, Monitor Capacity Planning, Redefine Target Audience Segmentation

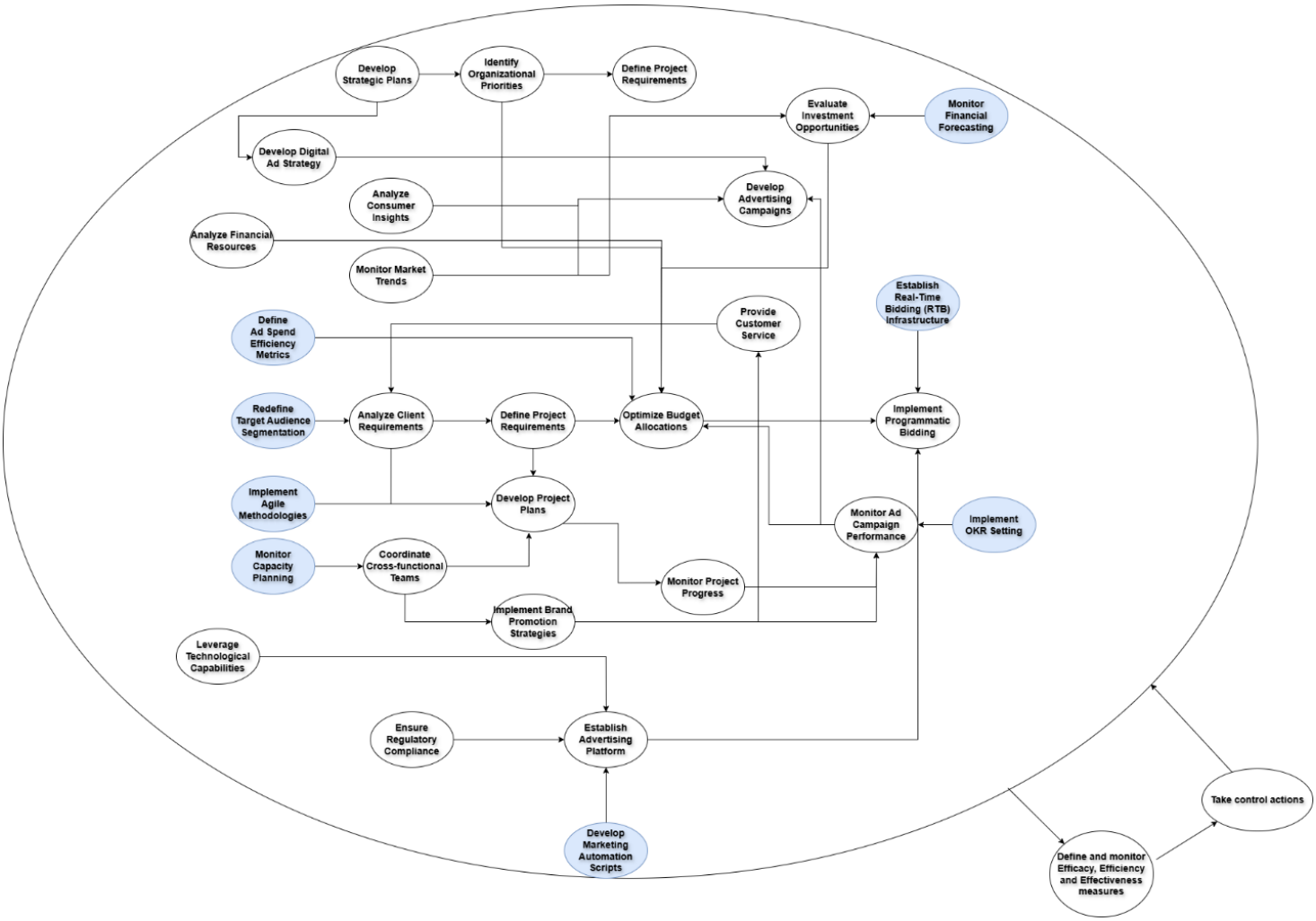

Figure 7. Final CPTM

5.4. Debate and discussion phase

The CPTM developed earlier serves as the foundation for structured discussions and debates in this phase. Involving diverse stakeholders leads to dynamic and energetic exchanges of ideas. This stage focuses on identifying roles crucial for implementing digital advertising model activities. It also enables a proper definition of governance elements in the model's execution, ensuring a comprehensive approach to digital advertising implementation.

Table 8. Digital advertising model activities and implementation

Activity	Exist/ Not Exist	Current mechanism	Performance measurement	Proposed changes	Roles	Required procedural changes	Required structural changes	Required attitudinal changes
Evaluate Investment Opportunities	Exist	Financial analysis, risk assessment	ROI, NPV, IRR	Use AI for predictive analytics	Financial analysts	Train staff on new AI tools	Integrate AI tools	Foster data-driven decision-making
Develop Advertising Campaigns	Exist	Creative teams, marketing research	Campaign reach, engagement	Integrate cross-platform analytics	Marketing team	Update campaign tracking processes	Cross-functional collaboration	Encourage innovative thinking
Provide Customer Service	Exist	Call centres, online support	Customer satisfaction scores	Implement AI chatbots	Customer service reps	Train staff on AI systems	Enhance the IT infrastructure	Promote a customer-centric approach
Monitor Project Progress	Exist	Project management software	Milestone completion, KPIs	Use real-time dashboards	Project managers	Update project tracking protocols	Real-time data integration	Embrace transparency in progress
Optimize Budget Allocations	Not Exist	Financial planning tools	Budget variance, efficiency	Implement automated budget optimisation	Financial planners	Update budgeting software	Integrate AI for budgeting	Adopt a proactive cost management
Define Project Requirements	Exist	Stakeholder meetings, requirement docs	Requirement satisfaction	Use agile methodologies for requirements	Business analysts	Shift to agile requirement gathering	Agile team structures	Encourage iterative feedback
Develop Strategic Plans	Exist	SWOT analysis, market research	Strategic goal achievement	Incorporate scenario planning	Strategy team	Enhance scenario analysis processes	Strategic Foresight Division	Foster long-term thinking
Identify Organisational Priorities	Exist	Leadership meetings, strategic sessions	Priority alignment	Use OKRs for prioritisation	Executives	Implement OKR framework	Streamline decision-making	Promote alignment and focus
Define Project Requirements	Not Exist	Stakeholder interviews, workshops	Requirement fulfillment	Use user stories and agile backlog	Business analysts	Adopt agile user stories format	Agile team structures	Embrace continuous refinement
Develop Project Plans	Exist	Gantt charts, project software	On-time delivery, budget adherence	Integrate agile planning tools	Project managers	Transition to agile planning methods	Create cross-functional teams	Promote flexibility and adaptability
Implement Brand Promotion Strategies	Not Exist	Marketing campaigns, PR	Brand awareness, engagement	Leverage influencer marketing	Marketing team	Update promotion tactics	Utilize new media channels	Encourage creative engagement
Coordinate Cross-functional Teams	Exist	Team meetings, collaboration tools	Team synergy, project success	Use integrated collaboration platforms	Team leads	Enhance team coordination processes	Flatten hierarchical structures	Promote interdepartmental collaboration
Analyze Client Requirements	Exist	Client interviews, surveys	Client satisfaction, requirement fit	Implement client feedback loops	Client managers	Create continuous feedback systems	Improve client communication channels	Prioritize client feedback in processes

Activity	Exist/ Not Exist	Current mechanism	Performance measurement	Proposed changes	Roles	Required procedural changes	Required structural changes	Required attitudinal changes
Monitor Market Trends	Exist	Market research, trend analysis	Market share, trend adaptation	Use predictive analytics	Market analysts	Update market analysis techniques	Invest in analytics tools	Encourage proactive market adaptation
Analyze Consumer Insights	Exist	Consumer surveys, focus groups	Consumer satisfaction, insights utilization	Use big data analytics	Consumer researchers	Integrate advanced analytics	Enhance data collection methods	Foster a data-driven culture
Develop Strategic Plans	Exist	SWOT analysis, strategic frameworks	Strategic goals achievement	Integrate digital transformation strategies	Strategy team	Update strategic planning frameworks	Form digital transformation teams	Embrace digital-first mindset
Develop Digital Ad Strategy	Not Exist	Digital marketing tools, analytics	Ad performance, ROI	Use advanced programmatic advertising	Digital marketers	Update digital ad processes	Enhance digital infrastructure	Foster innovation in digital marketing
Leverage Technological Capabilities	Exist	IT solutions, digital tools	Tech utilization, innovation rate	Invest in emerging technologies	IT and innovation teams	Create a technology adoption roadmap	Enhance IT support structures	Promote a culture of innovation
Monitor Capacity Planning	Exist	Resource management software	Resource utilization, capacity vs. demand	Use real-time capacity planning tools	Operations managers	Update capacity planning processes	Enhance resource management	Foster proactive capacity management
Implement Agile Methodologies	Not Exist	Scrum, Kanban	Agile metrics, sprint success	Expand agile to more teams	Agile coaches	Train more teams in agile practices	Restructure teams to be agile	Encourage an agile mindset across the organization
Redefine Target Audience Segmentation	Not Exist	Market segmentation tools	Target audience reach, engagement	Use advanced AI for segmentation	Marketing analysts	Update segmentation tools	Enhance data analysis capabilities	Embrace precision marketing
Leverage Technological Capabilities	Exist	Tech stack optimization	Innovation rate, tech utilization	Adopt new digital marketing tools	IT and digital teams	Update tool adoption processes	Integrate the latest tech tools	Promote continuous learning
Monitor Financial Forecasting	Exist	Financial models, forecasting tools	Forecast accuracy	Use AI for improved forecasting	Financial analysts	Train staff on AI forecasting tools	Integrate AI forecasting systems	Foster predictive financial management
Establish Real-Time Bidding (RTB) Infrastructure	Not Exist	Ad bidding platforms	RTB efficiency, ad performance	Enhance RTB algorithms	Digital advertising team	Update bidding processes	Invest in RTB technology	Embrace real-time decision-making
Implement Programmatic Bidding	Not Exist	Programmatic ad platforms	Bidding efficiency, ROI	Use advanced programmatic tools	Digital advertising team	Update programmatic bidding processes	Invest in programmatic tech	Encourage data-driven bidding strategies
Monitor Ad Campaign Performance	Exist	Analytics dashboards	Campaign metrics, ROI	Use AI for deeper insights	Digital marketers	Enhance performance tracking	Integrate AI analytics	Promote continuous improvement
Implement OKR Setting	Exist	Strategic goal-setting tools	OKR achievement	Use OKR software for tracking	Executives, team leads	Implement OKR tracking processes	Align team goals with OKRs	Foster goal alignment and accountability
Develop Marketing Automation Scripts	Not Exist	Automation tools	Automation efficiency, lead conversion	Use AI for script optimisation	Marketing automation team	Update automation processes	Invest in advanced automation tools	Promote a culture of efficiency
Establish Advertising Platform	Not Exist	Third-party platforms	Platform engagement, ROI	Create a proprietary ad platform	Digital team	Develop ad platform setup processes	Invest in platform development	Embrace platform-based advertising

6. Discussion and conclusion

This study presents a novel approach to designing a digital advertising model that employes systems thinking and considers multiple worldviews. The resulting model is comprehensive, addressing not only business aspects but also project management, technical considerations, and strategic elements of the implementing company. This holistic approach represents a significant advancement in the field of digital advertising research. Unlike previous studies that focused on singular aspects of digital advertising, this research encompasses all facets of digital advertising, including strategic, tactical, and operational dimensions. While Lee and Cho (2020) provided a foundational definition of digital advertising and identified key trends, and Taylor (2009) discussed factors contributing to the Internet's rise as a major advertising medium, our study builds upon these insights by integrating them into a comprehensive model that considers multiple perspectives. The pragmatic and action research approach adopted in this study allowed for the implementation and refinement of the model in practice. This methodology enhances the practical value of the research for both scholars and practitioners in the field of digital advertising, addressing the gap identified by Gordon et al. (2021), who noted that certain practical aspects of campaign planning and execution has been previously overlooked.

One of the key strengths of this study is its integration of systems thinking into the design of a digital advertising model. By considering various worldviews, including financial sustainability, technological innovation, market dominance, and project management, the model provides a more balanced and realistic representation of the digital advertising landscape. This multifaceted approach builds on the holistic framework of the digital advertising ecosystem proposed by Chen et al. (2016), which covers technical, social, and political implications. The model's consideration of project management and technical aspects alongside business elements is particularly noteworthy. This integration recognises the interdependencies between various organisational functions and the necessity of alignment in executing successful digital advertising campaigns. The current study extends the work of Bruce et al., (2017), who presented a dynamic model measuring the effects of ad formats, content, and targeting on performance over time by incorporating these elements into a broader organisational context. While previous research has often focused on specific techniques or channels, such as Cheng et al. (2009), which compared attitudes towards different types of interactive digital advertising, this study provides a holistic view of the digital advertising ecosystem. This approach enables practitioners to develop more coherent and effective advertising strategies that consider the interplay between different levels of decision-making and implementation.

The action research methodology employed in this study is particularly valuable in bridging the gap between theory and practice. By implementing and refining the model in real-world scenarios, the research offers insights that are directly applicable to the challenges faced by digital advertising professionals. This practical orientation addresses the concerns raised by Truong and Simmons (2010) regarding the lack of focused work on the intrusive aspects of digital advertising, providing a framework for addressing such issues. Our model also incorporates consumer perspectives, building on the work of Aiolfi et al., (2021) on data-driven digital advertising and online behavioural advertising.

6.1. Limitations and future avenues for research

While this study makes a significant contribution to digital advertising research, its limitations include the scope of implementation, which may limit generalizability across different organisational contexts. The rapidly evolving nature of digital technology and consumer behaviour necessitates frequent model updates. The study may not have captured all relevant perspectives, and the action research approach could have introduced biases. Each component of the model could benefit from more in-depth analysis. The integration with traditional advertising methods and the ethical implications of advanced techniques were not fully explored. Future research avenues include cross-cultural studies, integration of emerging technologies and industry-specific variations of the approach adopted in this study. These areas of exploration will further enhance our understanding and implementation of effective digital advertising strategies in an increasingly complex landscape.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix 1: Interviewees' data, and codes elicited from each interview

No	Mindsets	The data of interviewees (the relevant work experience)	Concepts (codes)
1	1	CFO with 15 years of experience in digital advertising firms	Evaluate Investment Opportunities, Analyze Financial Resources, Optimize Budget Allocations, Set Financial Metrics, Monitor Financial Performance
2	1	Financial Manager with 10 years of experience in ad tech companies	Evaluate Ad Tech Investments, Leverage Technological Capabilities, Integrate Systems, Analyze Client Requirements
3	1	Senior Strategy Manager with 12 years of experience in marketing agencies	Develop Strategic Plans, Identify Organizational Priorities, Implement Adaptive Management, Ensure Regulatory Compliance
4	1	COO with 8 years of experience in digital marketing operations	Optimize Budget Allocations, Implement Adaptive Management, Monitor Financial Performance, Analyze Client Requirements
5	2	Senior Software Engineer with 8 years in ad tech	Drive Innovation, Develop Software, Leverage Technological Capabilities
6	2	UX Designer with 6 years in digital advertising platforms	Design User Experience, Monitor Market Trends, Establish Advertising Platform
7	2	CTO with 12 years in digital marketing companies	Evaluate Ad Tech Investments, Develop Strategic Plans, Allocate Development Resources
8	2	Senior Systems Architect with 10 years in ad tech	Integrate Systems, Establish Advertising Platform, Ensure Regulatory Compliance
9	2	Technical Product Manager with 7 years in digital advertising	Provide Customer Support, Develop Digital Ad Strategy, Monitor Market Trends
10	3	Senior Account Strategist with 10 years in digital marketing agencies	Analyze Client Requirements, Develop Digital Ad Strategy, Provide Customer Service, Develop Advertising Campaigns
11	3	Digital Marketing Director with 8 years in e-commerce	Leverage Technological Capabilities, Implement Brand Promotion Strategies, Ensure Regulatory Compliance, Develop Digital Ad Strategy
12	3	Chief Strategy Officer with 12 years in ad tech companies	Monitor Market Trends, Monitor Ad Campaign Performance, Implement Programmatic Bidding, Optimize Budget Allocations
13	4	Senior Project Manager with 10 years in digital advertising agencies	Develop Strategic Plans, Identify Organizational Priorities, Analyze Client Requirements, Coordinate Cross-functional Teams, Develop Project Plans, Monitor Project Progress
14	4	Program Director with 12 years in ad tech companies	Monitor Market Trends, Ensure Regulatory Compliance, Optimize Budget Allocations, Implement Programmatic Bidding, Monitor Ad Campaign Performance

Appendix 2: Selected Interviews, Extracted Codes, and Relevant Conceptual Model

Interview (summarized)

Respondent (CFO with 15 years of experience in digital advertising firms):

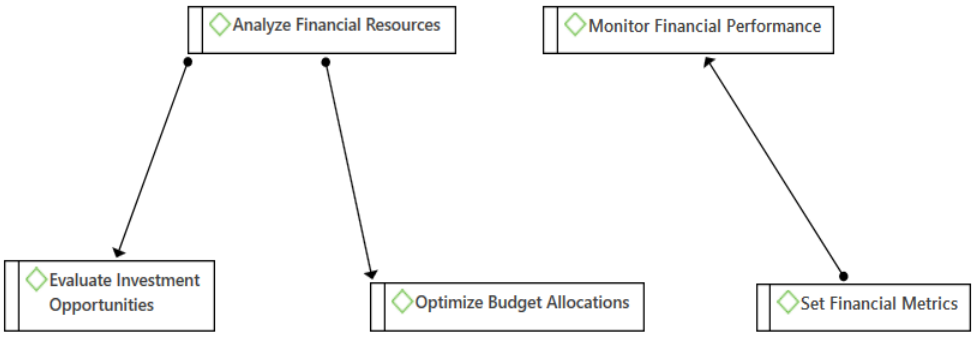
"Certainly. Our financial management process in digital advertising is interconnected and cyclical. We start by analyzing our financial resources, which directly informs how we evaluate investment opportunities. This analysis is crucial because it determines our capacity for new investments and helps us identify areas where we can optimize our budget allocations. Once

we've evaluated potential investments and optimized our budget, we set clear financial metrics. These metrics are tailored to each project or campaign and serve as our benchmarks for success. They might include ROI, ROAS (Return on Ad Spend), or customer acquisition costs, depending on the specific goals of each initiative. With these metrics in place, we then continuously monitor our financial performance. This ongoing monitoring is directly tied to the financial metrics we've set. It allows us to assess whether our budget allocations are effective and if our investments are yielding the expected returns. The results of this performance monitoring then feed back into our analysis of financial resources. If we're exceeding our targets, we might identify opportunities for further investment. If we're falling short, we might need to re-evaluate our budget allocations or investment strategies. This cycle of analysis, evaluation, optimization, setting metrics, and monitoring performance ensures that we're always making data-driven financial decisions in our digital advertising efforts. It allows us to be agile, adjusting our strategies based on real-time performance data, and helps us maximize the return on our advertising investments."

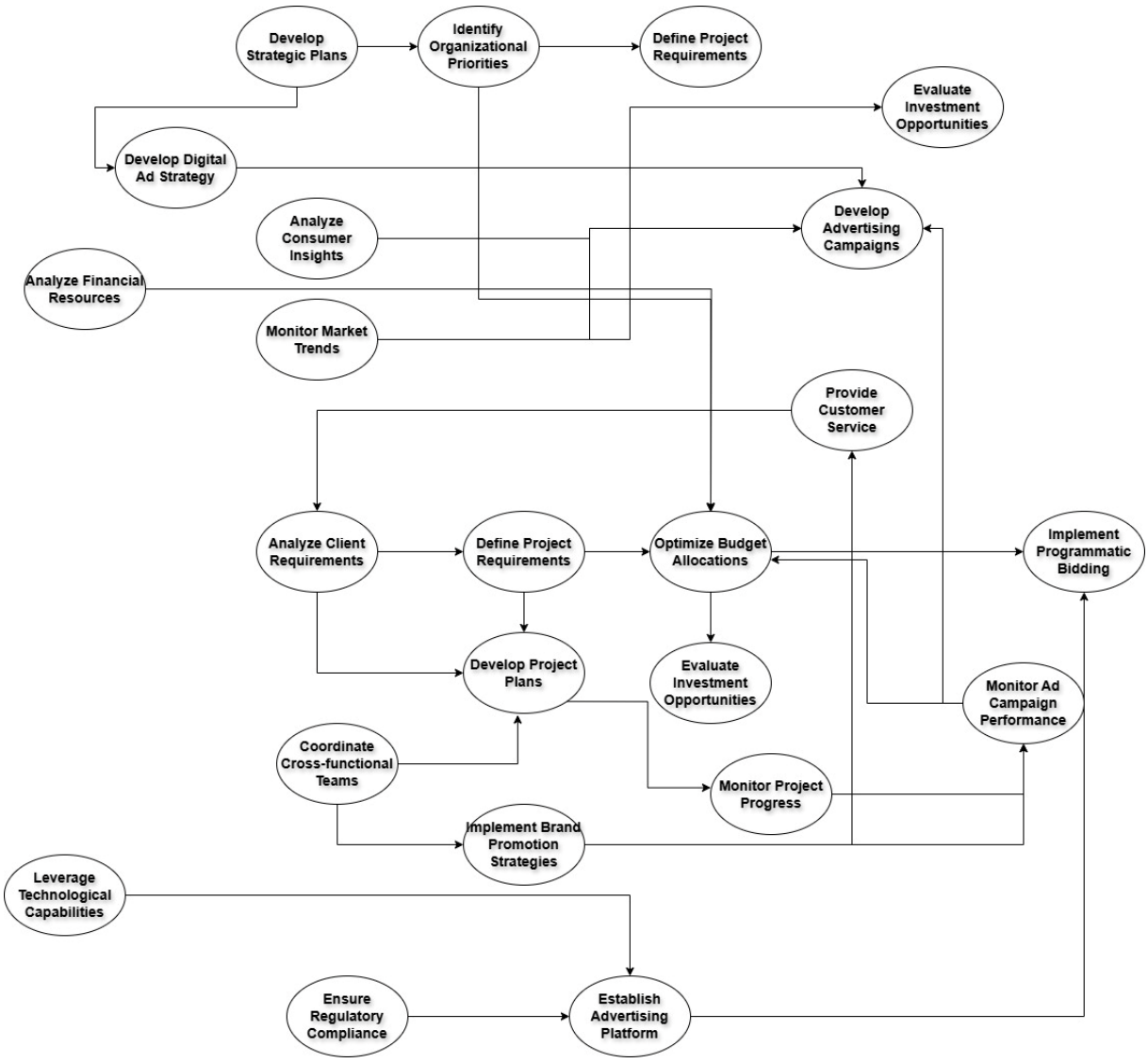
The codes elicited from the interview

Evaluate Investment Opportunities, Analyze Financial Resources, Optimize Budget Allocations, Set Financial Metrics, Monitor Financial Performance

Conceptual model



Appendix 3: CPTM



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Simulating the Impact of Blood Donation Policies on Donor Behavior in the Blood Supply Chain During the COVID-19 Pandemic

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ABSTRACT

The SARS-CoV-2 virus, which causes COVID-19, spread globally, disrupting various aspects of daily life and significantly affecting blood transfusion services and donation patterns. One of the primary factors contributing to the decline in donations was the fear and safety concerns of donors about contracting the virus at donation centres. This created immense pressure on blood transfusion facilities. To prevent a shortage of blood products, it became crucial to maintain donor engagement throughout the pandemic. This study investigates the impact of COVID-19 on blood donor behaviour and evaluates two strategies aimed at mitigating the decrease in donations: increasing public awareness through advertising and enhancing donation accessibility via mobile units. Using system dynamics modelling, a simulation was conducted with real data from 2018 to 2022. The results show a significant decline in first-time, sporadic, and repeat donors during the pandemic. While advertising policies initially increased donations, their effectiveness waned over time due to overcrowded donation centres and ongoing safety concerns. In contrast, the mobile unit strategy consistently increased donations, without experiencing a subsequent decrease. These findings underscore the importance of adaptive, context-sensitive policies to ensure a stable blood supply during public health crises.

Keywords

COVID-19, Blood donation incentive policies, Fear and safety concerns, Ease of donation, Advertising.

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1. Introduction

Blood donations tend to rise during short-term crises such as natural disasters, with many new donors registering in response to public appeals (Feeny and Clarke, 2007; Hess and Thomas, 2003).The COVID-19 pandemic severely disrupted blood supplies worldwide, with donations decreasing by 40–67% in areas with movement restrictions (Raturi and Kusum, 2020). In Iran, a 35% drop in blood donations was reported during the early phase of the pandemic (Moghimisfandabadi et al., 2023).

Beyond the fear of infection, logistical barriers such as travel restrictions and closure of donation sites had long-term effects on donor participation .Crises also shift donor motivations some people feel more socially responsible, while others avoid donating due to fear or inconvenience (Swanson, 2020). Most existing studies focus on short-term crises and immediate donor responses. However, there is limited research on the long-term effects of global health crises, like the COVID-19 pandemic, on donor behaviour. This gap is significant, as pandemics tend to cause extended disruptions in blood supply chains and alter donor motivations beyond the immediate aftermath.

Fear of infection and travel bans were major factors in the decline in donations during COVID-19 (Hakami et al., 2022). Sustaining donor motivation is essential, as the more time passes since the donation, the less likely the donor is to donate again (Kazemi Babaahmadi et al., 2023; Thomas et al., 2015). The main innovation of this study lies in employing a system dynamics approach to model long-term behavioural interactions among blood donors and to simulate the effects of various policies throughout a large-scale health crisis. One of them is the COVID-19 pandemic, an area that has received limited attention in previous research. To address this gap, this study seeks to answer the following research question: How can various policy interventions (e.g., awareness campaigns, mobile units) mitigate long-term donation decline among different donor types during pandemics?

This study aims to identify the most effective policy levers to mitigate donation decline during pandemics by simulating various scenarios. So, this study uses a system dynamics approach to analyse how COVID-19 and policies like advertising and mobile units affect donor behaviour over time, capturing interactions among fear, logistics, policy interventions, and supply chain disruptions. The system dynamics approach has been adopted because it effectively models complex interactions over time, including feedback loops, delays, and behaviour change patterns, which are common in health crises. Unlike traditional statistical or

optimisation methods, system dynamics allows for the simulation of evolving donor responses and policy impacts across different phases of a pandemic.

To better understand the impact of the pandemic, donors are divided into three key categories: repeat, sporadic, and first-time (Thomas et al., 2015). Repeat donors are typically more consistent due to intrinsic motivation, while first-time and sporadic donors are more sensitive to fear and access issues, which can result in larger fluctuations in donation behaviour during emergencies. Ensuring a stable blood supply requires understanding the unique behaviours of different donor types this study offers that distinction by modelling the behaviours of different donor types and examining the pandemic's effects on each group.

While most existing studies have focused on short-term donation behaviour (Zou, 2006; Veseli et al., 2022), this study provides new insights into how various policy interventions can influence different donor groups during extended health emergencies by shifting the focus to long-term donor behaviour. Using a system dynamics approach, the study captures how these interventions interact with behavioural patterns over time, offering a dynamic understanding of policy effectiveness.

This study's findings will have broader implications for future health crises, particularly in terms of how donor behaviour can be maintained or even improved during pandemics. By understanding the behavioural dynamics that influence blood donation, healthcare systems can better prepare for future crises. This includes developing targeted policies that address donor fear, barriers to donation, and the need for ongoing donor engagement. In particular, the research will contribute to understanding how to sustain a healthy and willing donor population during emergencies, ensuring blood supply chains remain resilient not only in the current pandemic but also in future public health emergencies.

2. Literature review

In this section, we explore various studies related to blood supply chains, donor behaviour, and the impact of crises, such as the COVID-19 pandemic, on blood donations.

Diabat et al. (2019) proposed a bi-objective optimization model to design resilient blood supply chains during disaster scenarios. Their approach minimises delivery time and disruptions, focusing primarily on logistical challenges. While their model is helpful in disaster management, it overlooks the social factors influencing donor behaviour, which are crucial in understanding blood donation dynamics during crises. Haghjoo et al. (2020) developed a robust model for blood supply chain network design, considering facility construction costs and post-disaster risk. While this study is valuable for optimising logistical operations, it does not address

the role of donors in such environments, failing to account for how donor willingness might fluctuate during or after a crisis. Hamdan and Diabat (2020) employed a stochastic optimisation model to minimise blood delivery time and costs in post-disaster supply chains. Like other logistics-focused studies, their work primarily concerns operational efficiency and does not explore the dynamics of donor behaviour, a significant factor when assessing blood donation during emergencies. Cheraghi and Hosseini-Motlagh (2020) created a stochastic programming model for managing red blood cell supply chains. This model focuses on minimising supply chain costs and ensuring blood availability, but fails to consider the evolving nature of donor behaviour, which is essential to understanding long-term blood donation patterns during crises. Seyfi-Shishavan et al. (2023) examined ways to reduce blood shortages and supply chain costs in Istanbul, proposing a multi-cycle model that accounts for disaster risks. While this approach addresses logistical concerns, it does not focus on the social and behavioural aspects of donor behaviour or the challenges faced by donors in crises.

Montazeri Takhti et al. (2016) evaluated the impact of advertising on blood donation, finding that TV advertisements had a greater impact on donation rates than other media. While their findings are insightful for short-term donor engagement strategies, they do not explore the long-term behavioural effects of crises, such as pandemics, on blood donation motivation. Hakami et al. (2022) investigated the impact of COVID-19 on blood donation services in Saudi Arabia, revealing significant disruptions resulting from quarantine measures. While their study provides insights into the immediate effects of COVID-19 on donor behaviour, it lacks a deeper exploration of the long-term effects of pandemics on blood supply chains. Kazemibabaahmadi and Kheirandish (2022) examined the effects of COVID-19 on blood transfusion centres, highlighting the introduction of new policies to protect donors. Their research primarily addresses logistical and safety measures but fails to explore how such policies influenced donor decision-making or affected their willingness to donate during and after the pandemic. Veseli et al. (2022) compared the impact of COVID-19 on repeat and first-time donors, finding that both groups became less motivated to donate. This study provides insights into donor behaviour during the pandemic, but it does not examine the underlying causes of the decline in motivation over time**.** Moghimisfandabadi et al. (2023) focused on blood product supply chain performance and suggested that increasing the number of blood donation sites would improve performance. While their findings are useful for optimising logistics and infrastructure, they do not consider the broader behavioural and social factors that influence donor participation, particularly during crises.

Siu et al. (2025) examined the barriers to blood donation during the COVID-19 pandemic among non-donors and lapsed donors in Hong Kong. Their study highlighted that pre-existing psychosocial factors, such as lack of trust and low-risk perception, significantly affected donation decisions during the pandemic. While insightful, their study relies primarily on cross-sectional data and does not capture dynamic behaviour changes over time, limiting its applicability for long-term crisis response planning. Weng et al. (2024) investigated the influence of modern media, particularly social media and online videos, on blood donation behaviour in the post-pandemic era. They found that emotionally charged narratives and visual storytelling significantly boosted donation rates, especially among younger populations. Although the study sheds light on communication strategies, it does not explore how these tools interact with behavioural patterns over time, missing a systems-level understanding of motivation dynamics. Dorner and Csordás (2025) explored the psychological determinants of blood donation willingness during the COVID-19 pandemic in Hungary. The study identified self-efficacy, altruism, and emotional barriers as key factors influencing donor behaviour. However, their analysis remains static and survey-based, without modelling how these variables evolve or respond to interventions, thus limiting insights for long-term policy effectiveness.

Table 1. Review of articles on blood supply during crises and pandemics

No	Article	Model/Approach	Main Focus	Gaps and Limitations	Analysis of Long-term Impact	Role of Crises and Epidemics
1	**Diabat et al. (2019)** – *Bi-objective Optimisation Model for Blood Supply Chains during Disasters*	Bi-objective optimization for disaster supply chain design	Focuses on minimising delivery time and disruptions	Does not account for donor behaviour in crisis scenarios	Lacks long-term focus on donor engagement	Does not address donor behaviour during prolonged crises
2	**Haghjoo et al. (2020)** – *Robust Model for Blood Supply Chain Network Design*	Robust optimization model for post-disaster blood supply	Focus on cost and facility construction	Ignores the role of donors during or after crises	Does not examine donor willingness or long-term engagement	No focus on donor behaviour or changes during crisis
3	**Hamdan and Diabat (2020)** – *Stochastic Optimisation for Post-disaster Blood Supply Chains*	Stochastic optimization for delivery time and cost reduction	Focuses on operational efficiency	Ignores social factors and donor behaviour	Does not explore behavioural aspects or long-term donor participation	Does not consider the long-term crisis impact on donors
4	**Cheraghi & Hosseini-Motlagh (2020)** – *Stochastic Programming for Red Blood Cell Supply Chains*	Stochastic programming model for supply chain management	Focuses on cost reduction and the availability of blood	Lacks consideration for evolving donor behaviour	Does not account for long-term donor participation	Does not address donor behaviour in prolonged crises
5	**Seyfi-Shishavan et al. (2023)** – *Reducing Blood Shortages and Supply Chain Costs in Istanbul*	Multi-cycle model accounting for disaster risks	Focuses on logistical and disaster risk factors	Ignores the social factors affecting donor behaviour	No exploration of long-term donor behaviour changes	Does not consider donor behaviour challenges during crises
6	**Montazeri Takhti et al. (2016)** – *Impact of Advertising on Blood Donation*	TV advertisement impact on donation rates	Focuses on the short-term effects of advertising	Does not address the long-term impact of crises	No focus on the long-term effects of pandemics on donation motivation	Focuses on short-term donor engagement

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No	Article	Model/Approach	Main Focus	Gaps and Limitations	Analysis of Long-term Impact	Role of Crises and Epidemics
				on donor behaviour		without a crisis context
7	**Hakami et al. (2022)** – *Impact of COVID-19 on Blood Donation Services in Saudi Arabia*	Analysis of COVID-19 disruptions on blood donation	Focus on disruptions caused by quarantine measures	Lacks deeper exploration of long-term pandemic effects	Does not address long-term pandemic effects on donor behavior	Examines short-term COVID-19 effects but lacks long-term analysis
8	**Kazemibabaahmadi and Kheirandish (2022)** – *Impact of COVID-19 on Blood Transfusion Centers*	Analysis of new policies for donor protection	Focus on safety measures and logistical disruptions	Lacks exploration of how policies affect donor decision-making	Does not analyze donor behavior over time	Focuses on policies but does not address donor psychology during crises
9	**Veseli et al. (2022)** – *Impact of COVID-19 on Repeat and First-Time Donors*	Comparison of donor motivation before and during COVID-19	Focus on donor motivation changes during the pandemic	Does not explore underlying causes of motivation decline	Provides insights but lacks long-term analysis	Looks at immediate crisis impact but lacks long-term behavior analysis
10	**Moghimisfandabadi et al. (2023)** – *Blood Product Supply Chain Performance and Donation Sites*	Focus on increasing blood donation sites for better performance	Optimisation of logistics and donation infrastructure	Does not consider behavioural aspects of donor participation	Does not focus on donor behavior during crises	Focus on logistics without addressing donor behavior
11	**Siu et al. (2025)** *Barriers to Blood Donation during COVID-19 in Hong Kong*	Cross-sectional survey	Investigated barriers among non-donors and lapsed donors during COVID-19	Relies on static, cross-sectional data; lacks behavioral dynamics	No dynamic or long-term behavioral analysis	Focused on psychosocial barriers during COVID-19
12	**Weng et al. (2024)** *Impact of Modern Media on Blood Donation in the Post-Pandemic Era*	Observational study	Studied the effects of social media and visual storytelling on donation behaviour	Does not model the interaction of media with behavior over time	Lacks a systems-level or longitudinal perspective	Examines media influence in the post-COVID context
13	**Dorner and Csordás (2025)** *Psychological Determinants of Blood Donation in Hungary*	Survey-based analysis	Analyzed factors like self-efficacy, altruism, and emotional barriers	Static analysis; no modelling of behavioural evolution or interventions	Limited insight into time-based policy impact	Investigate psychological factors during COVID-19

2.1. Contributions of this research

Recent years have seen a growing interest in blood supply chains, with various studies examining logistical challenges and supply chain disruptions (e.g., Seyfi-Shishavan et al., 2023; Diabat et al., 2019; Hamdan and Diabat, 2020; Haghjoo et al., 2020). However, these studies predominantly focus on optimising supply chains during crises and tend to overlook the dynamic factors influencing donor behaviour, which are crucial in understanding blood donation patterns during emergencies.

Several studies have examined variables influencing donor behaviour and strategies to increase donor engagement, such as those by Moslemi et al. (2008), Montazeri Takhti et al. (2016), and Abolghasemi et al. (2009). More recent research on the impact of COVID-19 on

blood donations, including studies by Hakami et al. (2022), Spekman et al. (2021), Veseli et al. (2022), and Raghuwanshi et al. (2022), has provided valuable insights into the immediate effects of pandemics on donor behaviour. However, these studies are primarily qualitative or statistical and do not address the complex, dynamic decisions involved in blood donation during prolonged crises. Additionally, studies such as those by Veseli et al. (2022) and Hakami et al. (2022) focus on the immediate effects of pandemics but lack a systems approach to explore the long-term changes in donor behaviour.

This research aims to fill these gaps by applying a systems dynamics approach to model the long-term effects of COVID-19 on donor behaviour. By examining the interactions between factors such as donor fear and policy interventions, this study offers new insights into how blood donation behaviours evolve. Moreover, it provides recommendations for improving donor engagement during future crises, especially by focusing on the behavioural factors that influence donors' decisions.

3. Research methodology

Because the goal of the current research is to increase the number of donors during the COVID-19 pandemic, it is a practical endeavour. To determine the pattern of previous variations in the volume of donations and in repeat, sporadic, and first-time donors, the research employed data collection methods, including document studies, and utilised data from the Mashhad Blood Transfusion Centre's databases. All initial simulation data were collected monthly over a 60-month period starting in 2018 (1397 in the Iranian calendar). The historical data specifically included accumulation (stock) variables such as First-Time Donors (FD), Sporadic Donors (ED), and Repeat Donors (RD). System dynamics is used in this research due to the system's complexity, latency, and interconnectedness.

In this approach, the research problem is defined in the first step. The research problem, as mentioned earlier, is how to prevent a decrease in the number of people who donate blood under the influence of the spread of COVID-19. Then, based on the research background, the variables related to the problem and the boundary of the donor system are identified, as shown in Table 2.

Table 2. The boundary of the blood donation model in pandemic conditions

Exogenous Variables	Endogenous Variables	Subsystem
Migration to the region, Death, Migration from the region	Under 18 years old, Over 60 years old, Between 18 and 60 years old, Birth Rate,	population

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Exogenous Variables	Endogenous Variables	Subsystem
Recovey time, Infection Rate, Congestion in blood collection units, Vaccination rate	Death from epidemics, Infected, Recovered, Infecting, Susceptible, Vaccinated, fear and safety concerns	Pandemic disease
Ease of donation, The effect of the season, SMS, Advertising via virtual networks,	Time between donations, Percentage of people informed about the need for blood, Ready donors population, Re-donation from Advertising, Re-donation Appropriate treatment of staff, Potential donation population, Re-donation from Teaching, Percentage of public education in order to increase awareness and attitude, First time donors, Sporadic donors, Repeat donors	Blood donation

To define the boundary of the model and select the appropriate variables, this study relied on content analysis of previous literature and organizational documents. Additionally, six experts and specialists from the Mashhad Blood Transfusion Centre were consulted. Variables and their relationships were selected based on their relevance, impact on the donation process, and their importance in system behaviour. Subsequently, the selected variables and causal relationships were reviewed and validated by these experts to ensure their accuracy and appropriateness within the model.

3.1. The dynamic hypothesis and Causal loop diagram

The causal loop diagram shown in this study was created through several processes. Initially, a content analysis of the research background was used to identify key performance variables and factors influencing donors before designing the causal loop model. The subsequent stage involved identifying the associations between variables and the behaviour of the main performance measures, as well as completing the causal loop models through expert interviews. The causal loop diagram of the blood donation model during pandemic infections is displayed in Figure 1.

The dynamic hypothesis is that the blood centre can increase the number of blood donors by implementing various strategies, such as advertising the need for blood. As the number of potential donors increases, it leads to overcrowding at blood collection centres. Overcrowding at these centres causes fear and safety concerns among donors, leading to them postponing their blood donations. In other words, the time between two blood donations increases for repeat donors, and consequently, the number of potential donors decreases. Therefore, in policymaking, attention should be paid to the effective factors within the system, and appropriate policies should be selected and implemented.

3.2. Causal loop diagram

3.2.1. Population subsystem

Changes in the age structure of the population affect many activities and processes. The minimum acceptable age for donating blood is 18 years, and the maximum age is 60 years. Since the population has a dynamic structure, the population subsystem was considered. This subsystem has a reinforcing loop and two balancing loops.

In the first balancing loop, the population aged 18 to 60 increases due to the population under 18 after a certain period; as the population aged 18 to 60 increases, the population under 18 decreases. The second balancing loop illustrates the relationship between the population over 60 and the population aged 18 to 60.

In the reinforcing loop, as the population under 18 years increases, the population aged 18–60 increases with a delay. Consequently, as this age group increases, the birth rate rises, leading to a further increase in the population under 18 years, thus repeating the loop. In the model of blood donation in pandemic conditions, the population subsystem is highlighted in orange (Figure 1).

3.2.2. Pandemic subsystem

Since the pandemic has resulted in a significant decline in blood donations, the epidemic's subsystem and its consequences must be incorporated into the model. SIR models, which are well-known and authorized models in the study of disease outbreaks, served as the foundation for the creation of this subsystem. In the SIR model, simple assumptions are taken into consideration, such as mortality not being considered. The present study developed the SIR model and incorporated the variable of mortality due to pandemic disease, as well as the influence of vaccination, fear, and safety concerns, into the model. This subsystem has two reinforcing loops and four balancing loops, as shown in Figure 1. The population subsystem is displayed in red in Figure 1.

3.2.3. Subsystem of donors

In the blood donation system, three categories of donors are considered: first-time, sporadic, and repeat donors. Unfortunately, the rate of positive HBsAg was 40% in first-time donors and 6% in sporadic donors. HBsAg-positive samples were not observed in repeat donors (Ranjbarian, 2008). Therefore, one of the goals of the Blood Transfusion Organisation is to invest in repeat and sporadic donors and to encourage first-time donors who have healthy

screening tests to become repeat donors.

As shown in Figure 1, first-time donors can be encouraged to donate again through various means, including advertising, education, and increasing awareness and positive attitudes. With the increase in the number of repeat donors, the number of sporadic donors decreases. However, under the influence of activities such as advertising and education, first-time donors often become sporadic donors, resulting in a decrease in the number of first-time donors. This cycle is balanced, but the population of first-time donors is influenced by the potential donor audience. In the figure below, the population system is shown in green.

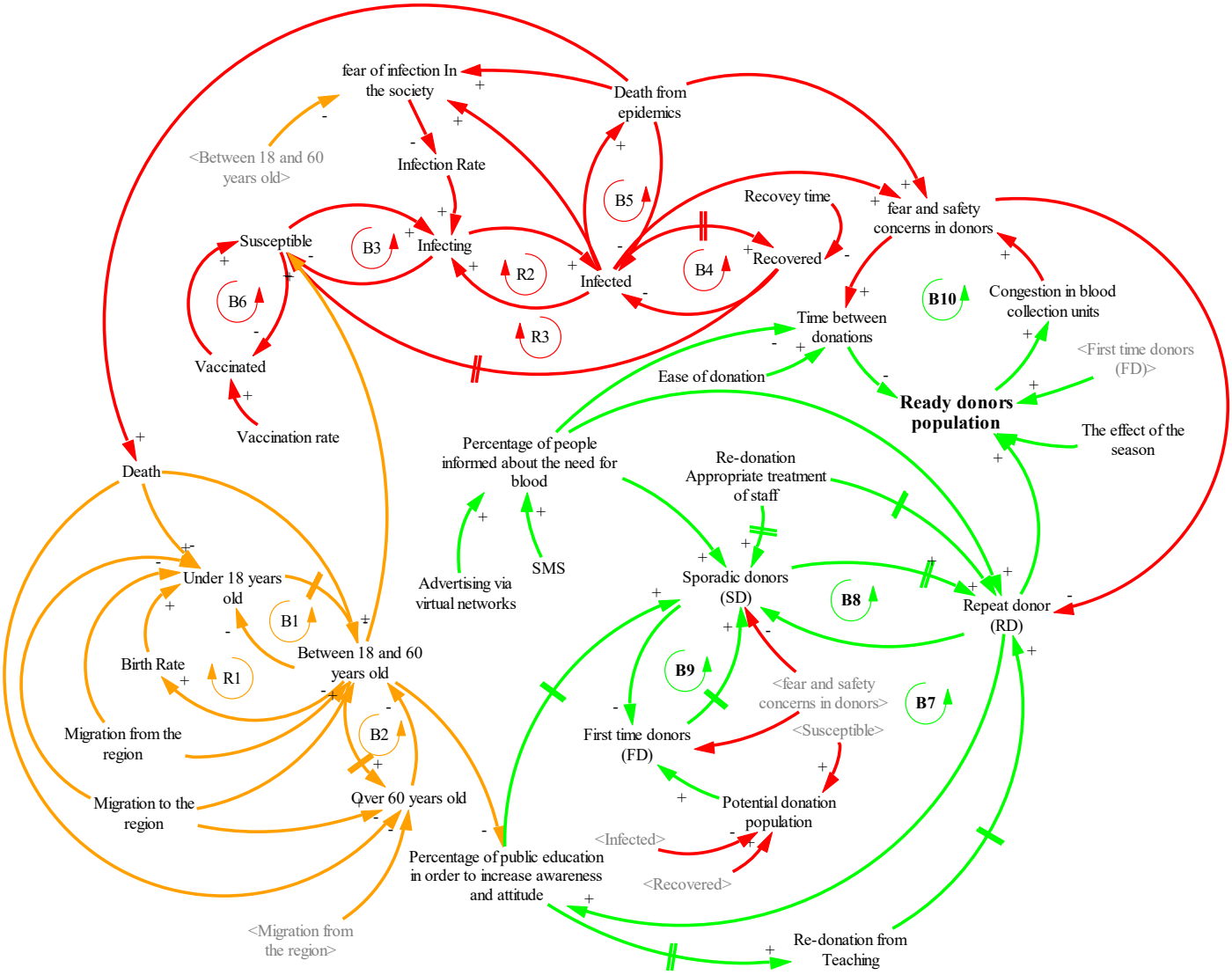

Figure 1. Causal loop diagram of blood donation model in pandemic conditions

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3.3. Stock and flow diagram

As shown in Figure 2, the relationship between the population subsystem and the blood donation subsystem, as measured by the population variable, ranges from 18 to 60. The pandemic disease subsystem causes the deaths of people in the population subsystem through the mortality variable caused by pandemic disease. Additionally, the population subsystem is linked to the pandemic disease subsystem through the variable of people between 18 and 65 years old. Of course, since the target blood donation model includes people between 18 and 65 years old, only this variable is considered in the pandemic disease subsystem.

The pandemic disease subsystem affects and reduces the potential population of blood donation subsystem donors through the ratio of susceptible, sick, and recovered individuals. Donors are also concerned about overcrowding in blood collection units, and as a result, the time interval between donations increases, even for repeat donors, leading to a decrease in all three donor groups.

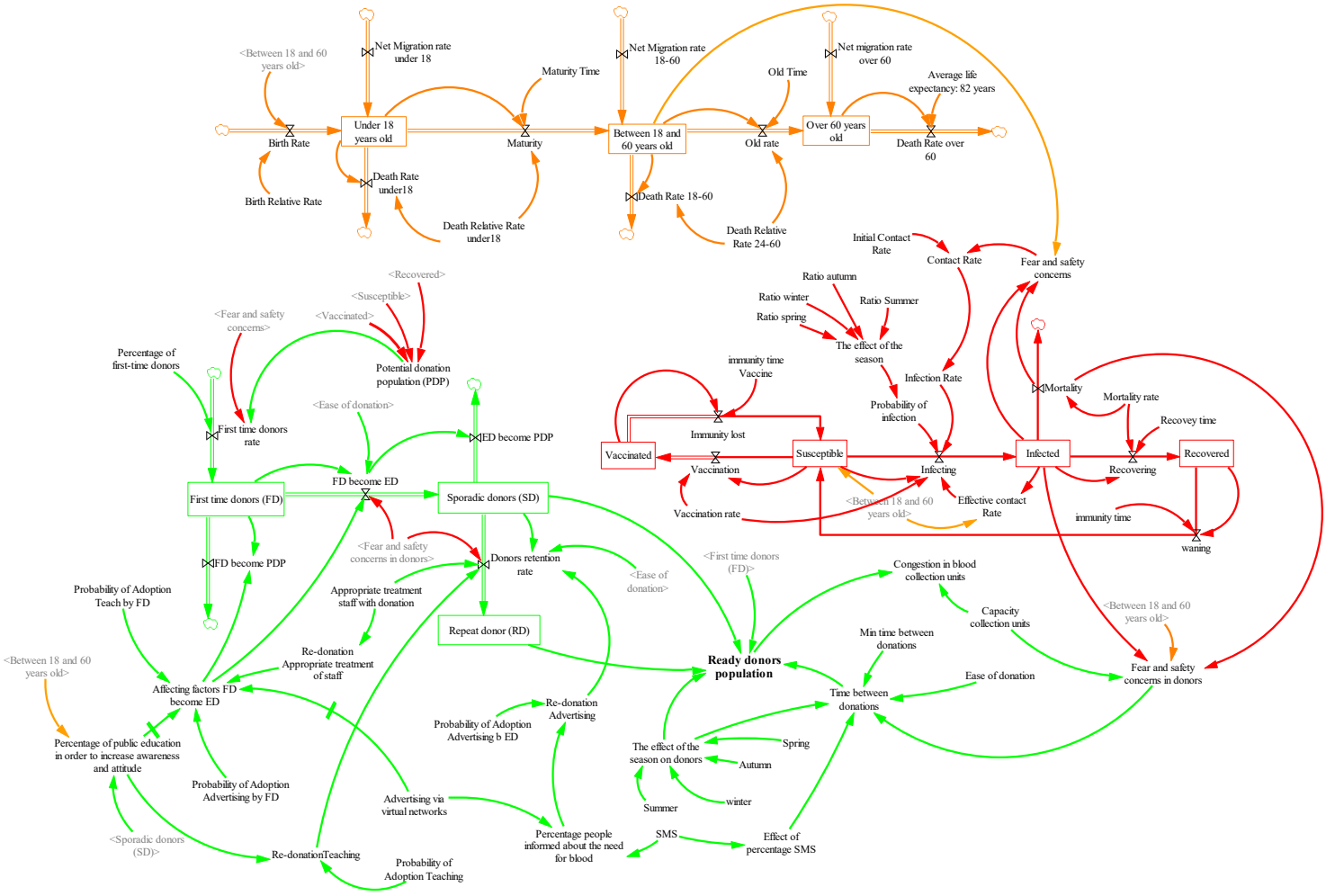

Figure 2. Stock and flow model of the blood donation model in pandemic conditions

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3.4. Formulation of the Stock and flow model

In this step, the connections between system components are formulated, transitioning from a conceptual (qualitative) state to a quantitative state, using relevant mathematical equations. In fact, by entering equations, mental models are linked to the real world. It should be noted that all simulations in the validation test were started in 2018. Simulation courses are monthly. Table 3 presents the formulas and changes in blood donation models under epidemic conditions. The values of the accumulation variables related to the year 2018 have been simulated and extracted from the documents and statistics of the Blood Transfusion Organisation.

Table 3 .The formula of some variables of the blood donation model in pandemic conditions

No	Variable name	Variable type	Equation	Unit	Reference	Value
1	Under 18 years old	Stock	Birth Rate+Net Migration rate under 18-Death Rate under18-Maturity	people	Khorasan Razavi statistics	2254350
2	Between 18 and 60 years old	Stock	Maturity+"Net Migration rate 18-60"-"Death Rate 18-60"-Old rate	people	Khorasan Razavi statistics	3772880
3	Over 60 years old	Stock	Net migration rate over 60+Old rate-Death Rate over 60	people	Khorasan Razavi statistics	592328
4	First time donors (FD)	Stock	First time donors rate-FD become ED-FD become PDP	people	Khorasan Razavi blood transfusion organization statistics	2271
5	Sporadic donor (SD)	Stock	FD become ED-Donors retention rate-ED becomes PDP	people	Khorasan Razavi blood transfusion organization statistics	3518
6	Repeat donor (RD)	Stock	Donor retention rate	people	Khorasan Razavi blood transfusion organization statistics	6802
7	Vaccinated	Stock	Vaccination-Immunity lost	people	Jahani (2020)	0
8	Susceptible	Stock	Immunity lost+waning-Infecting-Vaccination	people	Jahani (2020)	592128
9	Infected	Stock	Infecting-Mortality-Recovering	people	Jahani (2020)	150
10	Recovered	Stock	Recovering-waning	people	Jahani (2020)	0
11	Birth Rate	Rate	Birth Relative Rate*(Between 18 and 60 years old/2)	people/ Month	Experts	
12	Maturity	Rate	((1-Death Relative Rate under18)*Under 18 years old)/Maturity Time	people/ Month	Sterman (2000)	
13	Death Rate over 60	Rate	Over 60 years old/"Average life expectancy: 82 years"	people/ Month	Sterman (2000)	
14	Old rate	Rate	((1-"Death Relative Rate 24-60")*Between 18 and 60 years old)/Old Time	people/ Month	Sterman (2000)	
15	Death Relative Rate under18	Rate	Death Relative Rate under18*Under 18 years old	people/ Month	Sterman (2000)	
16	Death Rate 18-60	Rate	("Death Relative Rate 24-60"*Between 18 and 60 years old)+Mortality	people/ Month	Sterman (2000) + Researcher	

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No	Variable name	Variable type	Equation	Unit	Reference	Value
17	Immunity lost	Rate	Vaccinated/immunity time Vaccine	people/ Month	Rehman (2023)	
18	Vaccination	Rate	DELAY1(Vaccination rate*Susceptible, 4)	people/ Month	Researcher	
19	Infecting	Rate	(1-Vaccination rate)*Susceptible* (Probability of infection*Effective contact Rate*Infection Rate)	Contact people/ /Month	Researcher + Sterman (2000)	
20	Recovering	Rate	(1-Mortality rate)*Infected/Recovey time	people/ Month	Lazovic-Lønningen (2020)	
21	waning	Rate	Recovered/immunity time	people/ Month	Rehman (2023)	
22	First time donors rate	Rate	"Percentage of first-time donors"*"Potential donation population (PDP)"	people/ Month	Experts+Researcher	
23	FD become ED	Rate	("First time donors (FD)"* Affecting factors FD become ED)*(1-(tars))+("First time donors (FD)"* Affecting factors FD become ED j)* (1+Ease of donation)	people/ Month	Experts+Researcher	
24	Donors retention rate	Rate	((" Sporadic donor (SD)"*"Re-donation Advertising")+ (" Sporadic donor (SD)"*"Re-donationTeaching")+ (" Sporadic donor (SD)"*Appropriate treatment of blood collection department staff with donation)) + (" Sporadic donor (SD)"*Ease of donation)- (" Sporadic donor (SD)"*(fear and safety concerns in donors))	people/ Month	Experts+ Researcher	
25	The effect of the season	Auxiliary	(PULSE TRAIN(0, 3, 9, 100)*Ratio spring)+ (PULSE TRAIN(3, 3, 9, 100)*Ratio Summer)+ (PULSE TRAIN(6, 3, 9, 100)*Ratio autumn)+ (PULSE TRAIN(9, 3, 9, 100)*Ratio winter)	Percent	Experts	
26	Contact Rate	Auxiliary	Initial Contact Rate *(1- fear and safety concerns)	Contact /Month	Researcher	
27	Ready donors population	Auxiliary	("Repeat donor (RD)"/Time between donations)+ (("First time donors (FD)") *(1-The effect of the season on donors))+ ((" Sporadic d donor (SD)"/2)*(1-The effect of the season on donors))	people/ Month	Experts	

4. Model validation

Validating the model is one of the most crucial phases of modelling. Essentially, validation ensures that the model is accurate and effective as a tool for policymaking. This study employs extreme conditions and behaviour reproduction tests for validation. The simulation was conducted on a monthly basis, and the results were compared visually and statistically with real data from the Blood Transfusion Centre from early 2018 (1397) to late 2022 (1401). The comparison focused on the key stock variables: First-Time Donors (FD), Sporadic Donors (ED), and Repeat Donors (RD).

4.1. Behavior-Reproduction test

With the behaviour-reproduction test, the behaviour created by the model is compared with the real behaviour of the system (reference mode); in Figure 3, the behaviour created by the model in first-time donor, sporadic donor, and repeat donor variables is compared with the reference diagram. As can be seen, the behaviour produced by the model is similar to the behaviour of the reference model.

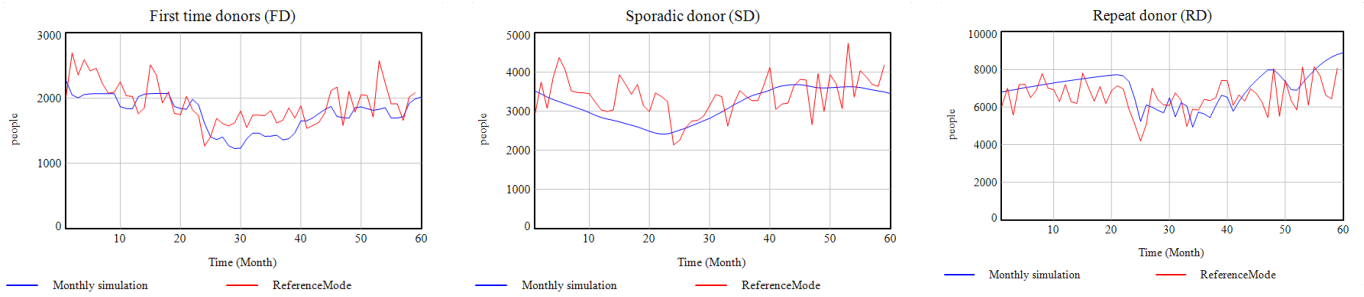


Figure 3. Comparison of the reproduction behavior of key variables with reference of mode

This comparison is based on both visual inspection and statistical analysis. Figure 3 illustrates the alignment of the simulated and real-world trends of FD, ED, and RD over the simulation period.

A comparison of the data from the simulation and the reference model for key variables has been conducted, as shown in Table 3. First, a variance comparison statistical test was used to assess the equality of variances between the two populations. The purpose of this step is to ensure that the variability in both datasets is comparable and that the observed differences are not due to significant differences in variance. The results of the variance comparison test confirmed the equality of variances at a 1% confidence level, which indicates that the two populations exhibit similar levels of variability. After verifying the equality of variances, the t-test for two populations with equal variances was performed to compare the means of the two populations. The outcomes of these tests demonstrated that, at the 1% confidence level, the variances and means of the two populations are statistically equal. This supports the validity of the behaviour reproduction process, confirming that the simulation model reliably reflects the real-world data. The detailed results of the variance comparison test, including the variance values for each population, the test statistic, and the p-value, are presented in Table 4.

Table 4. Comparison of reproduction behaviour and reference mode

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference	
									Lower	Upper
Repeat donor	Equal variances assumed	.413	.522	2.590	116	.011	404.62441	156.23417	-4.53380	813.78261
	Equal variances not assumed			2.590	115.545	.011	404.62441	156.23417	-4.56072	813.80953
Sporadic donor	Equal variances assumed	.572	.451	-2.473	116	.015	-204.12712	82.52680	-420.25471	12.00048
	Equal variances not assumed			-2.473	115.266	.015	-204.12712	82.52680	-420.27770	12.02347
First time donors	Equal variances assumed	.081	.777	-2.583	116	.011	-125.39305	48.53866	-252.50988	1.72377
	Equal variances not assumed			-2.583	115.946	.011	-125.39305	48.53866	-252.51086	1.72476

4.2. The extreme-conditions test

The extreme conditions test demonstrates the robustness of the model under extreme conditions. According to Dehghani Saryazdi and Owlia (2014), this means that the model should exhibit expected behaviour under all circumstances, including changes in input values or regulations.

As depicted in Figure 4, if the pandemic begins later, infections in society occur subsequently, leading to a corresponding delay and decrease in the number of potential donors.

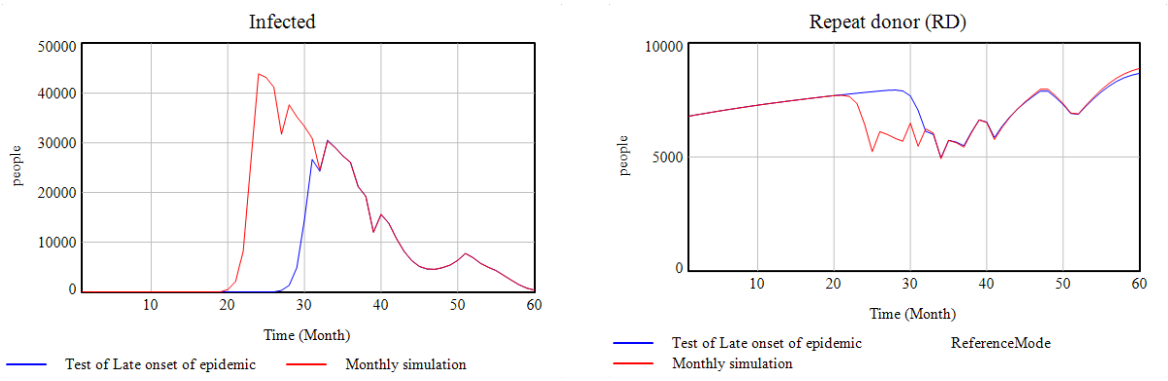


Figure 4. The extreme-conditions test of late onset of epidemic

As shown in Figure 5, when the probability of first-time donors becoming zero since 2018 is considered, this group reaches zero after two periods, causing a gradual decrease in the number of sporadic donors. Conversely, when the probability of first-time donors doubling since 2018 is considered, their donations also double, leading to an increase in the number of sporadic donors.

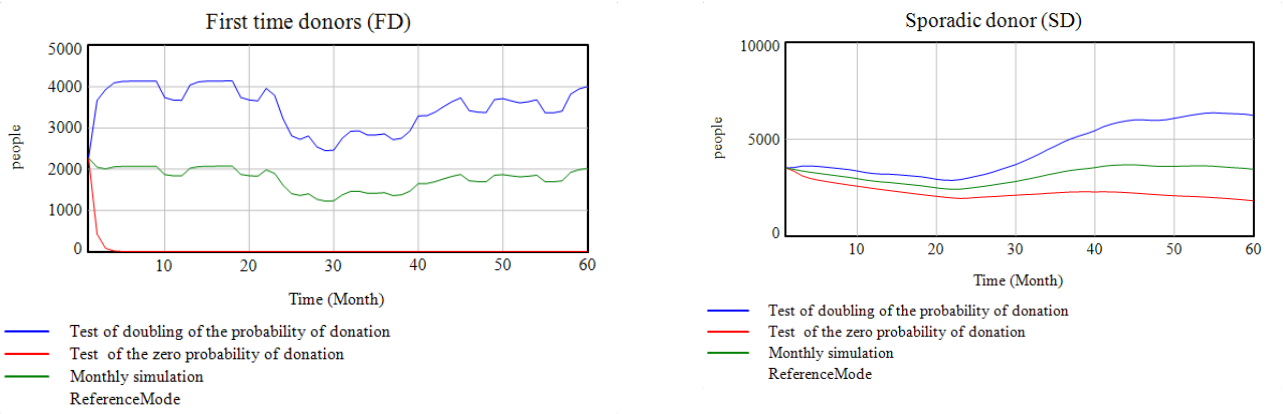


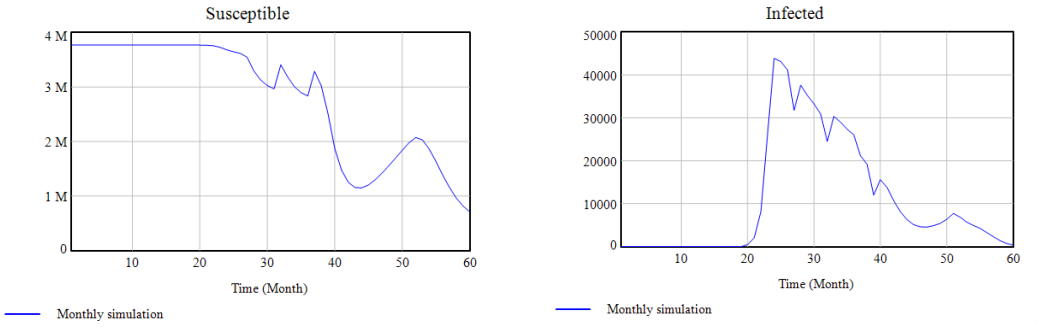
Figure 5. The extreme-conditions test of the zero and the doubling of the probability of donation

5. The results of the simulation of stock and flow model simulation

This model simulates four pandemic waves occurring during the third vaccination wave. Additionally, it posits that each new wave diminishes the immunity gained from previous vaccinations and antibodies, rendering individuals vulnerable to illness again.

As depicted in Figure 6, due to the pandemic and the associated fear and safety concerns, the numbers of first-time, sporadic, and repeat donors have all decreased. The population of potential donors, encompassing first-time, sporadic, and repeat donors, has also seen a sharp decline.

Note that the number of donors ready to donate is smaller than the sum of these three donor categories because a regular donor cannot donate blood again until 56 days after their last donation. The population of potential donors has also decreased due to the increased time interval between donations caused by fear and safety concerns during disease outbreaks, such as the coronavirus pandemic.



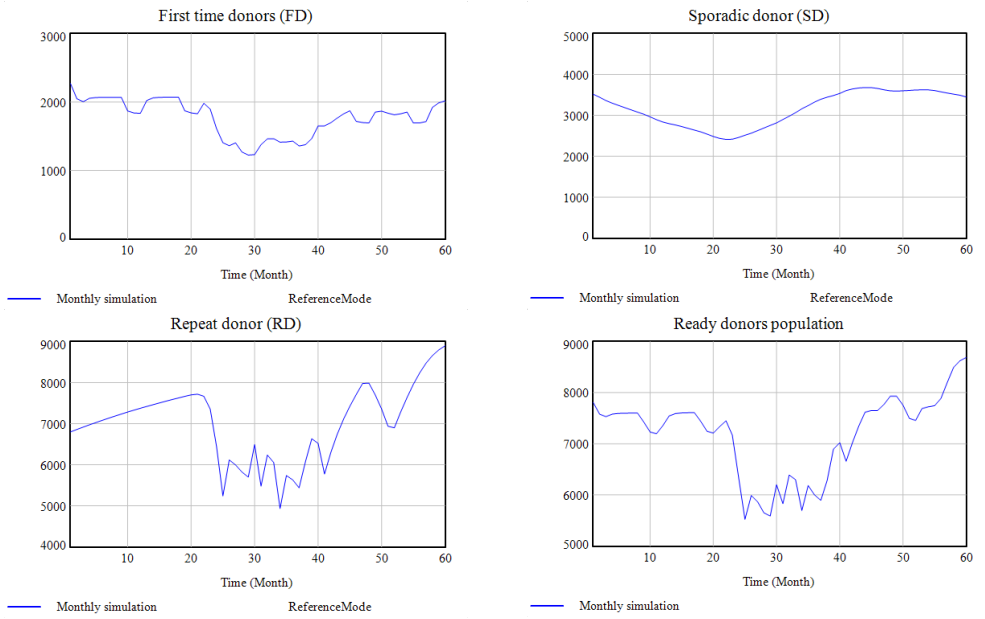


Figure 6. Monthly simulation of the blood donation model in pandemic conditions

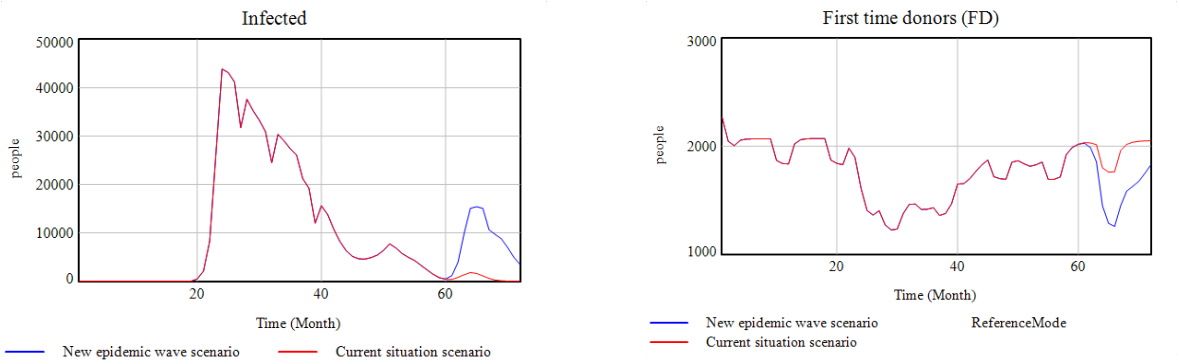
6. Scenario planning and policy design

6.1. Scenario planning

The planning and management of the blood donation system must consider potential scenarios external to the system boundary, given the unpredictability of future events. According to the scenario of a new pandemic wave, a new wave of COVID-19 infections is expected to emerge in the sixtieth month, and a vaccine will be ready seven months later. Table 5 lists the scenarios and policies.

Table 5. Scenario planning and policy design

scenario	**Policy**	
Current situation scenario (improvement of the pandemic situation)	Advertising policy	Ease of donation policy
Scenario of a new pandemic wave (new wave of the pandemic in the period of 60, and the supply of the vaccine 7 months later)	Advertising policy	Ease of donation policy



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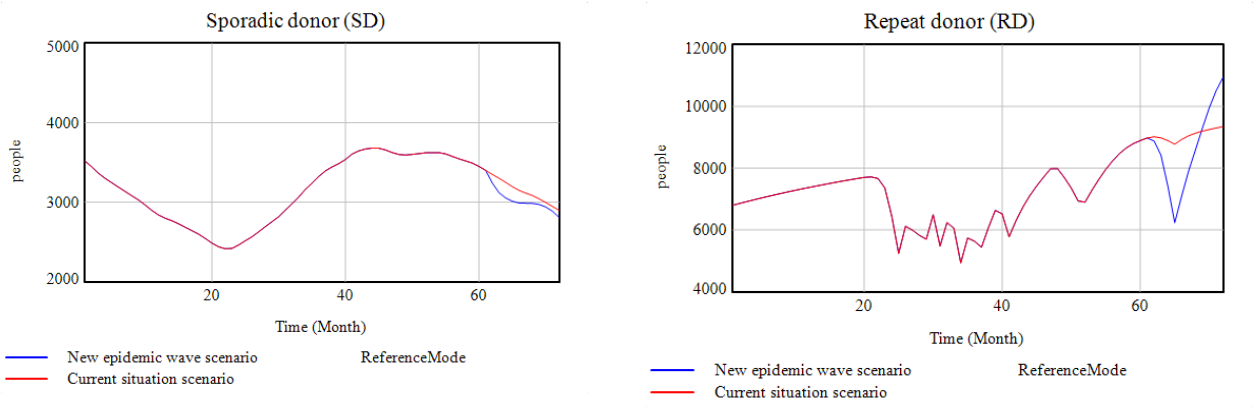

Figure 7. The scenario of the increase in the severity of the COVID-19 disease in the 60th month and the preparation of the vaccine 7 months later

As shown in Figure 7, all three donor groups experience a decline as the infected population increases progressively.

6.2. Policy design

After the designed model was confirmed, policies were developed to increase donor participation in the blood donation system. According to the articles of Reich et al. (2006) and Montazeri Takhti et al. (2016), at the time of disruption, the policy of advertising and recall increased the number of donors. According to the literature study and expert opinions, increasing the ease of donating through mobile units can reduce the impact of fear and safety concerns associated with contracting an epidemic. These policies came into effect on the 63rd and continued until the 72nd month.

In the 65th month, advertising policy has led to an increase in donors (Figure 8). The ease of donation policy is simulated in the current scenario. As shown in Figure 8, the number of donors has increased.

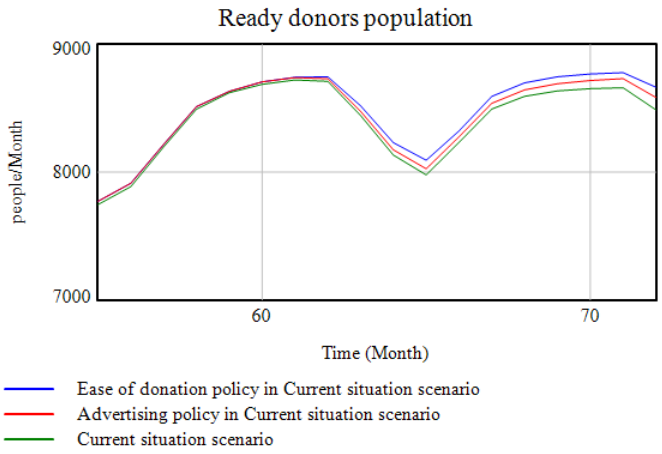

Figure 8. Policies in the current scenario

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The advertising policy is simulated in the scenario of the new pandemic wave. In the 65th month, the advertising policy initially increased donors, but after some time, it decreased again, indicating its short-term effect (Figure 9). The reason for this decline is that the increase in donors caused overcrowding in donation centres, which in turn heightened donors' fear and safety concerns. As a result, these concerns neutralised the effectiveness of the policy.

The ease of the donation policy is simulated in the scenario of the new pandemic wave. As depicted in Figure 9, the number of donors has increased without a subsequent decrease, unlike the advertising policy.

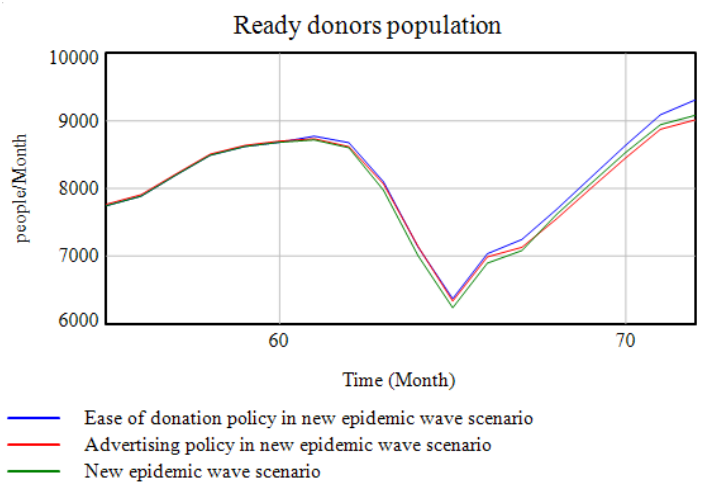

Figure 9. Policies in the new pandemic wave scenario

7. Conclusion

The COVID-19 pandemic created an unprecedented disruption in global blood donation systems, raising urgent questions about donor motivation and retention in times of crisis. One of the significant consequences of the COVID-19 pandemic has been a severe disruption in the supply of blood donations. The primary focus of this research is addressing how to prevent the decline in blood donors due to the influence of COVID-19, thereby ensuring an adequate and timely response to patient demand for blood products. Therefore, it is essential not only to prevent a decline in donations but also to understand the underlying factors that influence donor behaviour during pandemics, as well as to identify effective strategies for sustaining donor engagement in the long term.

This study highlights a critical issue: the importance of maintaining donor motivation during pandemics to prevent blood shortages at treatment centres. The pandemic has heightened fear and anxiety about the disease, reducing the willingness of individuals to donate blood. With the widespread transmission of the virus, public concern about contracting the disease has increased, leading to a decline in blood donations. As evident from the simulation results, the

pandemic has extended the time intervals between donations for repeat donors due to increased fear and safety concerns. Consequently, there has been a decline across all three donor groups: first-time, sporadic, and repeat donors. This emphasizes the importance of targeting different donor types with tailored policies to address their unique barriers and motivations.

The results of implementing advertising policies and enhancing donation accessibility through increased mobile units under normal conditions demonstrate that both initiatives lead to increased donations. However, when these policies were implemented during the COVID-19 pandemic, the advertising policy initially increased donor participation. Simulation results, however, indicated a decline around month 67, driven by concerns over overcrowding and potential exposure to illness, which diminished the policy's effectiveness. This highlights the need for adaptable policies that respond to evolving public perceptions and situational factors during prolonged crises. Therefore, it would be prudent to consider implementing policies that effectively encourage blood donation. Future research should explore how the timing and targeted messaging of advertising policies can be adjusted to address donor fatigue and fear in prolonged crises.

This study investigated the strategy of improving access through mobile units. In this policy, after coordination with donors, mobile units are activated in the homes of donors, workplaces of donors, or residences of educational institutions. Enhancing access can provide donors with more opportunities to contribute. The results indicated that this strategy mitigated the pandemic's impact on donor participation. However, further studies should investigate how mobile units could be scaled and integrated with other logistical systems to ensure sustainability during ongoing or future health crises. Therefore, including cost data in the model could lead to more accurate and reliable analyses.

In conclusion, this study provides valuable insights into the long-term behavioural impacts of the COVID-19 pandemic on blood donation over a five-year period—an aspect often overlooked in previous studies focused on short-term effects. Nevertheless, further research is needed to explore behavioural shifts beyond the pandemic and examine the broader implications for blood donation strategies in future public health emergencies. The current model has only been applied to the Mashhad region. Future research could include data from other regions of the country or even comparisons across countries. This could enhance the validity of the results and demonstrate whether these policies and findings are applicable in other geographical and cultural contexts. Incorporating more real-world data from diverse regions and blood centres could enhance the validity and generalizability of the findings.

Additionally, expanding the discussion of policy implications to include actionable and context-specific recommendations can help blood donation organisations develop more resilient and adaptive systems for crisis response and long-term donor retention.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Critical Systems Heuristics for Sustainable Management of Iran's Water-Energy-Food Nexus

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ABSTRACT

The Water-Energy-Food (WEF) nexus represents a critical framework for sustainable development, ensuring human survival and ecological balance amidst increasing resource pressures from population growth, urbanisation, climate change, and economic development. While many models aim to address this nexus, they often focus narrowly on specific sectors rather than adopting a comprehensive, holistic perspective. This study employs Critical Systems Heuristics (CSH), a reflective and emancipatory approach, to examine the systemic challenges and underlying assumptions within the WEF nexus in Iran. The research involved 25 experts from diverse fields—energy (n=6), water (n=5), food (n=4), academia (n=6), and systems (n=4)—selected through purposive sampling to ensure diverse perspectives. Using boundary critique, the study examines current realities ("is" states) and ideal visions ("ought" states) through twelve boundary questions that assess sources of motivation, power, knowledge, and legitimacy. Findings reveal fragmented decision-making structures, short-term planning approaches, and insufficient interdisciplinary collaboration as significant obstacles to sustainable resource management. While decision-making authority is concentrated in isolated governmental sectors, the study highlights the need for integrated management frameworks that align with long-term sustainability goals, emphasising public welfare, environmental preservation, and inclusivity. Additionally, the research uncovers a gap in leveraging relevant expertise, with reliance on politically influenced appointments over merit-based inclusions. The study advocates for systemic reforms, including interdisciplinary stakeholder engagement, the establishment of a unified governance body for the WEF nexus, legislative adaptations, and the integration of renewable energy and sustainable agricultural practices. These strategies aim to shift decision-making from short-term political gains to fostering resilience and equity for current and future generations. By addressing the socio-political, technical, and ecological dimensions of the WEF nexus, this research provides policymakers, stakeholders, and researchers with actionable insights, contributing to a more integrated and sustainable approach to resource management in Iran.

Keywords

Alternative roofing, Roof market Analysis, Sustainability, System dynamics, Multi-criteria decision making.

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1. Introduction

1.1. Forewords

Sustainable management of interconnected resources, such as water, energy, and food, has become a pressing global challenge as societies (Taghipour et al, 2023) grapple with growing population pressures, rapid urbanisation, and the intensifying impacts of climate change (Taghipour et al, 2024). The Water-Energy-Food (WEF) nexus provides a transformative framework for addressing these interdependencies; however, existing research and policy efforts often remain fragmented, focusing on sector-specific solutions that overlook broader systemic dynamics. In Iran, where water scarcity, energy inefficiency, and agricultural vulnerabilities converge, understanding and managing the WEF nexus is critical for long-term sustainability (Ghaedi et al, 2024).

The integration of supply chain management with environmental aspects is crucial, particularly in resource-constrained contexts like Iran (Gholian-Jouybari et al., 2024). Efficient supply chains enable the optimisation of resource allocation, reducing wastage and improving the resilience of critical systems to external shocks, such as climate change and geopolitical instability (Khazaei et al, 2023). In Iran, water-intensive agricultural practices, energy-inefficient food production, and logistical bottlenecks exacerbate vulnerabilities within the nexus. Addressing these issues through a systems-based supply chain approach can ensure that water, energy, and food are distributed equitably and sustainably across regions (Ramezani et al, 2024). Moreover, aligning supply chain strategies with the WEF nexus framework promotes innovation in resource management, such as integrating renewable energy into food production and transportation, or adopting water-saving technologies in agriculture (Ghaedi et al., 2024).

1.2. Water-Energy-Food nexus

Water, energy, and food are the essential elements that ensure the survival of human and animal life on Earth (Li and Ma, 2020). Global trends indicate a growing demand for water, energy, and food in the coming decades due to factors such as population growth, migration, industrial and economic development, international supply chains, urbanisation, socio-technological disparities, and climate fluctuations (Di Martino et al., 2021). The scarcity and significance of water and energy resources, coupled with inadequate energy provision and escalating water stress, pose a pressing challenge in catering to the food requirements of a burgeoning global population (Kondash et al., 2021).

As consumption pressure on resources mounts and intricate interdependencies between resources come to the fore, the necessity for a novel approach in identifying and analysing these interrelationships to safeguard the invaluable resources of water, soil, energy, and more becomes undeniable. The water-energy-food nexus approach emerges as a viable solution in this context (Garcia and You, 2016).

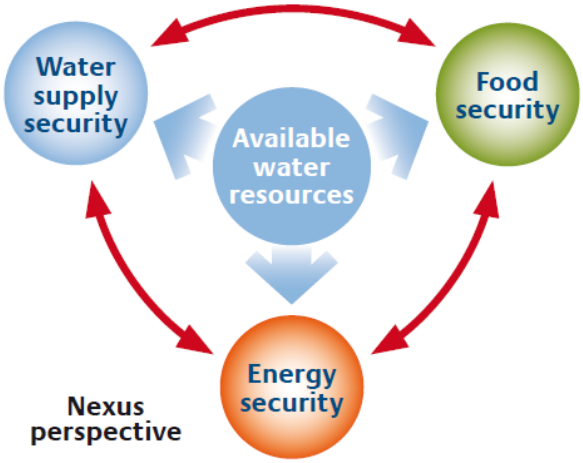

Figure 1. Conceptual framework for depicting resource nexus (Hoff, 2011)

Despite various models being developed to simulate the Water-Energy-Food Nexus, a key issue lies in their partial focus on specific nexus components, whereas the essence of the nexus concept lies in embracing a holistic perspective encompassing its distinct realms (Proctor et al., 2021; Wicaksono et al., 2019).

Significant research has been devoted to examining the water-energy-food nexus through a systemic structural lens, offering conceptual resolutions while critiquing prevailing methodologies. This research underscores the inherent need for systemic experiences in comprehensively analysing intricate problems, emphasising that addressing such challenges mandates a global, holistic systemic approach for crafting enduring solutions. It underscores the inadequacy of short-term solutions, highlighting the necessity for sustained actions and reactions to mitigate crises. The crises at hand are often the result of cumulative events rather than isolated incidents, necessitating a systemic, long-term approach for effective resolution and enhanced system performance.

This study aims to explore and investigate these challenges using a critical systems approach. It seeks to understand how the diverse perspectives of stakeholders shape the way that problems related to the WEF nexus are addressed. Using Critical Systems Heuristics (CSH), this study will explore the “is” (existing realities) and the “ought” (ideal values) states through a set of twelve boundary questions.

Despite the growing recognition of the interconnectedness of the water, energy, and food systems, decision-making remains fragmented, often resulting in short-term solutions that lack the authority to enact meaningful change. This disjointed approach, characterised by a lack of a shared, holistic perspective and collaborative decision-making, undermines the sustainability of the WEF nexus in Iran. This study aims to address this gap by examining how diverse stakeholder perspectives influence the management of the WEF nexus and seeks to propose strategies for fostering integrated and sustainable resource management.

The remainder of this paper is structured as follows: Section 2 delves into the theoretical foundations of the Water-Energy-Food nexus and its relevance to sustainability, drawing insights from existing literature and identifying key gaps. Section 3 outlines the methodology, focusing on the application of CSH and the boundary critique approach to analyze systemic challenges within the nexus. Section 4 presents the research findings, synthesizing expert perspectives to highlight current issues and opportunities for reform. Finally, Section 5 concludes by discussing the implications of the findings, proposing actionable recommendations for policymakers and stakeholders, and identifying future research directions to further advance integrated resource management in Iran's WEF nexus.

2. Theoretical foundations

Water, energy and food are essential for human well-being, poverty reduction and sustainable development. Global projections indicate that the demand for fresh water, energy and food will increase significantly in the coming decades due to population growth, economic development, urbanisation, increasing demand for food and diverse diets, climate change, resource degradation and scarcity (Hoff, 2011). Given the growing demands, the competition for increased use of water and energy resources in agriculture, healthcare, and the environment will intensify, having significant effects on both economic and environmental conditions. Over the past two centuries, the world's fundamental challenges have undergone significant changes, particularly in recent decades (Proctor et al., 2021).

2.1. Water and energy use in agriculture and food production

Even now, the agriculture sector is the largest consumer of water, consuming approximately %70 of the world's total freshwater resources. Water is used for agricultural production and throughout the food and agricultural supply chain, as well as for the production, transport and use of all forms of energy (FAO, 2014). However, food production and supply chains also

consume approximately 30% of total global energy (FAO 2011). Energy is needed for production, transportation and food distribution, as well as for extraction, pumping, lifting, collecting, conveying and water treatment. This situation is expected to worsen in the near future. It is predicted that by 2050, 60% more food will be produced due to increased demand for nutrients and improved quality. Global energy consumption has also been on an upward trend, increasing by nearly 50% by 2035 and by 80% by 2050 (FAO, 2014). As demand increases, there is growing competition for natural resources, including water, energy, agriculture, fisheries, mining, and other sectors. For example, on a macro scale, water infrastructure projects may have synergistic effects for Hydroelectricity generation and water storage provision. But this may have adverse effects on ecosystems and food systems. At the same time, growing bioenergy crops in an irrigated agriculture scheme may improve energy supply, but may also lead to increased water withdrawals and risk compromising food security (Lonbar et al., 2024; Biswas, 2004).

2.2. The Water-Energy-Food nexus as a dynamic system

Each of the water, energy, and food resources is significantly interdependent and intertwined with one another, collectively forming a dynamic system where changes in one sector impact others. Scientifically, these three sectors, which interact with each other, are collectively referred to as the Water-Energy-Food Nexus (Lu et al., 2021). Therefore, it is essential to understand the synergies and interactions in order to develop effective response options that ensure environmental sustainability and people's livelihoods (Lonbar et al., 2024). The aim of Nexus is to ensure sustainability and enhance system performance through a holistic understanding, resource management and reflection of integrated resource management objectives (Biswas, 2004). The Nexus concept acknowledges the need to consider water, energy and food not as separate entities, but as a complex and inseparable entity. This, in turn, allows for more integrated and cost-effective policy-making, planning, implementation, monitoring, and evaluation across the different Nexus sectors. At the same time, the Nexus approach reflects a wide range of perspectives from experts involved throughout the process, which helps to promote dialogue between different sectors and see solutions to challenges as collective efforts (FAO, 2014). Therefore, managing this nexus enhancing the security of the water, food, and energy sectors requires integrated approaches or exploratory tools and conclusions that can identify differences between various sectors, establish effective planning, and provide management strategies and decisions (Yuan and Lo, 2022).

2.3. Existing research and methodological advancements

The following will refer to the research conducted in this field, and subsequently, the gap in the literature will be identified based on the studies conducted. Zhang and Vesselinov (2017) introduced a multivariate socio-economic model. The goal of this model, abbreviated as WEFO, is to minimise the total cost of the system and the link. The costs include the sum of the costs of energy supply, water supply, electricity supply and generation, food production and distribution, and costs of reducing greenhouse gases. In the aforementioned study, a closed area with a certain number of producers and consumers was used, and the equations related to its production and consumption, which mainly considered its economic dimensions, were optimized (Zhang and Vesselinov, 2017). In a similar study, Li et al. (2019) developed an integrated WEFO-like model called AWEFSMI to assist in sustainable agricultural management by Water-Energy-Food Nexus with the aim of maximising net benefits and environmental impacts of food production and processing. This planning model is a nonlinear multi-objective mathematical model that transforms resource availability in the form of fuzzy numbers into a unified computable framework and is capable of considering a wide range of probabilities (Li et al., 2019).

Complementing the above research, Wicaksono et al. (2019) presented a simulation-optimisation model, WEFSIML-apt, related to the water-energy-food Nexus to help major stakeholders of the system make smart and fast decisions regarding sustainable resource management at their national and regional levels. Optimisation in the aforementioned study was developed with two conventional approaches: multi-objective genetic algorithm and single-objective genetic algorithm in order to maximize the user confidence index for the water, energy, and food domains, with special attention to optimizing the priority index and decision-making regarding water allocation (Wicaksono et al., 2019). Studies in this area have also been conducted in the Middle East. Karnib (2017) used an optimal-based simulation tool in a study in Lebanon. In the aforementioned study (the Q-Nexus Model), a type of mathematical model dedicated to simulating the Water-Energy-Food Nexus was used. This model is used for two purposes, including changes related to resource demand or damage reduction and the analysis of scenarios of technological change with greater efficiency (Karnib, 2017). Uen and Rodriguez (2021) conducted significant and comprehensive research in the field of modelling and simulation in Taiwan to optimise power generation and the final storage reservoir. In this study, a three-dimensional and comprehensive plan has been proposed, which combines the benefits of integrating the water, food, and energy nexus by merging short-term and long-term shared

utilisation of a multi-purpose reservoir with irrigation reservoirs in response to urbanisation (Uen and Rodriguez, 2021). Tian et al. (2022) proposed a unified modelling approach to optimize the water, energy, and food nexus with the aim of maximising the net benefit of the system and minimising the pollution emitted from agricultural activities for resource allocation in the water, energy, and food nexus with emphasis on agriculture (Tian et al., 2022).

In the aforementioned study, it is believed that uncertainties such as space-time changes, water availability, and changes and events in river water flows lead to uncertainties in dependent parameters such as the share of land irrigation, access to productive energy, and access to groundwater, due to the complex relationships of the nexus components, and the need to consider a concept such as uncertainty is essential. The research by Rai (2023) emphasises utilising the WEF nexus as a tool to combat environmental destruction, address climate change, and achieve Sustainable Development Goals (SDGs). This article explores the methodological paradigm and application of the WEF nexus within a relevant framework through case studies on water resources, energy efficiency, urban food production, food waste reduction, interdisciplinary perspectives, and circular economy (Rai, 2023).

The objective of the study by Moreschi et al. (2024) is to develop a unified Water-Energy-Food-Climate (WEFC) index using a life cycle approach and to examine its application in the agriculture-food sector, paving the way for decision support tools. After selecting relevant impact categories, a multi-variable optimization was conducted to search for the "best balance" among water, energy, food, and climate issues. Subsequently, a comparative analysis was performed to evaluate the performance of the WEFC index in analysed crops (tomatoes, corn, and chickpeas) in a case study in Italy (Moreschi et al., 2024).

2.4. Gaps and novelties

Research that has addressed the topic under study from a managerial and problem-solving perspective has mostly sought to optimise the current state related to this system or to deal with specific scenarios to reduce risk and uncertainty. In previous research, the existential vacuum of a holistic and systemic approach to creating long-term solutions by considering the interests of all stakeholders is necessary and vital in dealing with such a situation.

3. Methodology

The methodology of the present study is applied in terms of purpose and, considering the chosen methodology, is one of the action research studies that describes the multiple and contradictory

perspectives on the water-energy-food Nexus using the CSH method. This method involves conducting in-depth interviews with stakeholders, using predefined questions (boundary questions) that focus on the target topic, which is explained below. To review and analyse the interviews conducted at CSH, it is first necessary to describe the tools for interpreting these questions and the steps required to analyse the responses obtained in the context of Boundary critique. The stakeholder population for this study comprised a diverse group of 25 experts, selected through purposive sampling to ensure representation across key domains influencing the WEF nexus in Iran. These stakeholders included professionals from the energy sector (6 participants), water sector (5 participants), food sector (4 participants), academia (6 participants), and systems experts (4 participants). This composition reflects a deliberate effort to capture a broad spectrum of perspectives, ensuring insights from both technical and governance domains. Participants were chosen based on their expertise, professional roles, and involvement in decision-making processes related to WEF resource management. The interviews were conducted using a semi-structured format, allowing for both guided discussions based on predefined boundary questions and open-ended responses to capture nuanced insights. Each interview lasted between 60 and 90 minutes and was conducted either in person or via video conferencing, depending on the participants' availability and location. All interviews were recorded with the participants' informed consent to ensure accuracy in data collection and analysis. Detailed notes were also taken during the sessions as a supplementary measure. The recordings were later transcribed verbatim, and the transcripts were coded thematically using qualitative analysis software to identify recurring patterns, systemic challenges, and stakeholder-specific perspectives. Confidentiality and anonymity were strictly maintained throughout the process to encourage honest and uninhibited responses from participants.

3.1. The core principle of CSH

The basic idea of CSH is to support boundary critique—a systematic approach to critically evaluating boundary judgments. Boundary critique may take two primary forms: it can aim at addressing boundary judgments self-critically (reflective practice), or it can utilise boundary judgments for critical purposes against those who may not consider them so self-critically (emancipatory practice). The methodological core idea consists of revealing the unavoidable selectivity of claims in the dual sense of ‘partiality’ explained above (Mirhosseini et al., 2021). Boundary judgments are the perfect target for this purpose, for contrary to what one might think at first, they reflect a claim’s entire selectivity regarding both its empirical and normative

content. It is important to understand that boundary judgments are not merely one (perhaps even minor) among many other sources of selectivity; for example, once the reference system is determined, it is then the specific content of our thinking or discussion that determines how 'partial' they are. Instead, any partiality can and needs to be understood as amounting to boundary judgments for any content we do or do not consider, and the way we consider it implies corresponding boundary judgments. This consequence is the reverse side of the coin of 'clear and valid thinking'; as it were, we cannot meaningfully discuss any aspect of a situation or an issue without implying boundary judgments (Khazaei et al., 2021a).

What a certain aspect means depends on what consequences we anticipate it to have, whose concerns we assume to be affected, what criteria of success or improvement we associate with it (Nayeri et al., 2022), and so on; and all these assumptions and associations embody boundary judgments as to what is to be part of the picture and what is not. Whether these judgments are conscious and deliberate or unintended, the outcome remains the same. Let us now look at the methodological core principle embodied in the concept of boundary critique. As we have understood, the basic requirement for developing the required critical competence is grasping the way judgments of fact as well as of value depend on boundary judgments and are connected through them. CSH explains this through the eternal triangle (Figure 2). Whenever we propose a problem definition or solution or raise any other claim with a practical intent, we cannot help but assert the relevance of some facts and norms over others (Dehghan Nayeri et al., 2021). Which facts and norms we should consider depends on how we bound the reference system, and vice versa; as soon as we modify our boundary judgments, relevant facts and norms are likely to change as well. We are thus caught in an argumentative triangle.

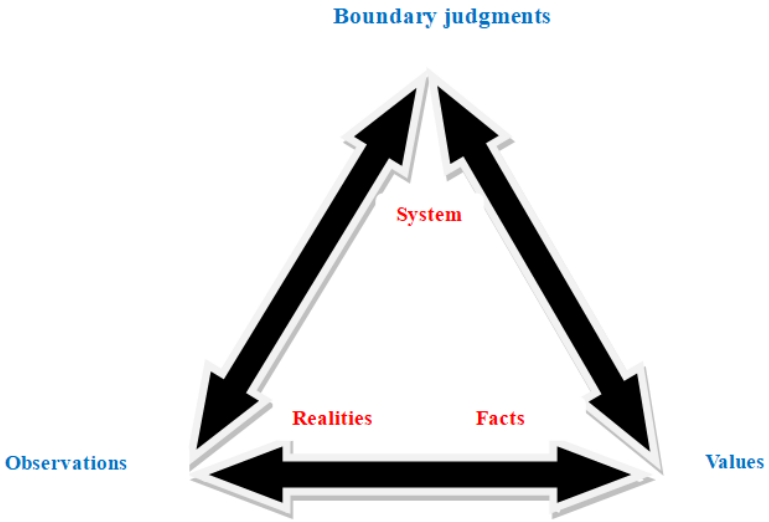

Figure 2. The 'eternal triangle' of boundary judgments, facts, and values Source: Ulrich (2005)

CSH refers to the process of thinking through the triangle as systemic triangulation. It means to consider each corner of the triangle in the light of the other two. For example, what new facts become relevant if we expand the boundaries of the reference system or modify our value judgments? How do our valuations look if we consider new facts that refer to a modified reference system? In what way may our reference system fail to do justice to the perspective of different stakeholder groups? Asking ourselves how the facts that we find relevant, the value considerations we deem adequate, and the context (reference system) that we consider mutually condition one another is highly relevant for developing a sense of modesty regarding our claims, as well as tolerance regarding those of others who appear to have got their facts and values wrong! Next, let us consider the intent of the four basic boundary issues (Dehghan Nayeri et al., 2020). They ask for a claim:

- Basis of motivation – Where does a sense of purposefulness and value come from?
- Basis of power – Who is in control of what is going on and is needed for success?
- Basis of knowledge – What experience and expertise support the claim?
- Basis of legitimacy – Where does legitimacy lie?

Together, the four issues make up a claim's 'anatomy of purposefulness'. Critical heuristics proposes that these four issues are essential for reflective practice in most (if not all) situations of problem-solving, decision-making, or professional intervention (Ramezani et al., 2021). They are essential, as without considering them, we do not truly understand what a claim means and whether or to what extent we should recognise it as valid, that is, as a basis for action. The underlying philosophical position is that of pragmatism.

3.2. Boundary questions

Boundary questions are categorised into four categories, comprising 12 questions (Dehghan Nayeri et al., 2018). As a rule, it makes sense to ask each question both in the 'is' and in the 'ought' mode. Our 'ought' answers always help to clarify the standpoint from which we are assessing a situation or related claim in the 'is' mode. Furthermore, differences between 'is' and 'ought' answers are frequent, not to say the rule; as they point to unresolved boundary issues, they can drive the process of unfolding the selectivity of a claim (Khazaei et al., 2021b). However, the specific way in which we combine the 'is' and the 'ought' mode depends on the particular application of boundary critique in which we are interested. The purpose of critical perceptions is that these four issues are necessary for practising reflection, which is essential in most situations (not always) in problem-solving, decision-making, or professional intervention. Since these four issues are essential, without considering them, we cannot understand what the

meaning (true meaning) of a claim is or to what extent we can recognise it as valid, that is, put it as a basis for actions. The basic philosophical position originates from pragmatism (Ulrich, 2005).

4. Research findings

In the present study, 25 experts were interviewed from various fields, including energy (n=6), water (n=5), food (n=4), academia (n=6), and systems (n=4). This distribution reflects the experts' focus on diverse areas, each of which holds significant importance in sustainable development and societal well-being. It indicates the diversity and depth of expertise among them while emphasising the necessity of interdisciplinary collaboration and knowledge exchange.

Table 1. Summary of interviewees' answers to boundary questions

	Questions	Energy experts group	Water experts group	Food experts group	Academic experts group	System experts group
1	Who is the client or beneficiary?	Agriculture sector /Ministry of Energy/Food and Drug Organisation/Ministry of Health	the government	Agriculture sector	Government/Agricultural Jahad/Ministry of Energy/Food and Drug Organization/Water and Wastewater Organization	The government/ Factories, and large industries/the agricultural sector
	Who ought to be the client or beneficiary?	All people	All people and the entire ecosystem	general society	All people	The main body of society that is concerned about health and the future
2	What is the purpose?	Provision of services to the people by the government	Preservation of the status quo	Short-term planning / providing food security at mandated prices	The silence and temporary satisfaction of the people	The government seeks to maintain public cohesion in the short term through policy making
	What ought to be the purpose?	Changing the cultivation pattern according to the climate and guaranteeing the purchase of agricultural products/ moving	Sustainable development from an environmental, economic, social and cultural point of view /balanced distribution of resources	Strategic planning - sustainable food security by preserving basic resources (water, soil, air and environment) with regard to the future generation	Balanced use of water, energy and food resources with a view to the future	Long-term planning (use of renewable energy, cultivation of strategic crops such as cereals and preventing the cultivation of water-intensive crops such

	Questions	Energy experts group	Water experts group	Food experts group	Academic experts group	System experts group
		towards the use of renewable energies with land use planning				as beets, cucumbers, watermelons) / the waste should enter the nexus cycle
3	What is the measure of improvement or measure of success?	People's satisfaction	Temporary satisfaction of the people by preventing water, electricity and energy outages	Fake statistics about food production, water and energy consumption	Consumption of water, energy and food	The silence and temporary satisfaction of people with fake statistics, such as the cut-off rate of water and electricity/and setting the market price for food
	What ought to be the measure of improvement or measure of success?	The condition of underground water tables / sustainable energy supply (in all seasons and conditions) /elimination of transgenic products, and healthy products in people's nutrition	The status of underground water tables / the status of providing energy to low-income areas / and the level of people's well-being	The rate of achieving sustainable development indicators	Satisfaction of the current and future generations	The rate of use of renewable energy instead of fossil fuels / the rate of use of waste in the Nexus cycle / the condition of underground water tables
4	Who is the decision-maker?	Ministries of energy, oil, health and agricultural jihad locally and separately	Local trustees locally and separately with a political view	Ministries of energy, oil, health and agricultural jihad locally and separately	Agricultural Jihad, Ministry of Energy, Food and Drug Organisation, Presidential Institution	The government, local representatives such as Imam Juma, and political officials
	Who ought to be the decision-maker?	A reference and an integrated organisation for all 3 areas with a comprehensive view	A non-governmental organization derived from elites and experts in the nexus issue	People's organisations specialised under the supervision of the government	---------	Technical experts who have executive power
	What resources and other conditions of success are controlled by the decision-maker?	All financial, executive and legal resources	Legal and executive sources	Human, financial, legal, and executive resources	All resources are at the disposal of the government	Legal resources and financial resources are available to the government

	Questions	Energy experts group	Water experts group	Food experts group	Academic experts group	System experts group
5	What resources and other conditions of success ought to be controlled by the decision-maker?	The integrated organisation that will be created to manage the nexus must have legal and executive power	Access to the media to change the culture with an eye on the environment	Human, financial, and legal resources	Strong legal resources (judiciary)	Executive resources and financial resources should be at the disposal of the government, but the source of legislation should be at the disposal of experts in the field of nexus
6	What conditions of success are part of the decision environment?	Decisions of the Islamic Council	.....	.....	Powerful institutions that are not from the government, but get help from the government in some way	Currently, there are no conditions for the success of the system
	What conditions of success ought to be part of the decision environment?	Using new technologies and up-to-date science in the field of cloud fertilization or cloud guidance	Macro policies of the country from the perspective of strategic management	Long-term planning from the side of governance/changing foreign policy due to sanctions	.....	Absence of sanctions and media problems
7	Who is considered a professional or further expert?	Expert experts working in all 3 areas of water, energy and food, who act locally and separately	Unrelated experts (based on political decisions)	Experts from government departments	Agricultural Jihad, Ministry of Energy, Food and Drug Organisation, Presidential Institution	.....
	Who ought to be considered a professional or further expert?	A working group consisting of three research institutes (water, food energy)	Relevant experts in the field of nexus based on experience, expertise and commitment	Elites and thinkers of society in the field of Nexus	Academic experts who have executive experience in these three fields	A working group consisting of three research institutes (water, food energy)
8	What kind of expertise is consulted?	Currently, the necessary expertise is not used, and appointments are based on relationships	Currently, the necessary expertise is not used, and the appointments are based on relationships and expediency only with a political view	There is no specialization, the appointments are based on the political and governmental view	Management, energy engineering, agricultural and water engineering	Management

	Questions	Energy experts group	Water experts group	Food experts group	Academic experts group	System experts group
	What kind of expertise ought to be consulted?	Management, artificial intelligence, data science	land use planning , strategic management	New energy specialist, strategic management	Process knowledge	Trained people in the field of solar/wind and artificial intelligence
9	What or who is assumed to be the guarantor of success?	No one guarantees	No one guarantees	Short-term planning	No one guarantees	No one guarantees
	What or who ought to be assumed to be the guarantor of success?	The support of the government and the parliament for the specialised nexus working group	Macro policy makers/House of Representatives/Government/and Judiciary with a consolidated and combined view	Long-term planning / macro policies /appropriate laws and regulations	.....	Nexus working group
10	Who is witness to the interests of those affected but not involved?	In fact, there is no one	There is no agent	Members of Parliament	In fact, there is no one	There is no agent
	Who ought to be witness to the interests of those affected but not involved?	City Governor/Social Media	NGOs	The real representatives of the people in the NGO Nexus	Having an expert and knowledgeable representative of Nexus in the Islamic Council	Nexus working group, despite having representatives in different strata
11	What secures the emancipation of those affected from the premises and promises of those involved?	Nothing is guaranteed	.....	Nothing is guaranteed	There is no system	Nothing is guaranteed
	What ought to secure the emancipation of those affected from the premises and promises of those involved?	Legal and executive power should be given to the nexus working group	By strengthening the monitoring tools and control mechanisms in the strategic management of Nexus /by giving the necessary powers to Nexus actors.	Phased monitoring based on control mechanisms	.....	To change the method with technical and legal mechanism
	What worldview is determining?	We will face a severe drought	Negative population growth rate	Basic resources (water, soil, and air) will be	Increasing immigration and	By 2050, a strange drought will happen

	Questions	Energy experts group	Water experts group	Food experts group	Academic experts group	System experts group
		/more air pollution / and less public health		depleted due to climate change, leading to the loss of vegetation, which in turn will increase fine dust and air pollution.	increasing frustration among people	in Iran
12	What worldview ought to be determining?	The status of underground water tables for future generations/food security / and sustainable energy supply for all people	Increasing food security	Soil protection/protection of all water resources/production of more and quality food in accordance with population growth by preserving basic resources / The waste enters the nexus cycle	Reducing withdrawal from underground water/use of renewable energy	Go to renewable energy

4.1. Energy expert group

The group identifies a fragmented approach to governance and management of the nexus, with separate ministries managing their respective sectors in isolation. This fragmented approach fails to recognise the interdependencies among water, energy and food, potentially leading to policies that optimise one sector at the expense of others. The ideal situation, as articulated by experts, calls for an integrated management organisation that oversees all three areas with a comprehensive and holistic view, recognising the inherent links between these resources.

Currently, the direct stakeholders and decision-makers are identified as various public departments and ministries. However, experts argue for a shift towards considering all people as primary stakeholders. This shift requires policies and decisions that prioritise public welfare and sustainability over sector interests. The recall of an integrated organisation for decision-making reflects a desire to move away from unrestrained decision-making towards a more coherent strategy that can address the complex interdependencies of the nexus. The shift from measuring success by public satisfaction to the state of groundwater and sustainable energy supply highlights a significant shift towards sustainability and long-term environmental health. It suggests that real progress in the nexus cannot be measured solely by immediate public satisfaction but also by the long-term sustainability of essential resources. The responses highlight the current underutilization of relevant expertise and the reliance on appointment-based relationships rather than merit. The government in question is calling for a multidisciplinary working group comprising experts from the water, energy, and food sectors

alongside specialists in management, artificial intelligence, and data science. It acknowledges the complexity of the nexus, which necessitates a broad range of expertise for practical innovation and management. A significant concern is the apparent lack of oversight and accountability mechanisms to protect the interests of those affected by decisions within the intra-nexus but who are not part of the decision-making process. The proposal to involve city governors and the media as representatives and observers represents a move towards greater transparency and accountability, ensuring that the interests of the wider community are considered and protected. The current worldview is pessimistic, predicting severe droughts, increasing air pollution and declining public health.

In contrast, the envisioned vision is one of sustainability, focused on preserving groundwater for future generations, ensuring food security, and providing sustainable energy for all. This vision highlights the pressing need to transition from short-term, reactive measures to long-term, proactive planning and action. The Energy Expert Group's responses provide a clear understanding of the challenges facing Iran's water, food, and energy nexus and propose a forward-looking framework for systemic change. The anticipated overhaul represents a paradigm shift from fragmented, sector-specific governance to an integrated, sustainability-focused approach. It requires not only structural changes in governance and decision-making but also a cultural shift towards valuing expertise, accountability, and long-term social and environmental well-being.

Implementing such comprehensive changes requires broad support from the government, civil society, and the international community, along with significant investment in technology, infrastructure, and human capital.4.2. Water Expert Group

The responses from this group reflect a critical view of the existing system, in which the government is the primary beneficiary and the primary goal is the preservation of the status quo, often measured by temporary solutions such as preventing power outages. This approach has been criticised for being short-sighted and inadequate in addressing the long-term sustainability of resources. Experts propose a paradigm shift towards recognising individuals and entire ecosystems as primary stakeholders, with the goal of sustainable development that encompasses environmental, economic, social, and cultural perspectives. This shift requires a balanced distribution of resources, measured by the well-being of groundwater levels, energy supply in deprived and underprivileged areas, and overall human well-being. One of the most notable points raised by the experts is their critique of the decision-making processes and the actors involved in them. According to the group, the current system suffers from being insular

and a political decision-making process run by local custodians. This process is at odds with the ideal scenario where decision-making is democratic, alongside NGOs composed of elites and experts on the subject of the nexus. It highlights the need for a more transparent and expertise-based approach that can bridge the gap between current practices and sustainable goals. The discussion on resources highlights a fundamental issue in the allocation and control of resources within the current system, pointing to the need for decision-makers to have access to media and other channels for cultural change, with an emphasis on environmental sustainability. It highlights a broader issue of governance and strategic management, where the current system's focus on temporary satisfaction and political expediency is criticised in favour of a long-term, strategic, and holistic approach to resource management. This criticism extends to the area of expertise and specialisation within the system, where current experts are considered irrelevant and appointed based on political decisions rather than their expertise in relevant areas. The call for relevant experts, based on experience, expertise, and commitment, emphasises the importance of specialised knowledge and strategic management in effectively addressing relevant challenges. It is noticeable that the responses also point to systemic guarantees (or lack thereof) for success, indicating a current lack of accountability mechanisms that ensure success. The envisioned system emphasises the role of macro-policymakers, including the House of Representatives, the government, and the judiciary, in ensuring success through an integrated view of related areas. Finally, the worldview and outlook for the system are critically assessed, with the current negative population growth rate perspective replaced to increase food security. This shift reflects a broader perspective that aligns with the Sustainable Development Goals, which emphasise the need for systemic changes that consider the long-term impacts on both the population and the environment. Finally, the responses of the Water Expert Group highlight the deep systemic challenges facing the water-energy-food Nexus in Iran and advocate for a transformative approach that incorporates environmental sustainability, equitable resource distribution, expertise-based decision-making, and strategic and long-term planning. This analysis suggests a multidimensional review of the system that emphasizes the importance of governance, accountability, expertise, and a shift in worldview toward sustainable development and food security.

4.2. Food expert group

The current focus on short-term food security planningprice controls in the agricultural sector is insufficient, experts say. They advocate a shift towards strategic planning, emphasising

sustainable food security by preserving essential resources such as water, soil, air and the environment for future generations and the wider community. This shift in focus is in line to achieveachieving sustainable development indicators, which represent a shift away from relying on inaccurate statistics on food production, water consumption, and energy as measures of progress. Experts also stress the need for changes in decision-making structures and advocate for the involvement of specialist grassroots organisations under government supervision rather than the isolated ministries that are currently responsible. They emphasise the importance of long-term planning, especially in the face of external challenges such as sanctions, which require changes in foreign policy and governance. From a professional perspective, experts also criticise the lack of expertise in current nominations, which are often based on political and governmental views. They emphasise the need for specialists in new energies and strategic management to guide effective decision-making in the food-energy-water nexus. Overall, the group's worldview and vision for the future of the system are based on conserving primary resources, protecting soil and water, and producing more and better quality food in line with population growth. They recognize the potential consequences of inaction, including loss of primary resources and increased environmental degradation. Their vision calls for a holistic approach that embraces the Nexus cycle, reflecting a deep understanding of the interconnected nature of the challenges facing the Food-Water-Energy Nexus in Iran. In conclusion, the Food Expert Group provides a comprehensive and forward-looking perspective on Food-Water-Energy in Iran, highlighting the need for systemic changes in planning, decision-making, and expertise to ensure a sustainable and secure future for all. Their insights provide valuable guidance for policymakers and stakeholders seeking to address complex Nexus challenges in Iran and beyond.

4.3. Academic expert group

They identified the government, especially the Agricultural Jihad, the Ministry of Energy and the Food and Drug Administration, as the main customers or beneficiaries of the system, indicating strong government influence in decision-making. However, they suggested that the people should be the ultimate beneficiaries and stressed the need to shift towards a more people-centred approach. The aim of the system, as the experts understand it, is currently focused on maintaining the status quo and ensuring temporary satisfaction for people. However, they suggest that the goal should be a balanced use of water, energy and food resources, with a focus on sustainable practices for future generations. The experts also emphasised the importance of

measuring progress and success, suggesting that while the current benchmark is based on water, energy, and food consumption, it should instead focus on the satisfaction of current and future generations. This perspective shift reflects a deeper concern for the long-term sustainability of the system. In discussing decision-making, experts noted that current decision-makers include government agencies and institutions. However, they suggested that academic experts should also play a role in the decision-making process. They emphasised the need for strong legal resources, especially the judiciary, to control decision-makers successfully. Experts identified expertise in management, energy and agricultural engineering, and water engineering as essential for the system. They also emphasised the need to involve academic experts with practical experience in these areas in decision-making. Furthermore, they suggested that process knowledge should be further explored to increase expertise in the system. Regarding ensuring success, the experts noted that currently, no one guarantees success in the system. However, they suggested that the presence of an expert and knowledgeable nexus representative in the Islamic Council could ensure success by monitoring and representing the interests of those not directly involved in the process. The experts also emphasised the importance of reducing groundwater withdrawals and increasing the use of renewable energy as a worldview and vision for the system. They suggested that these goals should be prioritized to address key challenges such as increased migration and frustration among the population. Ultimately, responses from a panel of academic experts offer valuable insights into the water-food-energy nexus in Iran, identifying potential areas for improvement and reform. Their suggestions emphasise the need for a more sustainable and people-centred approach, focusing on long-term goals and involving a diverse range of stakeholders in decision-making.

4.4. Systemic expert group

The current stakeholders, primarily the government, factories, and large industries, including the agricultural sector, represent a system skewed towards immediate economic needs and production. However, the proposal that the core body of society concerned with health and the future should be the primary stakeholders indicates a shift towards a more inclusive and sustainable approach. This shift emphasises the need for policies and practices that consider long-term social well-being over short-term economic gains. The current short-term objective of maintaining public cohesion through policymaking is in stark contrast to the long-term planning advocated for, which focuses on sustainable practices, such as the use of renewable energy and the cultivation of strategic crops.

The gap between existing decision-makers (government and political officials) and the proposed technical experts with executive power highlights the need for informed and expert decision-making that prioritizes environmental sustainability and community health. The allocation of legal and financial resources currently under government control suggests a centralized decision-making process. The proposal to place executive and legislative resources under the expertise of Nexus-focused experts represents a move toward decentralisation of power. It ensures that those with the necessary technical knowledge have a say in the legislative and resource allocation processes. This should theoretically lead to more informed and sustainable decisions that align with Nexus objectives. The current measure of success, based on temporary public consent and manipulated statistics, is considered inadequate. A shift toward measuring success by renewable energy use, the inclusion of waste in the Nexus cycle, and the state of groundwater tables represents a more comprehensive and accurate approach to evaluating the health and system progress. This shift highlights the need for transparent and reliable metrics that demonstrate long-term resource sustainability. The current outlook, which projects a "strange drought" by 2050, presents a passive and apocalyptic perspective. In contrast, the proposed shift toward renewable energy represents a proactive, solution-oriented vision that aims to mitigate future crises by embracing sustainable practices today. This perspective shift is crucial for the system preparation to withstand environmental change and ensure the long-term sustainability of the water-food-energy nexus in Iran.

5. Discussion

To bridge the gap between the current state and the desired future of the WEF nexus in Iran, several transformative actions are essential. First, there is a critical need for inclusive stakeholder engagement. Expanding the circle of stakeholders to include the general public, particularly those directly affected by resource mismanagement, necessitates a more democratic and participatory approach to decision-making. This inclusivity not only enhances transparency but also ensures that diverse perspectives, including those from marginalized communities, are considered in policy formulation.

A significant shift in decision-making authority is also necessary. By transferring power from politically motivated entities to technical experts with the capability to implement evidence-based strategies, decisions can be better aligned with scientific knowledge and Nexus sustainability principles. Such a shift would improve the coherence of resource management efforts and reduce the fragmentation that currently hampers the system's effectiveness.

Decentralisation of resource control is another critical aspect. Diversifying resource management by involving Nexus experts ensures that specialised knowledge is leveraged to promote sustainable practices. This decentralisation can help mitigate the risks associated with overly centralised governance, which often prioritises short-term political gains over long-term sustainability.

The adoption of sustainable success metrics is vital for fostering accountability and measuring progress toward long-term goals. Transparent and comprehensive indicators, such as groundwater levels, renewable energy utilisation, and food security indices, provide clear benchmarks for assessing the health and sustainability of the Nexus. These metrics also encourage continuous improvement and informed decision-making across sectors.

Additionally, a proactive and solution-oriented perspective must be embraced. It involves shifting from reactive crisis management to implementing forward-looking strategies, such as integrating renewable energy sources and optimising agricultural practices. Such measures not only enhance resilience but also position the system to better anticipate and address future challenges, including climate change and resource scarcity. The findings from this study underscore the urgent need for systemic changes in the WEF Nexus in Iran. Aligning the system's objectives, decision-making processes, and success measurements with principles of sustainability and inclusiveness can lead to a more resilient, equitable, and sustainable future. By addressing entrenched governance issues and integrating the expertise of diverse stakeholders, Iran can create a Nexus framework that balances immediate resource needs with long-term ecological and social priorities.

The analysis of boundary judgments further highlights the importance of addressing core systemic issues. In terms of motivation, the study identifies a significant gap, with current policies prioritising short-term governmental interests over the well-being of all stakeholders. The "ought" state calls for motivations rooted in long-term sustainability and equity. Regarding power, the research reveals imbalances in decision-making structures, where fragmented governance undermines holistic resource management. Creating interdisciplinary working groups and legislative mechanisms to redistribute power is essential for fostering collaborative and integrated governance. In terms of knowledge, the study identifies a reliance on narrow, sector-specific expertise, which neglects the benefits of interdisciplinary collaboration and capacity building. A shift toward integrating systemic knowledge, incorporating diverse perspectives and local expertise, is necessary to address the Nexus's complexities effectively. Lastly, legitimacy concerns are evident in the exclusion of marginalised voices and

perspectives. Equitable resource allocation and the inclusion of diverse worldviews in shaping solutions are critical to addressing this issue.

6. Conclusion

The responses from various expert groups regarding the water-food-energy nexus in Iran suggest a complex and multifaceted approach to addressing the interconnected sustainability challenges in the country. Each group, from energy and water experts to food specialists, academic scientists, and systems experts, offers unique perspectives that converge on the urgent need for an integrated and sustainable approach to resource management. However, their perspectives differ in terms of priorities, strategies, and implementations, reflecting the depth and breadth of the nexus challenge.

The Energy Expert Group and the Water Expert Group both identify the public sector as the main customer or beneficiary of the current system, but advocate a shift towards all people or the entire ecosystem, indicating a move from a sectoral to a more comprehensive stakeholder framework. They emphasise the importance of sustainable development and the sustainable supply of resources, including energy and water, as key objectives. The need for an integrated . The desire for more centralised organisation to manage this nexus, equipped with comprehensive legal and executive powers, is highlighted. The desire for more centralised and effective governance structures in the energy and water sectors is indicated. The Food Experts Group shifts focus to the agricultural sector and the general public, emphasising the importance of strategic planning for sustainable food security. Like other groups, they criticise short-term planning and advocate for long-term sustainability, emphasising the role of grassroots organisations under government oversight. The group also emphasises the critical need for expertise in new energies and strategic management to overcome complex food security challenges exacerbated by water and energy constraints.

Academic experts present a different perspective alongside representatives from the public, agriculture, energy, and health sectors, who serve as current stakeholders and advocates, advocating for a future in which the broader population benefits. Their vision includes a balanced use of resources and the demand for knowledge in management, energy, agriculture and water engineering to inform decision-making. Their vision includes a balanced use of resources and the demand for knowledge in management, energy, agriculture and water engineering to inform decision-making. Their emphasis on strong, non-public institutions that complement government efforts highlights a call for collaborative, interdisciplinary

approaches. The System Experts Group offers a systemic critique, pointing to a broader societal concern for health and the future as ideal beneficiaries.

They criticise short-term government policies and fake complacency, and advocate long-term planning that includes renewable energy and strategic crop cultivation. The group advocates for decision-making to be entrusted to technical experts with executive authority, reflecting a strong conviction in the necessity of expertise-based governance to address the challenges at hand. In conclusion, while all groups acknowledge the current system's focus on short-term solutions and sector-specific stakeholders, there is a unanimous call for a shift toward comprehensive and sustainable management of the water, food, and energy nexus, with a strong emphasis on long-term planning, renewable resources, and expert decision-making.

The differences lie in their areas of focus on energy efficiency, water conservation, food security, and the role of academia versus technical experts in governance. These responses underscore the complexity of addressing the nexus challenges in Iran and highlight the need for an integrated approach that balances immediate needs with long-term sustainability, engages a wide range of stakeholders and draws on expertise across disciplines to ensure the health and well-being of both the ecosystem and the wider community.

This research employs CSH, a powerful systems thinking approach, to analyze the Iranian WEF Nexus. Unlike previous research, predominantly focused on optimisation and simulation models (e.g., WEFO, AWEFSMI, WEFSIML-apt, Q-Nexus Model, and Tian et al.'s (2022) unified approach), which primarily address economic efficiency and resource allocation, our study delves into the underlying socio-political dimensions shaping decision-making within this critical nexus. These previous models, while valuable in their specific contexts, often overlook the broader societal implications and the diverse perspectives of stakeholders, failing to address the deeply that influence ingrained values and power dynamics that shape resource management.

For instance, the analysis of sources of motivation uncovered a dominant focus on short-term public sector gains, neglecting the long-term ecological and social consequences. Examining sources of power, we identified a concentration of decision-making authority, limiting the participation of diverse stakeholders, particularly marginalised communities. The analysis of sources of knowledge revealed a reliance on fragmented, technical expertise, overlooking indigenous knowledge and interdisciplinary collaboration. Finally, investigating sources of legitimation uncovered a deficiency in accountability mechanisms to protect the interests of future generations and the environment.

These findings, derived from a rigorous application of CSH, illuminate the urgent need for a paradigm shift in the management of Iran's WEF Nexus. The current fragmented, short-term approach, driven by unsustainable practices and power inequalities, must give way to a holistic, integrated, and equitable system. This transformation necessitates:

- **Legislative Reform:** Strengthening legal frameworks to protect long-term sustainability and ensure equitable resource distribution.
- **Interdisciplinary Collaboration:** Fostering collaboration among diverse stakeholders, including experts from various fields, local communities, and government agencies.
- **Capacity Building:** Investing in programs to enhance understanding of the WEF Nexus and build the capacity for sustainable practices.
- **Climate Change Adaptation:** Integrating climate resilience into water management, energy production, and agricultural practices.
- **Long-Term Planning:** Implementing long-term planning that considers ecological, economic, and social dimensions.

This research provides a crucial foundation for policymakers and stakeholders to create a more sustainable and equitable future for Iran's Water-Energy-Food (WEF) Nexus. By adopting a systemic approach that acknowledges and addresses the complex interplay of power, knowledge, values, and interests, Iran can pave the way towards a more just and environmentally responsible management of its vital resources. Future research should focus on operationalising these findings, translating them into concrete policy recommendations, and monitoring the progress toward a truly sustainable WEF Nexus.

The CSH method provides many output analyses but is not considered a decision-making method. Therefore, it is recommended that, in future research, the present method be combined with a decision-making method that can rank and evaluate the obtained options. For future researchers working on issues related to the water, energy, and food nexus, as well as other environmental sustainability concerns, it is recommended that they employ integrated approaches to incorporate diverse and complementary perspectives into their analysis. These approaches can include a combination of systems modelling, critical analysis, and quantitative and qualitative methods to more comprehensively understand and interpret the complexities of the issues under study. Considering uncertainties in data and decision-making processes is a primary challenge in sustainability-related research. The use of fuzzy computing can help researchers manage and analyze these uncertainties more effectively.

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Designing an Organisational Strategic Planning Model in the Iranian Forensic Medicine Organisation

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ABSTRACT

Strategic planning is one of the important and effective concepts that organisations have always paid attention to in order to survive, improve competitiveness, adapt to changing environmental conditions and finally provide better services. This issue requires close attention, especially considering the current conditions in important and influential organisations such as the Forensic Medicine Organisation. The purpose of this research is to explain the strategic planning model of the country's forensic medicine organisation through a futures research approach. The research method employed in this study is qualitative. The current research is career-oriented in its purpose and employs both qualitative and survey methodologies. The method of data collection was library studies and semi-structured interviews, and MAXQDA version 20 software was used for data analysis. The statistical population included 15 experts (directors, managers organisation, and supervisors of the organisation's human resource strategy projects, as well as business experts and academic experts in the field of management). The research findings showed that the strategic planning model Forensic Medicine Organisation includes organisational factors, support factors, and individual factors. Organisational factors include cultural, structural, and process criteria. The support dimension includes motivation criteria, an extroverted management team, and a focused management team. Individual factors include interpersonal communication criteria, creativity, and general skills. The results of the research have also shown that strategic futures research operates at two levels of organisation and product employing two approaches: perception and prediction (interpretation). From the perspective of product innovation management, futures research is conducted at both the organisational and product levels. At both levels, environmental monitoring activities, data interpretation and learning are conducted separately.

Keywords

Future research, Strategic planning, Forensic medicine, Support, Individual creativity.

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1. Introduction

Strategic planning is one concept that has received increasing attention in economic enterprises and organisational planning in recent years due to its comprehensiveness (Waltert et al., 2024). Parallel to the more dynamic environment and the rise in environmental uncertainty, strategic planning has also gained prominence in organisations, enabling them to navigate environmental changes and turbulence while solidifying their orientation towards long-term goals (Napoleone, 2024). Strategic planning facilitates understanding the organisation's strategic position, determining strategic goals, and selecting appropriate strategies to achieve these goals (Munoz et al., 2023). Regarding the strategic position of the organisation, it is essential to acknowledge that this involves evaluating the organisation's strategic capabilities (resources and skills), the expectations of stakeholders, and identifying how the external environment influences the organisation's strategy (Almeida et al., 2022). The strategic capabilities of the organisation encompass the resources and skills it must acquire to survive and thrive. These resources encompass physical assets (buildings, equipment, and production capacity), financial resources (capital and funds), human resources, and intellectual capital. Therefore, strategic management aims to transform the organisation's ordinary resources into distinctive resources (Irawan et al., 2023). The key point is that organisations employ various strategic planning approaches to succeed in areas such as enhancing performance, competitiveness, survival, and adaptability to different environmental conditions. Therefore, depending on the specific circumstances affecting organisations and their environment, each organisation adopts distinct strategic plans to achieve these objectives (Lafioune et al., 2023). According to his opinion, there is no single perfect version of strategic planning that suits all organisations; rather, each organisation selects a model based on the nature of its operations and, by making modifications, employs this model as its strategic planning process (Theoharakis et al., 2024). This issue is of great importance, especially considering the challenges that organisations will face in the future—whether in the near or distant future—which will lead to a range of diverse and unpredictable conditions for organisations (Hayati et al., 2023). Such conditions—that is, the formulation and implementation of various strategic plans under different and sometimes unpredictable circumstances have heightened the focus on future studies within the field of strategic planning, establishing the foundation for developing strategies and plans across multiple strategic domains (Kohtamaki et al., 2023). In general, the concept of future studies reflects how the reality of "tomorrow" emerges from the changes or stability of "today." Accordingly, strategic planning futurology represents a type of planning aimed at defining and formulating the

necessary, effective, and efficient strategies for the future of organisations (Hofhuis et al., 2024). The concept of strategic future research encompasses two main aspects: understanding the present and predicting the future. Decision-making is the essence of planning, which involves studying internal and external variables to determine the best approach for transitioning from the current situation to the desired one (Nygaard, 2024). Therefore, the basis of the strategic planning process is the study of internal and external variables in the current conditions. Such an approach involves selecting the method to achieve the goal in the future based on current conditions. The current conditions will not continue. Therefore, organisations face strategic plans that are constantly outdated (Pereira et al., 2022). Strategic futures research can outline a strategic and dynamic path by predicting the future internal and external situations, which form the basis of the organisation's strategy, unlike the static approach found in traditional texts. A path that considers different future states and conditions (Bhatti et al., 2023). As we know, forecasting is the basis and prerequisite of any type of planning, especially strategic planning. In the current situation, it is unexpected events can sometimes destroy the foundations of plans, including strategic ones. In this situation, it is not reasonable to give up planning and expose ourselves to future events. So, a solution should be found to solve this problem (Stapleton et al., 2024).

Following the announcement of the country's 20-year vision document by the Supreme Leader, the Forensic Medicine Organisation's 20-year vision document was compiled for the first time in 2013, and the organisation's goals were outlined in the form of its fourth five-year development program (Ghanavati, 2023). Since 2017, the organisation's twenty-year vision document has been revised and redesigned. So far, five specialised meetings have been held in line with the development of the country's Forensic Medicine Organisation’s strategic plans within the relevant organisation. According to the 1401 statistics, this organisation provides services to more than 2 million, 996 thousand, 637 clients in the country, with nearly 336 centres (Mansouri, 2024). 90.6 percent of these experts are involved in clinical examinations, 1.3 percent are specialised commissions, 4.9 percent are involved in laboratory affairs, and 3.3 percent are related to the examination and autopsy of corpses (Dalir, 2023). According to available statistics, on average, more than 500,000 conflict victims refer to the country's forensic medicine centres every year. In 2023, the statistics on conflict-related referrals to forensic medicine were 876,753 people, representing an increase of 0.8% compared to the previous year (Alimohammadi, 2023). According to the conducted research, to date, a comprehensive local model for the strategic planning of the country's forensic medicine

organisation has not been presented in the country, and future research is necessary to address this gap. By examining the preparations made, it was determined that the Forensic Medicine Organisation is one of the most important and influential organisations in Iran. It should be possible to improve the functioning, deliver better service, and provide appropriate management and executive perspectives within this organisation through strategic planning. For this reason, the presentation and application of strategic management in the Forensic Medicine Organisation is very important. Based on this, the current research aims to develop a strategic planning model for the country's forensic medicine organisation, adopting a future research approach. It will enable the identification of constructive scientific and practical solutions to enhance the strategic planning of the country's forensic medicine organisation. Therefore, the question of the current research is: "What is the strategic planning model of the country's forensic medicine organisation with a future research approach?" In the current research, as we examine the theoretical foundations and theories related to the relationship between future research and the process of strategic management, as well as the country's forensic organisation, the processes by which future research leads to value creation are presented. Then, the literature related to strategic foresight is presented, and by stating the key success factors of organisational foresight, a conceptual model of the role of these factors in the success of the organisation is developed.

2. Literature review

2.1. Strategic planning

Strategic planning refers to a process during which organisations make decisions, identify solutions, and design a roadmap to achieve desired goals (Kurpiela and Teuteberg, 2022). Thus, it can be acknowledged that strategic planning serves as an official representation of the organisation's future. The strategic planning process comprises several steps, which are briefly reviewed below:

Initial agreement: It means that the organisation first recognizes the desired goal of its opinion and undertakes comprehensive planning to achieve that goal;

Establishing duties: It means establishing the dos and don'ts as well as determining the position of the people that the organisation needs to achieve its desired goal;

Stakeholder analysis: Organisations must also consider the conditions of stakeholders to adjust their organisational plans because, one of the secrets to the success of organisations is obtaining the satisfaction of stakeholders;

Developing a mission statement: The organisation's mission statement determines the goals of the organisation, its governing structures and values, and how to respond to the needs of customers and stakeholders;

Understanding the organisation's environment: Another necessary and important condition for organisational strategic planning is understanding the organisation's environment. The mentioned environment includes both the internal and external environments of the organisation, It is very important to pay attention to each of these two environments because, based on it, you can get a proper understanding of the weaknesses and strengths of the organisation;

Determining strategy: This stage is considered the basis and focal point of strategic planning. Strategic contents or issues refer to the set of structural, political and economic decisions of the organisation, based on which it determines the areas of authority, missions, products, services, costs, budgets, etc. of an organisation;

Setting the organisational perspective for the future means drawing up the future conditions, in other words, the possible perspective of the organisation, based on the existing material and human resources of the organisation.

A one-year operational plan means setting up a plan based on the organisation's facilities and priorities over a one-year period (Lafioune et al., 2023).

In general, the realisation and correct implementation of organisational strategic planning includes three stages:

Developing strategies: Developing the mission of the organisation; identifying opportunities and threats of the external environment, identifying the strengths and weaknesses of the organisation; determining short, medium and long-term goals; determining and choosing multiple and diverse strategies to continue the activity;

Implementing strategies: Setting annual goals in the organisation, determining policies, motivating employees and allocating resources to implement the formulated strategies;

Strategy Evaluation: Strategy evaluation refers to the process in which a business determines the effectiveness of the company and its ability to reach its future goals (Borchers and Enke, 2021).

Figure 1. Three stages for realising and correctly implementing organisational strategic planning

2.2. Organisational future research

Future research, organisational strategy and operational management are important and effective organisational issues that each follow different lines (Mariano and Laker, 2024). Future research provides a type of knowledge that is crucial to apply within an organisation. Based on future research, the set of organisational approaches, strategies and policies designed has been implemented, and its strengths and weaknesses are evaluated (Galan, 2023). An important point regarding organisational future research is the ability of the organisation's managers to recognise two key issues. First, providing organisational needs, including capable and expert human resources, financial capital, and technological capabilities, and secondly, their ability to see and predict the future. The future research of organisations is essentially discussed in two dimensions: the far and near future. In most cases, the attention, focus, and emphasis of organisational managers are on near-future research, which will confront organisations with significant problems. In fact, due to the intense competitive conditions in the current era and the pressing issue of organisational survival, most managers focus on the near future (Jabhan, 2023). This issue may bring important achievements for organisations at first, but if they do not pay attention to the distant future, threats will be far more significant for them. In general, the organisational futures research process is realised during several stages:

1. **Determining both short-term and long-term changes**: Based on this, it is crucial to identify the set of probable cases related to what will happen in the near or distant future.

2. **High ability to change and replace**: Another important item for future research for an organisation is the ability to apply change or the ability to quickly replace. Based on this, an organisation should be able to identify the set of environmental changes and threats, can adapt to the changes, and have a high capacity for replacement (Marquez et al., 2025);

3. **The ability to use up-to-date knowledge and new and efficient technologies**: Planning

and implementing a set of efficient scenarios of an organisation requires an important principle called new and efficient knowledge and technology. Based on this, new knowledge and modern technologies give organisations the ability to use different approaches and methodologies to achieve an important principle of organisational balance and maintain itself against changing and unbalanced environmental conditions;

4. **The ability to predict all possible future scenarios**: Among other important things for planning and implementing the appropriate future research of an organisation is the ability of its managers to predict all possible future scenarios. Based on this, managers who can predict more situations and prepare the conditions for those different situations will, of course, have a more successful organisation (Lafioune et al., 2023);

5. **The ability to creatively interpret and understand basic reality**: Predicting the future requires creative interpretation. Creativity that can create an exclusive status for the organisation, which will greatly contribute to the success of the organisation in today's competitive conditions;

6. **Evaluation of changes or continuation of the situation**: Finally, the future research of an organisation depends on the evaluation of all its stages. Based on the evaluation process, the managers of the organisation will determine the degree of success or failure of the organisational strategies. In addition to identifying existing weaknesses, strengths, and threats, they will reach a final conclusion on whether the adopted policies and strategies are effective or not. If it achieves a suitable level of efficiency, the current situation will typically continue; if it has not met the desired expectations, then a policy of changing the situation and revising organisational strategies will be implemented. (Jin et al., 2024).

Marquez et al. (2025), in an article titled: “Expanding Strategic Vision: The Role of Non-Utopian Unreal Scenarios in Decision-making”, showed that Mathematical reasoning is used to develop a framework for calculating the implications of these scenarios, emphasising the importance of probabilistic thinking in risk assessment. Organisations can benefit from adopting NUUS to navigate uncertainty and reduce risk the practical applications of NUUS illustrate its potential to inform strategic decisions in complex environments. Mohammed Mousa et al. (2024), in their research titled “Strategic Planning and Organisational Performance: An Empirical Study on the Manufacturing Sector”, demonstrated that the process of strategic planning has a beneficial effect on financial performance. Environmental scanning has a statistically significant positive effect on a company’s nonfinancial performance.

Management participation and planning formality have a positive and statistically significant effect on a business's non-financial performance at the 10% level. The domain of strategy and technique does not impact a company's nonfinancial performance. Yuan et al. (2023), in an article titled:" Integrated resource strategic planning considering inter-regional flexibility supply-demand balance: A case study for the Northwest and Central Grid in China", showed that incorporating these constraints and interconnections into the strategic power plan enables greater integration of renewable energy while reducing both installed capacity and the overall cost of regional power resources. In the S3 scenario, which includes inter-regional flexibility supply-demand balance, the total integration of wind and solar power increases by 1.54%. Additionally, the combined average annual fixed and operating costs decrease by 1.44 billion yuan compared to the S2 scenario, which only considers single-region flexibility supply-demand balance furthermore, evaluating flexibility demand at a shorter timescale results in a higher proportion of flexible resources, with an average annual growth of 24.43%.-Klepej and Marot (2024), in an article titled "Considering Urban Tourism in Strategic Spatial Planning", showed that strategic spatial planning documents are not responsive enough to tourism growth, and there is a lack of strategic measures steering towards sustainable tourism development in cities.

Sorkhabi et al. (2024), in an article titled:" A Futures Study on the Strategic Competencies of Human Resources Training and Development Managers (A Case Study of the Social Security Organisation)", showed that the analysis of the interviews led to the identification of 67 primaries and 36 secondary competencies, and 14 of them were confirmed by screening through fuzzy Delphi. Among the 14 competencies, the most strategic key competencies were determined as situational awareness, peer education, digital leadership, unity of effort, and unification of efforts. As a result, it is necessary to examine these competencies in the design of human resource development programs and measures for the SSO, focusing on future human resource training and development managers within the organisation, and to always consider these strategic steps for their excellence and prosperity.

Gharavi et al. (2023), in an article titled " Identifying effective strategic factors in the field of sales performance and the role of social media marketing with a future research approach", showed that eight factors related to sales performance are divided into three categories of influencers, dependent and autonomous, according to social media in terms of permeability and dependence. Factors such as sales performance, sales behaviour, the use of social media, and the collection of competitive information about the research topic are more effective. In

contrast, other factors, such as media type and goal-oriented education, as well as attitude towards media utility, have the most impact and are the least affected. The research findings also showed that, in terms of future research and identification of strategic variables, the variable of customer relationship technology is the most strategic research variable affecting sales performance.-Akbarpoor and Tizroo (2022), in an article titled ” Futures studies of the strategy of knowledge-based companies with a scenario approach”, showed that the results of the scenario wizard software provided eight acceptable (strong) scenarios, among which three optimistic, pessimistic and most likely scenarios were analysed. By categorising the advantageous components into four categories—political/strategic, economic/financial, social/cultural, and technological the results of the three scenarios were also presented in this manner. In the final stage, a 6-person group was formed to develop the necessary measures and policies. This group ultimately proposed 12 measures for the optimistic scenario, nine measures for the probable scenario, and four measures for the pessimistic scenario. In general, it can be said that in knowledge-based companies, the distribution of knowledge management power across four categories production, market development, project result orientation, and quality can provide a favourable scenario for maximising the use of facilities and opportunities.

Mohammadpour et al. (2022), in an article titled ”Designing Strategic Model of Entrepreneurial University Based on Approach Future Studies in Higher Education”, showed that the main categories include: 1) Entrepreneurial organisational structure; 2) Entrepreneurial management; 3) Entrepreneurial vision and mission; 4) Entrepreneurial educational system; 5) Entrepreneurial research system; 6) Entrepreneurial human resource management; 7) Entrepreneurial financial resource management; 8) Culture of entrepreneurship and sustainability; 9) New ICT; 10) Role models and reward systems; 11) Entrepreneurship centres; 12) Government support; 13) Economic factors; 14) Socio-cultural factors; 15) Committed relationship of industry and university; 16) Internationalisation. As mentioned earlier, in this study, to complete the discussion of foresight, in addition to gathering the factors affecting the entrepreneurial university, the factors that shape a favourable future for the university were separately collected and discussed. To build a futuristic entrepreneurial university, it is essential to consider not only the factors affecting entrepreneurial universities but also the factors that will shape the future university. Given this in mind, the concepts of foresight institutionalisation and strategic thinking should be applied to all university activities, especially in the university's vision and mission. In the process section, to build a foresight entrepreneurial university, foresight planning factors, the discovery of internal and external trends, bedrock and structural

reforms in the educational and research system, organisational structure, organisational culture, role models, and reward systems, as well as information and communication technologies, should be considered. In the output section, to build a futuristic entrepreneurial university, the factors of entrepreneurial university scenarios, as well as science and technology foresight, should also be highly considered.- Ahmadi and Saeedi (2021), in an article titled " Identifying the Drivers of Future Strategic Thinking of Managers in the Iranian Budgeting System with a Futures Research Approach", showed that the selection of experts was based on the method of theoretical sampling of snowballs and theoretical saturation Delphi results Two-sentence test and fuzzy Delphi were used. After preparing the list of initial proponents, incorporating the opinions of professors specialising in this field as well as experts from the interview stage, the initial propulsion was aggregated and modified. Finally, 22 drivers were selected and sent to Delphi stage experts. The results showed that 22 drivers are among the most important drivers in the future of strategic thinking in the country's budgeting system. In this study, 22 propulsions were identified, which were approved by experts.Table 1 shows that most of the dimensions identified in the field of organisational strategic planning are general and may not meet the specialised needs of this issue, especially in important and influential organisations such as forensic medicine. In this regard, it seems that in order to identify the dimensions of organisational strategic planning, other important dimensions can also play a role, the gap of which is evident in previous researches, and this indicates the existence of a theoretical gap in this field.

Table 1. Dimensions of strategic planning extracted from the empirical research background

Author(s)/ Year	Identified dimensions					
	Organisational innovation	Strategic evaluation	Strategic prioritization	Strategic knowledge	Strategic competition	Smart decisions
Marquez et al., (2025)		√	√		√	
Mohammed Mousa et al., (2024)	√	√	√			√
Yuan et al., (2024)	√		√		√	
Klepej and Marot (2024)	√	√	√			√
Sorkhabi et al., (2024)	√	√		√		√
Gharavi et al., (2023)		√	√	√		√
Mohammadpour et al., (2022)	√	√		√		√
Akbarpoor and Tizroo (2022)		√	√	√		√
Ahmadi and Saeedi (2021)	√		√	√	√	

By reviewing the literature and research background, it was found that no independent and comprehensive research has examined the organisational strategic planning model in the Iranian Forensic Medicine Organisation, and this is the most important innovation of the current study. Also, examining the most important dimensions of organisational strategic planning in the Iranian Forensic Medicine Organisation is considered to be another innovation of the present study.

3. Research methodology

The research method employed in this study is qualitative. The present research is applied in terms of its purpose, and qualitative and survey methods are employed in its methodology. Information was collected through library studies and semi-structured interviews, and MAXQDA version 20 software was used to analyse the data. The statistical population consisted of 15 experts (heads, managers, and supervisors of the organisation's human resources strategy projects and academic experts and experts in the field of management). The statistical population includes experts (heads, managers and supervisors of the organisation's human resources strategy projects, as well as academic experts and experts in the field of management) who have the following conditions: 1- They have held an executive position in at least one of the organisation's human resources strategy projects. 2- They have more than 15 years of related experience, and 3. Professors who have experience in at least one strategic planning project in public or private departments. Based on this, the sample size of the present study included 15 people.

3.1. Coding and analysis process

The authors identified them by using reliable articles and books that have been cited at least five times a year by other researchers. Then, according to these articles, they identified and extracted the materials used in the table below. It is stated along with the names of the authors and the year of their publication. The main and subcategories were presented based on the process of open and central coding of the data obtained from in-depth and exploratory interviews with key experts, as well as the refinement of conceptual codes. The priority of each factor was determined by the frequency with which the concepts were mentioned in the interviews. In general, coding is a systematic procedure developed by Strauss and Corbin (2006) to discover categories, characteristics and dimensions of data. During these analyses, stratified content analysis was employed, along with the analytical technique suggested by Strauss and

Corbin (2006). Based on this, in the first step, open and central coding was performed by examining the data at the sentence and phrase levels for each interview, and conceptual codes were extracted from the interview transcripts. Sometimes, a sentence was related to more than one concept. By extracting standard conceptual codes and refining and removing duplicates using theoretical foundations, concepts were identified and specified. In the next step, by refining and reducing these concepts, they were organised into subcategories (components). Through continuous examination of these categories and their concepts, the main categories (dimensions) were temporarily named. To ensure the proper organisation of each concept and category, the transcripts of the interviews were rechecked, and the concepts and categories were carefully examined. The data was analysed multiple times to achieve logical saturation for the main categories and subcategories. From the beginning of the analysis, the limits and even the titles of each category were not definitively determined, and these categories were revised throughout the analysis process. Open and axial coding was stopped when a meaningful classification was achieved after several reviews of the interview transcripts, the subcategories were duplicated, and no new relevant information could be found in the interview transcripts, even if additional information was discovered. It was consistent with the existing classification. The classification done was not the only possible classification with absolute limits, but it can be considered sufficient for the following stages of data analysis and questionnaire design. In accordance with the research questions, participants were asked various questions during individual interviews regarding the dimensions and indicators within the strategic planning model of the Forensic Medicine Organisation of the country, approached with a future research perspective. The participants provided diverse responses, enabling the researcher to identify concepts through a content analysis of the text at the phrase, sentence, or paragraph level by extracting conceptual codes. This process continued, and by identifying additional sub-categories through comparison and data matching, these types of sub-categories were classified under the main category or dimension. The interview transcripts were reviewed several times, revealing further concepts and sub-categories that enhanced the saturation of these macro categories. Below is a sample of the interview text:

The success of any organisation depends on having a comprehensive, efficient programme and efforts to realise it. The necessity of this issue is the existence of a regular and purposeful structure. Based on a regular and purposeful structure, a set of strategies and goals of the organisation can be set. Forensic medicine is pursued to achieve the goals of organisational

development. This issue also depends on capable human resources, modern organisational knowledge, and capable and competent managers."

Strategic planning in the forensic organisation should have the necessary efficiency in critical situations and this issue depends on the realisation of high organisational skills in this organisation. For example, considering the ever-increasing volume of referrals to the Forensic Medicine organisation, the employees of this organisation should be able to organise clients well with their high skills."

Strategic planning in the forensic medicine organisation should be based on the realization of new ideas. In fact, considering the existing conditions in this organisation, it is no longer possible to provide services to clients based on traditional ideas and procedures. Therefore, the senior managers of the forensic medicine organisation should firstly respect new ideas, and secondly, by creating a diverse think tank, they should try to provide new and creative approaches".

An example of how to perform the familiarization and data labelling steps is presented in Figure 2:

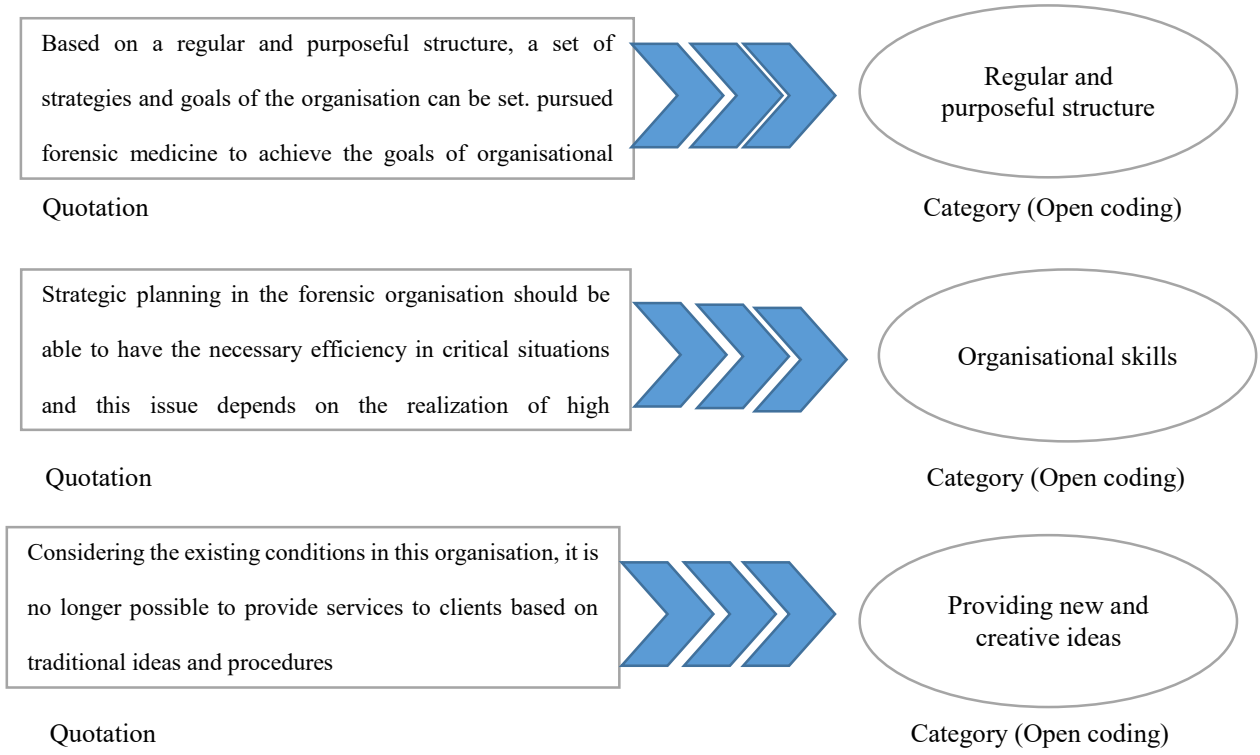

Figure 2. An example of how to perform the familiarization and data labeling steps

4. Findings

4.1. Indicators extracted from the interviewees

In the qualitative part, first, the key points related to each semi-structured interview were marked by listening to the recorded interviews and studying the written notes during the interview, then the key and essential points from each interview were extracted. Next, by using the classification of key points in the form of professional terms, the necessary labeling was done. Then, the labelled terms of each interviewee were organised in the form of a table and classified into dimensions based on their relationship and compatibility. In the following, the obtained primary codes are examined, and then the researcher groups codes that are close to each other in terms of meaning and concept, which have a semantic affinity with each other, and creates new meanings and words. In fact, the researcher categorizes the codes in the form of sub-themes. To learn more about these categories, an example is given in Table 2.

Table 2. Results of interviews with experts

Introduction of codes and indicators	Number of repetitions
Extensive organisational structure/communication	8
General skills/operational skills	7
process/existence of the central process	7
Structure/structural agility	7
Creating motivation/rewarding in order to request plans based on future research	7
Interpersonal communication/discourse based on future research concepts	6
Structure/Creation of education structures based on future studies	6
Extrovert management team/expression of thoughts to introduce and recognize the plan from the managers to the employees	6
Centralized management team/creating a think tank for me for executive and operational days	6
Creativity/identification of creative and innovative ideas and solutions	6
Culture/existence of teamwork	6
Culture/credibility and acceptance of the norm	6
Interpersonal communication / communication with other organisations and competitors	5
Centralized management team/use of experts in management teams	5
Interpersonal communication/creating intra-organisational communication platforms with a focus on the future of knowledge	5
Extrovert management team/Using client/project oriented teams	5
Creativity\Focusing on important, attractive and exciting ideas	5
Support/motivation	5
Creating motivation/giving spiritual privileges to employees	5
Extroverted management team/involvement of managers in work	5
Organisational/cultural factors	5
Systematized and formal process/processes	5
General skills/correct understanding of abilities	5
Organisational/process factors	4
Organisational/structural factors	4

Introduction of codes and indicators	Number of repetitions
Support and support\outgoing management team	4
Centralized management team/Using an exclusive management team for the activity	4
Visible and transparent process	4
Individual factors/interpersonal relationships	4
Structure/existence of necessary structure for development	4
Extroverted management team/manager's presence in the field of activity	4
Individual factors/general skills	4
structuring/providing development and training and rewarding research and development	4
Organisational factors	4
Individual factors/creativity	3
Participatory decision-making process	3
Support and centralized management team	3
General skills/methodological skills	3
Individual factors	3
Support	3
Total (Valid)	195
Total	195

Based on Table 2 and the results obtained, the total number of repetitions of the indicators identified in the expert interviews, each of which lasted 30 minutes and was semi-open (guided), has been determined. Then, using this information, the results related to the phishing technique are displayed through the MAXQDA software, showing the usage of each variable, and the results are graphically illustrated in Figure 3.

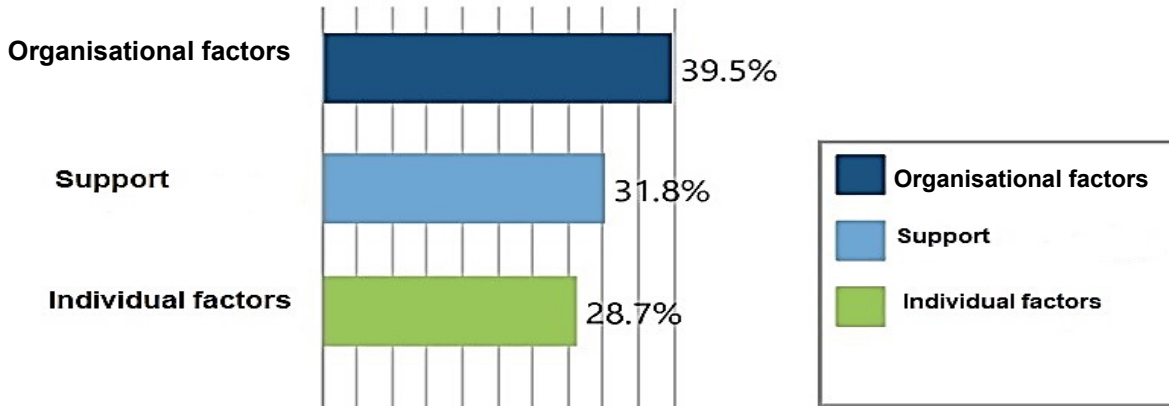

Figure 3. The amount of benefit from the identified indicators

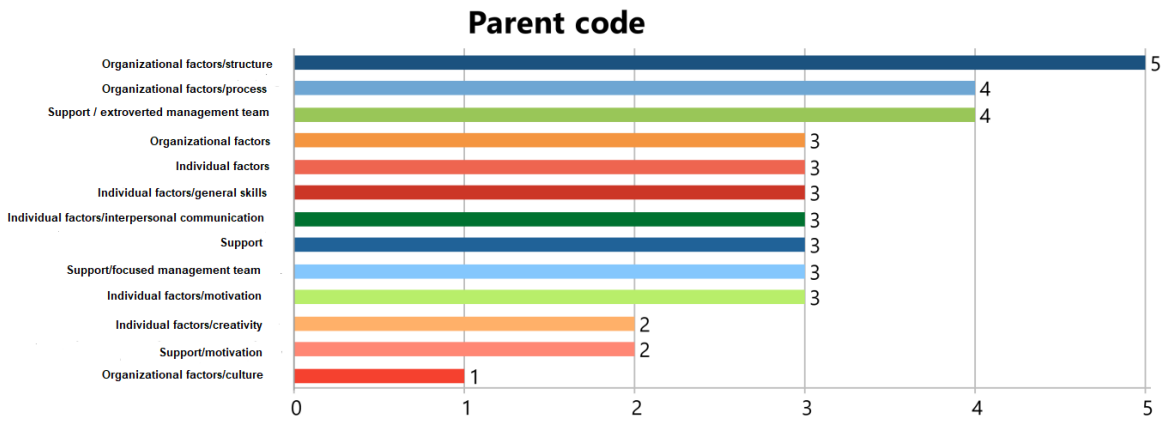

Figure 4. The amount of repetition of identified codes

Based on visibility data, the most repetition is observed in each of the identified variables related to organisational factors. Now, by identifying these cases and receiving the specified relative information, we have implemented the brainstorming technique among experts, which we will discuss further. In Figure 5, all the identified codes and variables are presented in a general diagram, which is displayed here.

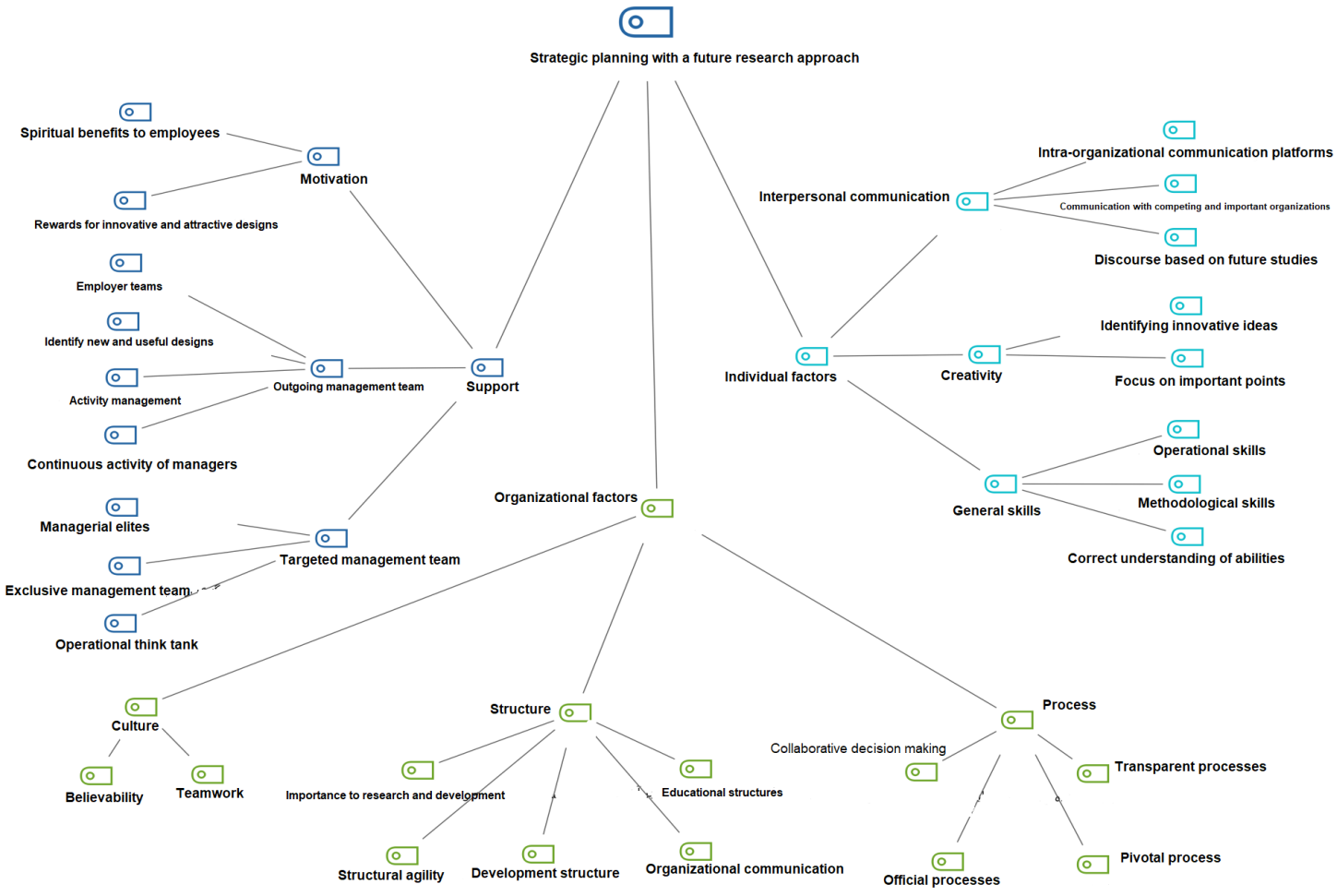

Figure 5. Complete diagram of identified codes

In Figure 5, all the identified codes and identified variables are drawn as a general diagram, which is displayed in this diagram.

4.2. Brainstorming technique

This technique, which is a derivative of the Delphi technique and is formed by using the opinions of experts, in the current research, as previously stated, the number of experts in this research was 15 people and after the initial interview and the results obtained from the codes It has been identified that this technique has been implemented among experts. The implementation steps of this technique are as follows: 1. The researcher's questions are distributed among the experts, and they are asked to express their opinions regarding the questions, with 1 being the lowest score and 5 being the highest score. 2. Then, by averaging the results of the questions, remove the questions whose relative score is less than 3.7 and repeat this technique until all the questions are higher than the obtained value. The point of interest in the table below is that the questions before removal (with lower scores, marked in a different colour) and those remaining after removal are equal to 77, which is the number of questions cited as the questionnaire used in this research. Based on the obtained information and values, questions 34, 53, 57, 63, 69, and 73 were removed from the questionnaire due to not meeting the required quota. Consequently, the researcher's questionnaire was formed after these questions were removed. Additionally, this process has been repeated three times, and the general results of the work are summarised in Table 3.

Table 3. Research checklist

Row	Rate each of the following factors based on the events of your company/organisation	Score
1	Ideology of the organisation	4.31
2	Credibility of norms in the organisation	4.29
3	Support and acceptance of community beliefs	4.32
4	Supporting and accepting employees' beliefs	4.36
5	Implementation and teamwork	4.31
6	Creating the necessary platforms for research and development	3.94
7	Support and encourage employees to conduct research and development	3.92
8	Creating educational structures	3.90
9	Creation of halls / think rooms	4.07
10	Organisational communication and relationship	4.33
11	Taking advantage of the experiences of organisations	4.18
12	Design of dynamic structures	4.29
13	Giving points to people who are researchers and interested in educational projects	3.88
14	Structural agility	3.74
15	Eliminate cumbersome rules and bureaucracies	3.79
16	Employee agility	3.76
17	Necessary training for employees in order to strengthen the morale of employees	3.81
18	Collaborative creation and decision making	3.79
19	Taking advantage of employee participation in decision making	3.84
20	Using the consulting technique	3.77

Row	Rate each of the following factors based on the events of your company/organisation	Score
21	Benefit from systematic processes	4.18
22	Using project/process oriented techniques	4.30
23	Benefiting from observational reasoning methods	3.99
24	Benefiting from inductive-contingent techniques	3.95
25	Touchable and understandable processes	3.5
26	Central transparency in decision making	3.82
27	Efficiency of formal and recognized processes	3.84
28	Maintaining hierarchical bureaucratic desperation in the work process	3.91
29	Productivity of the combined process system (traditional-dynamic)	3.99
30	Granting family travel privileges	3.92
31	Holding encouraging parties and making those people's faces	3.96
32	Payment of incentive bonuses to employees	3.90
33	Financial support for people's families	3.85
34	Creating plans for financial institutions and funds	2.12
35	Inviting the family of the top employee and appreciating them	4.19
36	Financial support for employees interested in research projects	4.06
37	Granting incentive leave	4.33
38	Using project-oriented teams	4.41
39	Presentation of plans by managers to employees	4.35
40	Clarification of plans for employees and proper understanding for them	4.32
41	Involvement of managers in the field of work	4.14
42	The intellectual-advisory presence of managers in the field and work process	4.61
43	Benefit from consulting teams	4.53
44	Use of expert opinion in business activities	3.49
45	Carrying out projects/activities in the organisation with the continuous physical presence of managers and employees	4.08
46	Productivity of active managers and employees and checking their suggestions in doing work	3.94
47	Productivity in terms of employees in doing work	3.99
48	Participation of managers and supervisors in doing work	3.95
49	Using experts in management teams	3.78
50	Using the existing opinions within the organisation to present new designs	3.72
51	Using an exclusive management team for the activity	3.94
52	Use of cooperative groups in doing work	3.91
53	Taking advantage of auctions/tenders to do work in the organisation	2.99
54	Create competitive teams/groups to do the work	3.72
55	Allowing new plans to enter the system and holding brainstorming sessions	4.10
56	Creating intra-organisational communication platforms	4.63
57	Creating communication bridges of virtual space for the organisation - employees	3.06
58	Creating web platforms for communication between employees	4.21
59	Establishing a platform and culture of communication among employees	4.02
60	Creating and bridging between organisations similar to the organisation	4.23
61	Benefiting from the experiences and expertise of similar organisations	4.11
62	Modeling the successful plans of competing organisations	4.09
63	Create specific patterns for specific situations	2.94
64	Recognizing the problem of unsuccessful projects of other organisations and giving guidance and counseling to the organisation (in order to increase the credibility of the organisation)	3.96
65	Establishing working group meetings to identify plans	3.99
66	Dialogue with employees to understand their needs and wants	3.94
67	Direct bridging between employees and senior managers/supervisors	3.90
68	Identify ideas	4.44
69	Recognition of new cross-border ideas and implementation of identified projects	3.18
70	Knowing creative and innovative solutions	3.86
71	Giving points to creative and innovative people	4.01
72	Focus on important ideas	3.96
73	Productivity of new research projects	3.22
74	Providing exciting and attractive ideas	3.82

Row	Rate each of the following factors based on the events of your company/organisation	Score
75	Presenting utilitarian/green ideas (environmentally oriented)	4.36
76	Benefit from staff with ICDL skills	4.18
77	Benefiting from employees with specialized skills	4.02
78	Benefit from employees with consulting skills	4.21
79	Benefiting from employees with problem solving skills	4.65
80	Benefiting from employees with problem simplification skills	4.53
81	Benefiting from the forces with a correct understanding of the organisational problem and goal	4.17
82	Benefit from expert executive teams	4.24
83	Benefiting and correctly understanding the employees' attitude to the problem	4.33

5. Discussion and conclusion

Considering the drastic changes and developments in the environment and the high intensity of competition in global markets, every organisation has an urgent need to benefit from strategic planning in order to survive and achieve greater success, as organisations are increasingly important today. They also require strategic planning of their activities, but to date, few studies have been conducted on this topic. Sufficient models of strategic planning for organisations have not been presented. Additionally, the results of the data analysis presented in the previous chapter were used to explain the strategic planning model and future research approach, which encompassed three main dimensions: organisational factors, support, and individual factors. Organisational factors include the criteria of culture, structure, and process. The support dimension includes the criteria of creating motivation, an extroverted management team, and a focused management team. Individual factors also include the criteria of interpersonal communication, creativity, and general skills. The appropriate model for designing and explaining the strategic planning model of the country's forensic medicine organisation with a future research approach is shown in Figure 6.

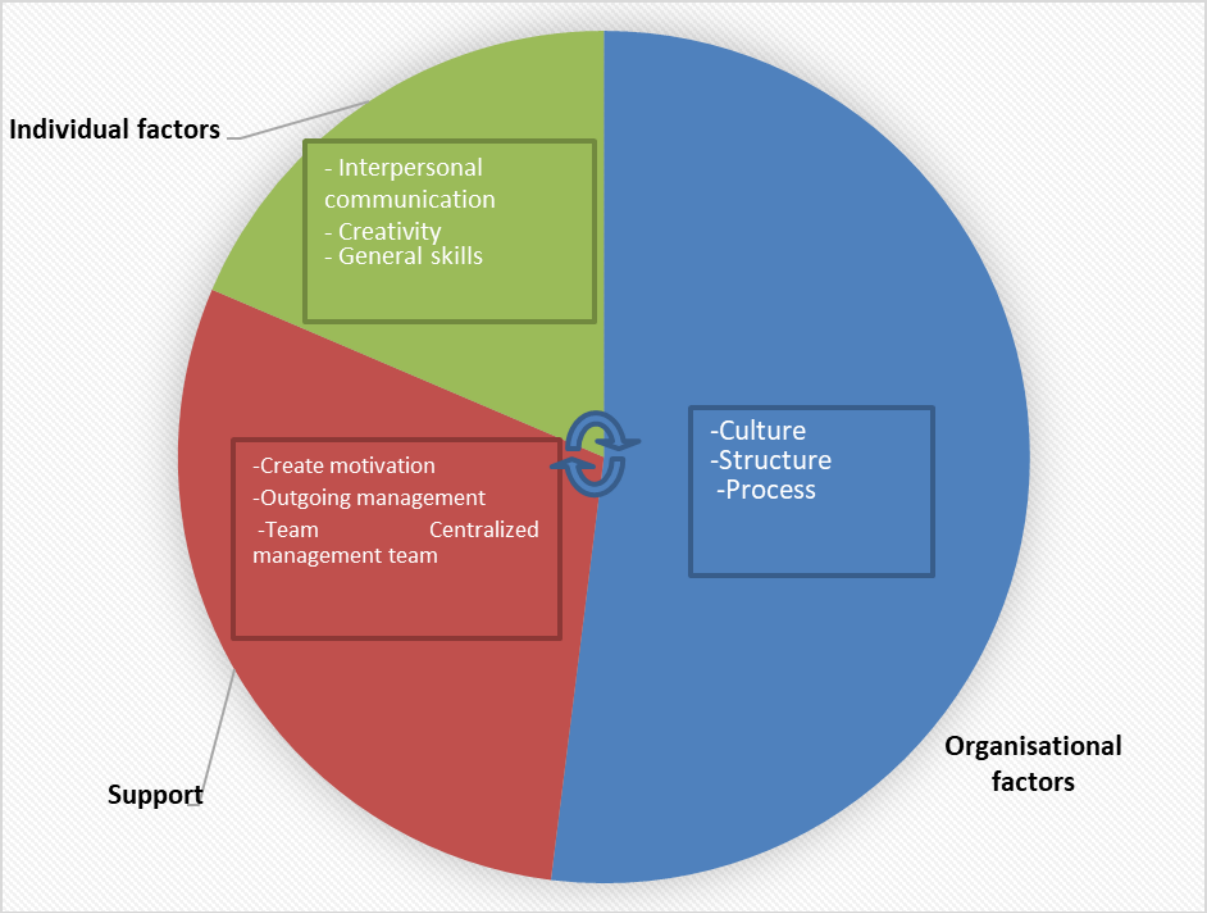

Figure 6. Strategic planning model of the forensic medicine organisation: a futures research approach

In explaining the obtained results, strategic future research works at two levels of organisation and product with two approaches of perception and prediction (interpretation). From the perspective of strategic forecasting and strategic management, future research is at the organisation level. From the perspective of product innovation management, future research should focus on the product level. At both levels of environmental monitoring activities, data interpretation and learning are done separately. As the use of strategic foresight can be significantly helpful in creating value for organisations, not using it or implementing it incorrectly can lead to failure. Organisations play a fundamental role. In a world full of contemporary transformation, far-sighted managers and planners, instead of waiting to welcome the future and making a decision when facing it, being present in the desirable future and with the approach of "looking back from the future to today" scrutinize the development paths and the policies to achieve it draw the desired future.

One of the requirements for development and progress in any field is to have insight into the environment, make timely decisions, and have a comprehensive and targeted plan. It is not possible unless future research is conducted correctly and successfully. Future research is the

knowledge that informs the organisation about future events, opportunities, and potential risks, reduces its corrosive ambiguities, doubts, and concerns, and increases the organisation's ability to make wise choices. In a word, futurology is a tool for intelligently engineering the future. Successful managers select aspects of various management techniques that apply to their environment and disregard the more complex approaches outlined in management texts. One of the most important elements of strategic plans is paying attention to the future and formulating plans and programs based on future conditions.

The presence of multidisciplinary teams and individuals with diverse expertise is necessary for future research processes. Each of these individuals should possess the skills relevant to their field, as well as the necessary skills for future research activities. The existence of a close connection between future research and innovation makes creativity necessary for team members. Since future research team members have different disciplines and expertise, the ability to communicate and discuss the goals and methods used to achieve them is considered one of the most important success factors of future research in any organisation, according to the agreement. Since strategic future research is a systematic process, the existence of visible and transparent processes, a central process, and collaborative decision-making is necessary. Also, the need to adapt the organisation to the phenomenon of uncertainty in the future makes organisational agility one of the success factors of strategic future research. Among other organisational factors that are effective in the success of future research is the extensive organisational communication between different levels of management and employees, and the teamwork culture that has been mentioned before. The support of senior management as a moderating variable is the foundation of a platform that enables a more effective implementation of future research processes. In other words, without the existence of individual and organisational factors, the process of strategic future research will not achieve success, but it can be said that in the absence of the support of the senior manager, significant success may not be achieved. According to the obtained results, the results can be aligned with the research results of Marquez et al. (2025), Mohammed Mousa et al (2024), Sorkhabi et al. (2024), Yaun et al (2024), and Akbarpoor and Tizroo (2022).

5.1. Suggestions

Based on the results obtained from the current research and referring to the results of the research questions, the following suggestions are presented:

In the first step, senior managers and employees of this organisation should always consider the mission of providing forensic medicine services. This issue is especially important in critical situations such as the spread of Corona. In the second step, compliance with safety and medical requirements in this organisation should be achieved through regular training of personnel. This issue has a deep connection with the category of organisational social responsibility in such a way that the primary mission of the forensic organisation can be seen as a continuous relationship between comprehensive service delivery and compliance with safety and medical requirements in this organisation;

Compiling educational topics on medical issues and holding in-service training courses in this regard. The interaction of the forensic organisation with higher education institutions, especially medical and therapeutic centres, to take advantage of the potential of universities in the implementation of operational projects of this organisation. Additionally, conducting training programs for managers and employees alternately and during different seasons ensures they become aware of and sensitive to the organisational issues of forensic medicine, thereby adhering to them. On the other hand, it is essential to create a culture regarding how to deal with clients, with a focus on timely and competent handling at the managerial and employee levels within this organisation. The belief and commitment of senior managers and employees in the forensic organisation in responding to people will lead to an improvement in the managers' attitude and awareness. The benefit and use of consultants who benefit from current knowledge will also significantly improve the attitude and awareness of managers;

Legal obligations to the issues of the forensic organisation with the supervision of direct representatives from the Ministry of Health and Medicine as well as the judiciary. Continuous monitoring of the performance of senior managers in the forensic medicine organisation will require them to comply with medical and legal issues in the accurate, targeted, and legal implementation of forensic medicine. One of the most important things in terms of facilities and technical equipment is the use of the latest and most up-to-date medical tools;

Real and pragmatic prioritization of senior managers and senior decision-makers of the forensic medicine organisation in five-year plans. Effective communication and modelling of projects carried out in other countries will be effective in formulating mid-term and long-term policies of the Ministry of Health. Compilation and explanation of medical and legal regulations and guidelines will be effective in the mid-term and long-term policies of the forensic organisation. Additionally, future research and forecasting regarding social crises is a crucial category that can help prevent the deepening and severity of crises when faced with widespread

crises and enable the organisation's forces, including managers and employees, to deal with the crisis with greater readiness. Correct supervision and control, along with the use of expert and committed personnel in formulating the policies of the forensic organisation, will also be constructive. Another important aspect of adopting appropriate strategies for developing organisational performance in forensic medicine is the redesign of complex and time-consuming rules and regulations, which requires collaboration between the Ministry of Health and the judiciary.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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