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An integration of operations research and design science research methodology: With an application in hospital disaster management

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ABSTRACT

This paper presents a conceptual hybrid model that embodies a synergistic approach by integrating principles from operations research (OR) with steps from the design science research methodology (DSRM). The model is applied to develop an evacuation support system for a group of hospitals located in Western Sydney, Australia, exposed to the risk of floods induced by climate change. By combining these two approaches, the conceptual hybrid model effectively overcomes the limitations associated with traditional DSRM and provides a comprehensive research framework for addressing OR problems. The research findings hold significant implications for academia, professionals, and policy makers engaged in the field of disaster risk management. Moreover, this study offers valuable insights into enhancing the effectiveness and efficiency of OR-based solutions in practical scenarios, thus contributing to the advancement of knowledge in this area.

1. Introduction

Science encompasses two broad schools of thought: formal and empirical [26]. Formal sciences centre around the deductive testing of formal hypotheses and theories without considering their applications in reality or to human beings [4]. Conversely, empirical sciences depend on observations to establish new theories and phenomena by studying their actual occurrences in the real world [6]. The two main branches of empirical sciences are (i) natural sciences, which aim to describe, comprehend, and predict natural phenomena using empirical evidence from observations and experiments, and (ii) social sciences, which examine societies and the relationships among individuals within those societies [7]. However, the objectives of natural and social sciences may not necessarily coincide with those in applied fields such as the engineering aspect of disaster science, which centres around the creation of artefacts and solutions for solving real-life problems, such as hospital evacuation planning, in the most effective and efficient way, often considering the perspectives of multiple stakeholders who may have conflicting and divergent interests [25].

The progression of emerging fields of research such as disaster science has redefined the boundaries of science and led to an increase in multidisciplinary research [22]. For instance, disaster science previously only focused on social science perspectives, but with the integration of new technologies and the emergence of decision science, it has undergone a transformation and created branches that utilise decision-making methods such as operations research (OR) [27,30]. The progress of disaster science knowledge necessitates tackling real-world scientific challenges and devising practical solutions that cater to diverse stakeholder groups [16,20]. Therefore, the research methodologies employed in this field must be designed to capture the intricate nuances and complexities inherent in such scenarios.

The use of OR as a scientific methodology for decision-making and problem resolution in disaster science is widespread [33–35]. This approach employs mathematical modelling and computational techniques to assess complex problems and identify optimal solutions within the realm of disaster management [8]. The systematic nature of OR provides a foundation for informed decision-making in disaster science and improves the efficiency and efficacy of disaster response and recovery efforts by serving as a guide for disaster management agencies [39]. However, despite the widespread use of OR, there is a scarcity of established research methodologies for the application of these techniques in practice, particularly in the realm of disaster response strategy

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development. To address this challenge, a modified Design Science Research Methodology (DSRM) has been developed, based on the principles of OR.

The DSRM is based in the design sciences and is a structured and systematic approach that is commonly used to conduct research and develop design solutions for addressing real-world problems [21]. However, its structured and sequential process may lead to limitations in complex and dynamic problem domains, such as those encountered in the realm of disaster management [1]. Despite the strong emphasis on design and development, the DSRM approach may overlook other crucial aspects such as implementation, deployment, and validation and verification of disaster management solutions. In addition, the DSRM approach may not encompass all crucial components, such as data analysis, mathematical modelling, and simulation, that are integral to OR. Moreover, it may not offer sufficient techniques for evaluating the actual impact and efficacy of the proposed solutions in real-world settings.

In this study, to overcome the limitations discussed above of both the OR and DSRM approaches in complex and dynamic problem domains such as disaster management, the authors present an integrated OR and Design Science Methodology that merges the strengths of traditional DSRM and OR methodologies. The efficacy of this novel hybrid methodology for resolving complex dynamic problems in real-world settings is demonstrated in this paper through reporting the results of research where it was employed in the field of disaster science, specifically in the creation of a mathematical evacuation support system for a set of hospitals facing serious climate change flooding risk in Western Sydney, Australia. Many hospitals in Australia are built in flood-prone areas and as flooding risks increase with climate change, there is a recognised need for more research into the way in which vulnerable patients are evacuated from such facilities in the future [37].

The rest of the paper is organised as follows: Section 2 provides a historical overview of research methodology development and discusses the DSRM approach. Section 3 discusses the merging of the DSRM and OR steps into a hybrid methodology. Section 4 offers a summary of the research design, including the methods for modelling, data collection, and analysis, and demonstrates how the study meets the criteria for a good "design science" study. Section 5 provide managerial insights. In Section 6, the outcomes of the modelling process are presented, and practical suggestions are given for applying the proposed research methodology.

2. The DSRM approach – a critical review

Fuller and McHale [40] introduced the concept of design science, which underpins the DSRM methodology. However, the design sciences only became legitimised after Simon [25] formative paper entitled "The Sciences of the Artificial," which classified design problems as artificial (human-made) challenges, as opposed to those generated by and associated with the natural world. The field of design science was subsequently developed further by researchers such as Takeda et al. [29], Nunamaker et al. [18], Walls et al. [32], March and Smith [14], Romme [24], and Hevner et al. [9] in the field of information systems and engineering. As design science research in different fields of engineering has evolved, it has also found application in other research fields, including business and e-commerce [3], management [31], accounting [5], and the built environment [1]. DSRM was widely used in these various fields in response to criticism that some communities were suffering from a lack of practical application of scientific knowledge.

According to Peffers et al. [21], the fundamental and distinctive characteristic of the DSRM methodology is the development of practical artefacts and solutions to address real-world issues. These artefacts are designed to embed solutions to well-defined research problems, as they represent any object that has been intentionally designed to tackle a particular issue. March and Smith [14] and Hevner et al. [9] classify DSRM outputs or design artefacts into four categories, namely: constructs; models; methods; and instantiations (see Fig. 1).

Geerts [5] perceives relevance and novelty as two key characteristics of the DSRM methodology. Relevance indicates that the artefact must solve important and pertinent business problems. Novelty relates to the solution addressing problems in a unique and innovative way [9]. Peffers et al. [21] propose a DSRM approach which involves sequential activities as depicted in Fig. 2. These include: (1) problem identification and motivation; (2) defining the objectives of a solution; (3) design and development; (4) demonstration; (5) evaluation; and (6) communication.

Peffers et al. [21] describe the first stage in Fig. 2 as the stage in which the motivation for the research is described, and the understanding and importance of the significance and relevance of the problem are clarified. The second stage addresses the question of how the problem should be solved and specifies the criteria that the proposed solution must meet in order to be considered successful [5]. DSRM's third stage involves the design, development, and implementation of an artefact, the development of the artefact's architecture, its main functions, and the steps needed to develop it. To accomplish this step effectively, researchers should use existing theoretical knowledge to propose artefacts that assist in problem-solving. After the artefact has been developed and designed, it should be demonstrated that it is capable of solving the identified problem. As a result, during the fourth phase, the use of the designed artefact is investigated using a prototype implementation. During this stage, experimentation, demonstration, simulation, case studies, proof, or any other appropriate activity may be conducted [19].

DSRM's fifth step is evaluation, where researchers seek to discover appropriate answers to the research question and assess how well the artefact works in practice. This phase involves comparing the observed

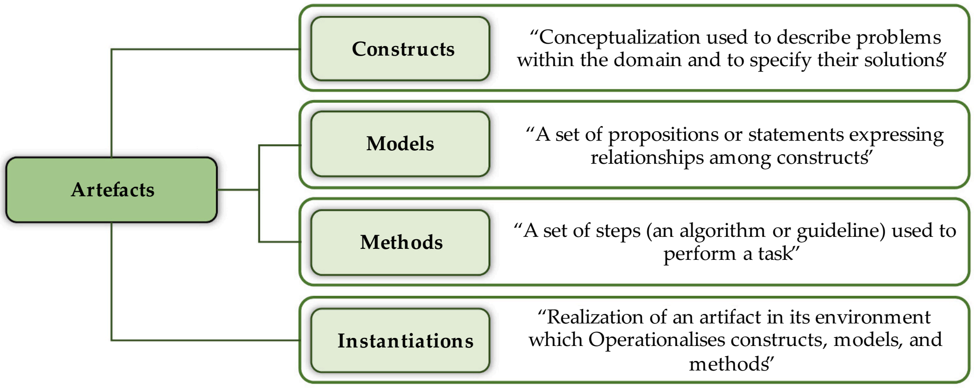

Fig. 1. Four types of artefacts in DSRM (Source: [14]).

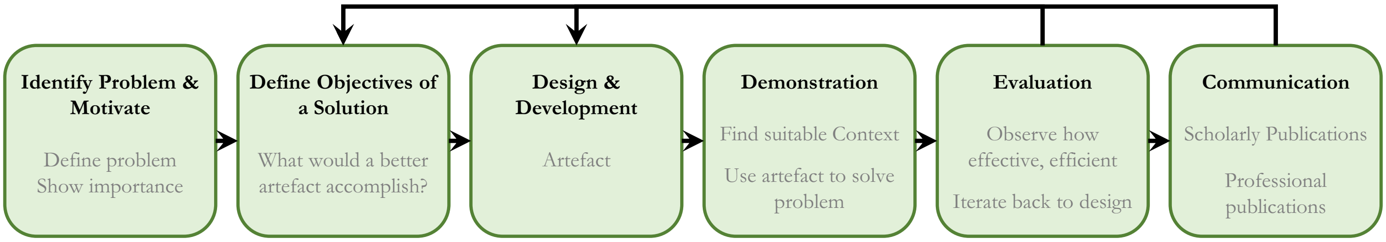

Fig. 2. DSRM process model (Source: [21]).

results of the artefact's performance with the objectives established in phase two of the DSRM. Researchers can modify the artefact or design and develop a new one if the observed results do not match what was expected. An understanding of relevant metrics and analysis methods is required for effective evaluation [21].

The final 'communication' stage of the DSRM approach requires researchers to communicate the problem and its importance, the artefact as the proposed solution, and the utility, novelty, and effectiveness of the solution to other researchers and practitioners in the field as well as any other interested parties. Dissertations, journal articles, reports, conference presentations, and other formats of research dissemination are all possible forms of DSRM communication [19].

In DSRM, the activities in Fig. 2 are organised rigorously and iteratively with the goal of designing and evaluating artefacts in response to identified problems. Though the DSRM activities are presented in a sequential order, Peffers et al. [21] indicate that the research method can be applied differently, and its starting point can be modified depending on the type of identified problem, the research objective, and the researcher's insights. In other words, research based on the DSRM does not have to start at phase one and end at phase six.

3. Synergizing DSRM and OR methodologies to develop new research methodology

Many studies utilise OR approaches to model and solve real-world problems. This includes developing mathematical models and proposing solutions using a variety of OR tools and techniques. By using advanced analytical methods, techniques, and tools, OR aims to improve decision-making in complex real-world situations. In practice, OR is implemented following the phases described by Taha [28]:

1. Problem Definition: This is the first step in which the scope of the problem is clearly defined. It comprises three main stages: (i) description of the various decision variables, (ii) determination of the objective that the study sets out to achieve, and (iii) specification of the constraints or limitations under which the system being modelled operates.
2. Model Construction: This phase involves transforming the problem definition into mathematical relationships using available methods. In certain instances, it may be necessary to combine a variety of models—mathematical, simulation, and heuristic—to effectively solve the decision problem.
3. Model Solution: This phase is typically the most straightforward aspect of OR, as it employs well-established algorithmic techniques. A key component of this phase is sensitivity analysis, which is the process of acquiring additional information about the behaviour of the optimal solution when specific parameters change.
4. Model Validity: The validity of a model is gauged by its effectiveness in predicting the behaviour of the system being studied. A common way to validate a model is to compare its output with historical data. If the model can accurately reproduce past performance under similar input conditions, it is deemed valid. However, it's important to remember that a valid model does not guarantee future performance will align with past performance. In cases of uncertainty, simulation can be used as an independent tool to verify the mathematical model's output.
5. Implementation: The final stage involves transforming the validated model solution into comprehensible operating instructions. These instructions are then issued to those who will operate the system.

Fig. 3 illustrates how OR stages map to the process model of the selected DSRM. The combination of OR and DSRM can yield significant benefits for problem-solving. By integrating these methodologies, researchers gain a holistic, quantitative, and user-centred perspective on problem resolution. It also optimizes outcomes, ensuring solutions meet user needs while remaining within established constraints. This combination supports innovation by bridging problem-solving with solution design, encouraging creativity and interdisciplinary collaboration. It also fosters flexibility in the research process, allowing for the exploration of various solution pathways and the potential for novel discoveries. Therefore, the integration of OR and DSRM can lead to more effective, innovative, and adaptable solutions to complex problems. Green boxes represent operational research steps, whilst grey boxes represent DSRM activities. Peffers et al. [21] DSRM model describes problem identification, objective definition, design, development,

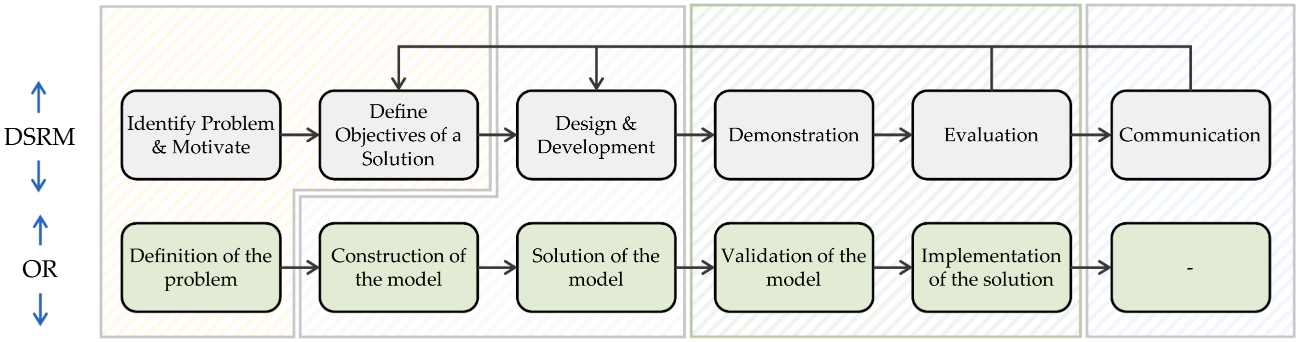

Fig. 3. Mapping of OR stages to the process model of the selected DSRM.

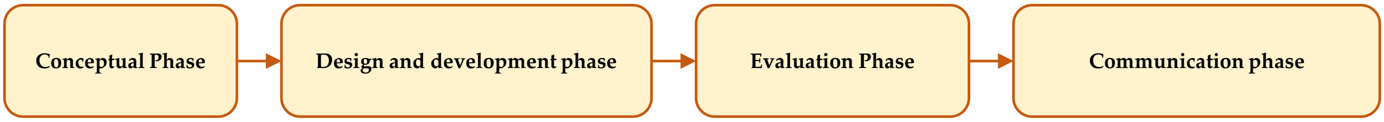

Fig. 4. A New Integrated Operations Research and Design Science Methodology.

demonstration, evaluation, and communication.

Fig. 4 demonstrates the mapping of these two procedures into four sections, signifying the foundation for a new Integrated OR and Design Science Methodology. The first box represents the conceptual phase, in which, within the OR phases, only "definition of the problem" has been identified. Meanwhile, within DSRM, it encompasses two boxes: "identifying the problem and motivation" and "defining objectives of a solution". During this phase, the research problem is defined, as are the objectives of the study.

The second box pertains to the design of the artefact. In DSRM, only one box is outlined for this phase, whereas in OR studies, as depicted in Fig. 4, the solution approach is presented after the model is constructed.

The boundary between the fourth and fifth boxes is somewhat difficult to delineate in both procedures; hence, these boxes are mapped together. Both procedures aim to test the developed model and evaluate the results to ensure that there are no concerns regarding the reliability of the results.

There is only one box in the final mapped section that belongs to DSRM, which pertains to "communication".

Each phase of this new hybrid methodology is described in detail below (See Fig. 5):

The Conceptual Phase: This initial phase of research, termed the conceptual phase, is a critical step in defining the research problem, outlining the research aim and objectives, and determining the study's requirements. Various methods, including literature reviews, stakeholder interviews, and observation, may be employed to define the research problem, identify knowledge gaps, and gain valuable insights into the target population or industry. During the conceptual phase, decision variables, which are the model inputs representing the researcher's control over the study, should also be defined. These variables are crucial as they can substantially influence the research outcome. In addition to decision variables, it's crucial to establish the study's objective, which should adhere to the SMART (Specific, Measurable, Achievable, Relevant, and Time-bound) criteria [41]. The objective should align with the research problem and provide a clear focus for the study. Specifying the constraints under which the modelled system operates is another critical step during the conceptual phase. Constraints are limitations on decision variables that can influence the research outcome and may be resource-based, policy-based, or technology-based. These constraints can significantly affect the research's feasibility and should be carefully considered when designing the study.

Design and Development: The Design and Development Phase is a pivotal stage in the research methodology, as it requires the researcher to translate their understanding of the decision problem into a mathematical model-based solution. This involves developing a comprehensive understanding of the problem by collecting and analysing all relevant data from the previous phase. Once the problem is defined, the model is constructed using mathematical equations that simulate the real-world problem. Model construction involves identifying decision variables, defining the objective function, and formulating constraints that mirror the limitations of the real-world problem. Additionally, constructing the mathematical model involves selecting appropriate optimisation techniques and developing the model itself. After the model is constructed, the subsequent stage involves devising a methodology to solve it. This solution methodology can take the form of an algorithm, a set of procedures, or a combination of both, that aids the decision-making process. The chosen method should be robust enough to handle different scenarios and flexible enough to accommodate changes in the model's input parameters. The researchers need to validate the model and the solution method to ensure they are reliable and accurate. The model's assumptions and the solution method's robustness are tested by analysing the sensitivity of the solution to changes in the input parameters. The researchers also verify the model's results by comparing them with actual data from the real-world problem.

Evaluation Phase: The evaluation phase of developing a model or solution method involves collecting or generating relevant data, testing

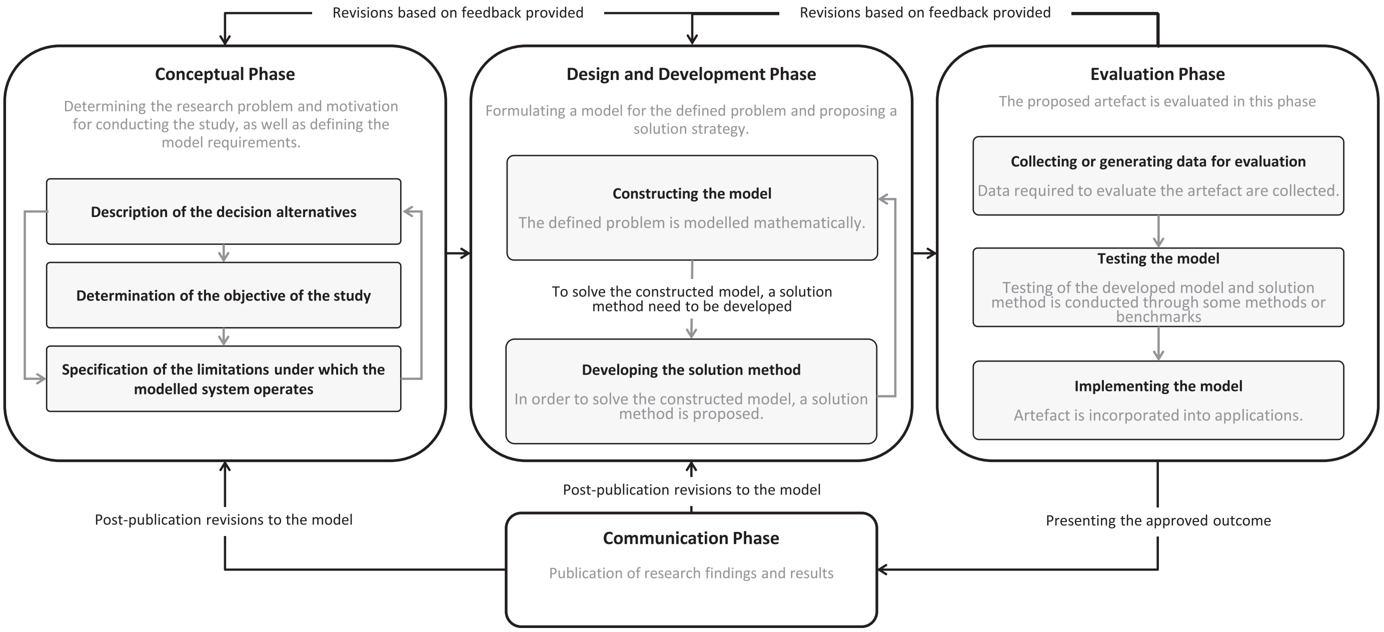

Fig. 5. The Proposed Research Methodology.

the artefact against benchmarks or real-world cases, implementing the artefact into applications, and presenting the results for expert review. This comprehensive approach helps ensure that the artefact is effective and reliable in solving the problem at hand. In the evaluation phase of developing a model or solution, it's vital to collect or generate suitable data to test the artefact's accuracy and effectiveness. The data can be sourced from real cases, interviews with individuals, historical data, or via simulation techniques that generate random data. It's essential to ensure that the collected or generated data are relevant to the problem being solved to yield meaningful results. Once the data is available, testing of the model or solution method can begin. This testing involves applying the model or solution method to the data to generate results. The obtained results are then compared to benchmarks or real-world cases to assess the model's validity. This comparison serves to evaluate the artefact's accuracy and to identify areas for improvement. Following testing, the model or solution method is implemented into applications. This process involves incorporating the artefact into systems or processes that will use it to solve real-world problems. It necessitates careful consideration of the artefact's limitations and the potential impact of its use in practical applications. It is also essential to present the results to an expert or a team of experts for review and validation of the artefact's effectiveness. This review process helps identify any potential biases or limitations in the model or solution method and aids in ensuring that the artefact is reliable and effective in solving the problem at hand.

Communication Phase: Effective communication is essential in the research process to disseminate findings and results accurately to the intended audience. The communication phase consists of two critical activities: writing the research report and presenting the research outcomes. To convey research outcomes effectively, a well-structured research report is needed, employing clear and concise language that is objective. This report should include an executive summary, introduction, methodology, results, discussion, and conclusion. Similarly, presentations should be organised and utilise suitable language and visual aids to provide a comprehensive understanding of the research outcomes. Obtaining feedback from the audience is critical for effective communication. Feedback can aid in improving the artefact and identifying future research directions. This feedback can be received through various means such as peer reviews, audience feedback during presentations, and post-publication discussions. Incorporating feedback can enhance the quality and impact of the artefact, as well as highlight areas for future research. Conducting the communication phase ethically and professionally is paramount. The research results must be presented accurately and objectively, with any potential biases or limitations acknowledged. Respecting the privacy and confidentiality of research participants is crucial, as is obtaining their informed consent before sharing any information about them. Furthermore, it's essential to inform researchers and relevant audiences about the problem's significance, the utility of the artefact, and its novelty. This process can serve as a framework for scholarly research publications, akin to the conventional structure of a typical empirical research paper. To communicate effectively, understanding the disciplinary culture is necessary, and a well-structured research report and presentation can facilitate this process.

4. Case study

This section demonstrates the application of an integrated operations research and design science methodology in disaster science. Specifically, it presents a mathematical model for the evacuation of Western Sydney hospitals, in Australia threatened by climate change-induced floods. The model, which integrates a flood simulator and a time-dependent shortest path method, is designed to optimize evacuation time, considering various constraints. A Benders decomposition approach is proposed to solve the problem, please see [38].

Fig. 6. The impact of a 1-in-500-year flood at Penrith (of comparable magnitude to the largest flood on record—the 1867 flood). Source: Infrastructure NSW [10].

4.1. *Case study context*

The Hawkesbury-Nepean River region in Western Sydney, Australia, known for its high flood risk, faces heightened exposure due to urban development and potential climate change impacts, influencing rainfall extremes and patterns [11,15]. Figs. 6 and 7 illustrate the impact of a 500-year flood on Penrith and Windsor.

The region's unique 'bathtub' topography, characterized by large upstream catchments, narrow downstream gorges, and a single outlet at Sackville Gorge, facilitates rapid, substantial flooding [10](See Fig. 8). Unlike most river valleys, this region doesn't expand near its mouth, exacerbating flood levels.

The Hawkesbury-Nepean valley's unique geography can lead to extensive damage to crucial infrastructure such as roads, bridges, and healthcare facilities during major floods [23]. It also hinders safe and timely evacuation due to limited road capacity . Many local health facilities are established within flood-prone zones, making them particularly vulnerable.

4.2. *Conceptual phase*

Through the performance of a systematic literature review, preliminary requirements for developing the model were ascertained, encompassing decision variables and parameters. The research comprised two steps: defining keywords and retrieving relevant literature and analysing the content of the papers. The examination of existing studies involved conducting an electronic desktop search using structured keywords and excluding records unrelated to hospital evacuation. A subcoding framework for hospital evacuation models was proposed, taking into account scenario and problem characteristics, evacuation modelling objectives, and applied solution methods (see: [36]). The

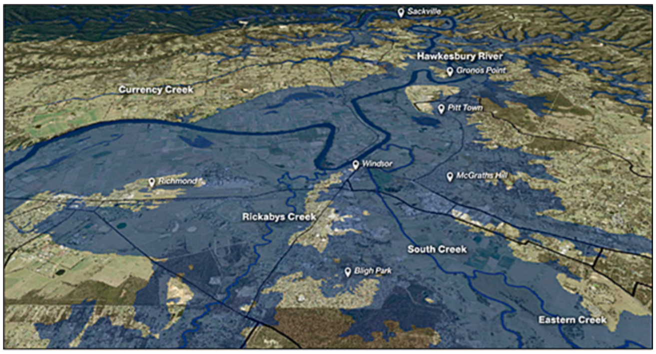

Fig. 7. The impact of a 1-in-500-year flood at Windsor (of comparable magnitude to the largest flood on record—the 1867 flood). Source: Infrastructure NSW [10].

Fig. 8. The "bathtub" effect in the Hawkesbury-Nepean valley near Penrith. Source: https://www.ses.nsw.gov.au/

model integrates patient transportation, evacuation resources, hospital types, and travel times. Evacuation objective encompass time factors. Limitations, research gaps, and model requirements were identified during this phase, leading to the formulation of research questions based on the literature review summary.

4.3. Design and development phase

Generally, the design and development phase consists of two steps: "Methodology of the model formulations" and "Methodology of solution method approaches." In the first step, mathematical methods used for modelling the hospital evacuation problem are discussed, followed by an explanation of the solution approach used in this study. Neumaier [17] defines modelling as "the art of translating problems from an application area into tractable mathematical formulations whose theoretical and numerical analysis provides insight, answers, and guidance useful for the originating application." A real-world problem or situation can be simplified by using a mathematical model, converting it into a mathematical form. This model can then be solved using mathematical tools, and the obtained solutions are interpreted in real terms. The mathematical modelling process is illustrated in Fig. 9.

As shown in Fig. 9, the modelling process started with a real-world problem: developing a decision support system for evacuating hospitals. Our goal was to solve this problem. At the modelling stage, variables, constraints, and assumptions were identified, and relationships between variables were defined. In this process, formulating the model was the most challenging step. After developing the model, the next step was to find an appropriate technique for solving it. Subsequently, the results of the model were interpreted within the context of the real-world problem, and the solutions were compared to the data.

In [37], the findings of this section were published. The researchers presented a robust possibilistic programming optimization model to design a mathematical model that addresses the uncertainties associated with hospital evacuation during floods. To tackle the complexity of a practical hospital evacuation system, the researchers developed a Benders-Decomposition approach as part of their solution methodology.

4.4. Evaluation phase

Case studies were used to demonstrate the developed artefact following the design phase. A set of hospital exposed to a potential risk of major floods were used as a case study to demonstrate the feasibility of the developed artefact.

4.4.1. Collecting data and utilizing data resources

The required data can be classified into two categories. The first group pertains to flood simulation, where topographic and rainfall data available on the Geoscience Australia and Bureau of Meteorology websites, respectively, are collected. A simulation software program generates flood scenarios for the disruption of the road network, and data for various scenarios are imported into a mathematical model. Other data required for flood simulation includes hospital capacities obtained from the Australian Private Hospitals and the Australian Institute of Health and Welfare. The Bureau of Meteorology's reports were used to determine the evacuation time horizon, and evacuation routes identified by the NSW State Emergency Service. The case study's street network was created using OpenStreetMap data. The Bureau of Meteorology, Road and Maritime Services, Geoscience Australia, OpenStreetMap, Australian Institute of Health and Welfare, and Infrastructure NSW are some publicly available resources used in the study.

Road-based movements are deemed the most effective for evacuating residents, given the 12.5–13.5 m cut in the Richmond railway line near Vineyard, which limits rail-based evacuation in the Hawkesbury local government area flood islands. The Richmond Air Force Base provides only limited evacuation capabilities, confined to some critical areas [11]. The current capacity of roads is inadequate for quick and safe evacuation, especially in localities with shared and packed road networks, posing a significant threat to people's lives during flood disasters. Therefore, it is essential to evaluate access roads to flooded areas [11].

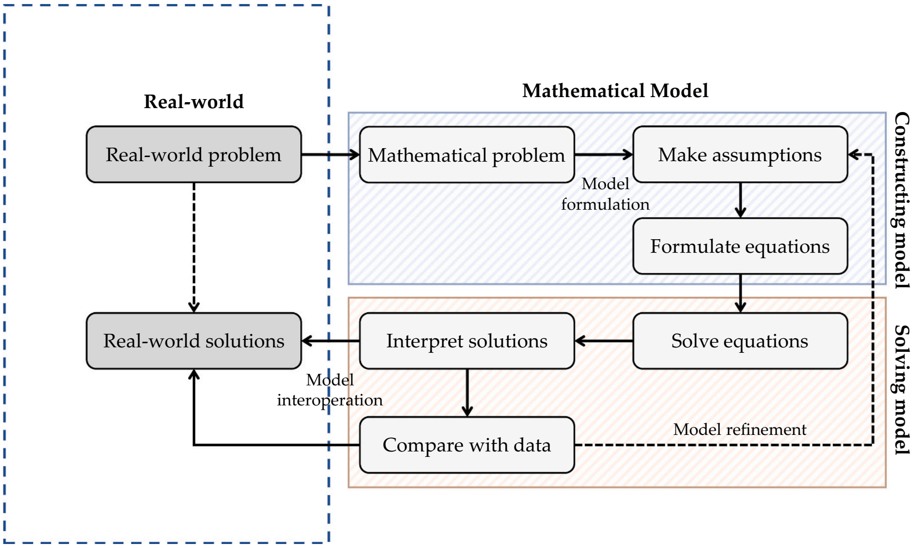

Fig. 9. The modelling process adopted from Ang [2].

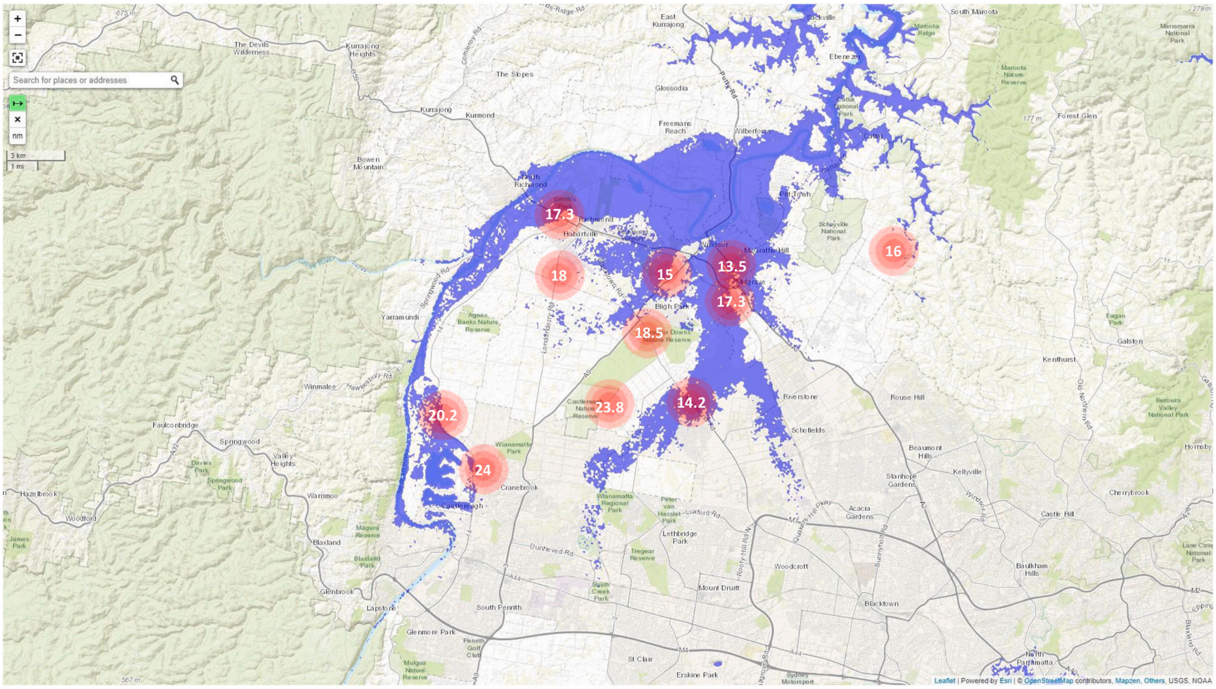

Fig. 10. The floodplain evacuation routes in the Hawkesbury-Nepean valley, along with the corresponding flood level (measured in meters above mean sea level (AHD)) at which the routes become impassable, were taken from [42].

The government websites provide publicly available reports nominating routes for area evacuations to support flood operations, along with their predicted level of interruption (See Fig. 10).

4.5. Communication phase

Upon completion of the research, the findings are disseminated through peer-reviewed journals. Additionally, all published outputs will be made accessible through open access databases to ensure the study reaches the broadest possible audience. This stage also involves discussing future recommendations and limitations of the research. Research works conducted using this methodology have been published as [37,38].

5. Managerial insights

In today's rapidly evolving and unpredictable business environment, relying on conventional problem-solving approaches is proving insufficient. The groundbreaking research on the integration of Operations Research (OR) with Design Science Research Methodology (DSRM) in hospital disaster management serves as a beacon, demonstrating the potency of hybrid methodologies. For modern managers, this implies a paradigm shift. The fusion of OR and DSRM underscores the value of interdisciplinary solutions. It's a call for managers to step out of their domain silos and embrace insights from diverse fields, aiming for a holistic resolution to challenges. This hybrid approach stands out especially in dynamic scenarios, like disaster management, where traditional static models may fall short. It offers managers a chance to continually adapt and refine their strategies based on the situation at hand. Furthermore, the integration highlights a pivotal managerial lesson: every methodology has its limitations. By amalgamating two or more distinct approaches, inherent constraints of one can be mitigated by the strengths of another. However, the success of such a robust approach demands seamless collaboration between stakeholders. Using the hospital scenario as an example, effective evacuation mandates coordination between hospital staff, emergency responders, and local authorities. Hence, managers must proactively establish and nurture these critical partnerships. Lastly, the evolutionary nature of hybrid models emphasizes the importance of continuous learning and iteration. They aren't static but evolve with each application, necessitating managers to be receptive to feedback and ready for iterative refinements. In essence, the era of integrative decision-making has dawned, pushing managers to the forefront of interdisciplinary collaboration, ensuring their organizations' resilience and adaptability in a tumultuous landscape.

6. Conclusion

The use of OR methods in disaster science studies has become increasingly prevalent. However, the existing literature has identified a lack of structured research methodology for creating a robust process in this domain. To address this gap, a paper proposes an integrated OR and DSRM for developing a mathematical model using OR techniques. To demonstrate the application of this methodology, a case study was conducted on the development of a *Mathematical Based Evacuation Support System* for healthcare provision during major floods in Western Sydney, Australia. The case study involved testing and validating the system using the proposed research methodology. The results of the case study demonstrated the effectiveness of the proposed methodology and its potential to improve disaster management planning and decision-making processes.

The integration of OR and DSRM offers significant advantages in problem-solving and solution design. By combining these two methodologies, researchers can take a holistic approach to solving complex problems, optimize solutions to meet user needs, bridge the gap between problem-solving and solution design, foster collaboration among different disciplines, and provide flexibility in the problem-solving process. This integration has the potential to create more innovative and cost-effective solutions that are efficient, user-cantered, feasible, viable, and desirable. It can contribute to the advancement of various fields, including engineering, computer science, and business, while also helping decision-makers make better choices by quantifying the potential outcomes of different alternatives.

While the integrated OR and DSRM methodology presented in this study offers valuable insights and practical applications, there are limitations that should be considered. Firstly, the case study focused on hospital evacuation during severe flooding in the Western Sydney region, which may limit the generalizability of the findings to other types of disasters or geographical locations. Future research should evaluate the methodology's effectiveness in diverse contexts to ensure its broader applicability.

The study utilized publicly available data sources, which may have limitations in terms of accuracy, completeness, and timeliness. Future research should explore accessing more comprehensive and real-time data sources to enhance the reliability and validity of the modelling and decision-making processes. Additionally, the scalability of the methodology to a larger number of facilities or different healthcare systems needs further investigation. The performance and efficiency of the methodology in different scenarios should be explored.

Building on the foundation of this study, future research can further advance the integrated OR and DSRM methodology in disaster management. One potential direction is to incorporate a broader range of disaster types, such as earthquakes, wildfires, or pandemics, to assess the methodology's adaptability and effectiveness across different contexts. Exploring the integration of emerging technologies, such as artificial intelligence, machine learning, and data analytics, can enhance the methodology's capabilities in data-driven decision-making and real-time monitoring.

Furthermore, stakeholder engagement, collaborative decision-making, and participatory approaches should be emphasized in future research. Involving various stakeholders, including government agencies, emergency responders, and community members, is crucial to ensuring the practical relevance, acceptance, and effectiveness of the methodology in real-world disaster management scenarios.

CRediT authorship contribution statement

Maziar Yazdani: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Martin Loosemore:** Conceptualization, Methodology, Validation, Data curation, Writing – review & editing, Supervision, Project administration. **Mohammad Mojtahedi:** Conceptualization, Methodology, Validation, Data curation, Writing – review & editing, Supervision, Project administration. **David Sanderson:** Conceptualization, Methodology, Validation, Data curation, Writing – review & editing, Supervision, Project administration. **Milad Haghani:** Conceptualization, Methodology, Validation, Data curation, Writing – review & editing, Supervision, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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