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CONCEPTUAL MODELLING OF EMERGING TECHNOLOGIES - THE USE OF NOVEL ELECTRIC AIRCRAFT FOR EMERGENCY MEDICAL SERVICES

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ABSTRACT

Implementation of new technologies in operations systems sets specific requirements on simulation conceptual modelling, relating to uncertainties with respect to their specifications, changes implied for operations systems and regulatory frameworks restricting their operation. Furthermore, modelling objectives may have to be tailored to innovation agendas made by potential adopters of technologies. In this paper, we explore the needs for extending current frameworks to facilitate conceptual modelling of new technologies, using a case study on the introduction of novel electric aircraft (eVTOLs) for Emergency Medical Services. Extensions proposed concern the choice of modelling objectives – which should be aligned with an innovation agenda, technology representation as model content, inputs and outputs – accounting for various uncertainties, and the modelling process – requiring a careful concerting with engineering efforts.

Keywords: Conceptual Modelling, Emerging Technologies, Emergency Medical Services

1 INTRODUCTION

The aviation industry is on the cusp of a significant system change, where novel electric aircraft are enabling a wider adoption of air operations (Schwab et al., 2021). The main enablers for electric aircraft are advancements in key areas such as electric motors, batteries, sensors, connectivity, lightweight materials and advanced manufacturing processes. Perceived benefits of electric aircraft are in their sustainability (no direct emissions), operational costs, lack of noise and higher levels of automation. Two categories of novel aircraft may be distinguished resembling airplanes and helicopters, i.e., electrically-powered Conventional-TakeOff-and-Landing aircraft (eCTOLs) and electrically-powered Vertical-TakeOff-and-Landing aircraft (eVTOLs). Their market availability is expected around 2025, depending on the timely introduction of new regulatory frameworks (European Union Aviation Safety Agency, 2021).

The potential of electric aircraft for enhancing operations may be significant throughout various domains, including Emergency Medical Services (EMS) (ADAC, 2020). Their high speed, cost level, independence of ground infrastructure, and sustainability make them an interesting alternative for ground ambulances and helicopters. At the same time, implications of their use for EMS may be significant, in terms of large investments over a longer period of time, and considerable changes in EMS network and operations. Hence, a timely, and careful assessment of gains implied by their use, and changes required in EMS organization is required. Simulation, being much applied in optimizing EMS network design and use, may offer support in doing so. However, such simulation use would go along with specific modelling challenges. This is due to the emergent status of electric aircraft, possibly impacting on model validity and credibility. Some main uncertainties to address concern their specifications, like speed and range, changes implied for EMS operations and regulatory frameworks within which they have to operate – being not fully clear yet. In addition, also managerial context may matter, requiring a tailoring of modelling objectives to technology development stages as perceived by the EMS provider. Such tailoring may be reflected in, for example, model accuracies required, and alternative system configurations studied in experimenting.

Figure 1 *eVTOLs for EMS – Exploring the Near Future (Source: AXIRA)*

Motivated the observed lack of support offered by simulation conceptual modelling frameworks in addressing emerging technologies, in this paper, we explore the needs for extending guidance for the analyst. To do so we perform a case study concerning a simulation project on the introduction of eVTOLs for a Northern Netherlands subregion (Degel, 2022). Essentially, we compare modelling network extensions using an emerging technology (i.e. eVTOLs) vs. a known technology (i.e. ground ambulances). By scrutinizing differences in formulating modelling objectives, choice of model content, inputs and outputs and set-up of the model process we seek to identify extensions required for modelling frameworks in addressing emerging technologies.

Many EMS systems worldwide face similar challenges. Firstly, fewer people are available or willing to work as professionals in the EMS, causing staff shortages (Uppal and Gondi, 2019). Secondly, budget cuts by local governments lead to further restrictions and centralization of these resources. Especially in rural areas, this results in longer transportation times (Matinrad, 2019). In addition to declining supply, EMS faces increasing demand for service (Hegenberg et al., 2019), aging populations being among the main reasons (Veser et al., 2015). Being "caught" in these developments, the EMS transportation system is under pressure to increase productivity. EVTOLs may contribute EMS productivity by reducing transportation times in an efficient and sustainable way vs. ground ambulances and helicopters (Figure 1). Scarce evidence suggests that eVTOLs may be a well performing alternative for current transport modalities in bringing doctors to a scene (ADAC, 2020; Nakamoto, 2022). At the same time, being an emergent technology, its gains implied for EMS and requirements set on their operations are still largely unclear.

This paper is structured as follows. In Sections 2, and 3 we consider perceived benefits of eVTOLs for EMS and introduce the case setting. Next, in Section 4 we discuss simulation study set-up and key findings. In Section 5 we identify, and scrutinize decisions made in modelling eVTOLs – representing emerging technologies. In Section 6 we discuss how findings in Section 5 may underpin the need for extensions of modelling frameworks. Finally, in Section 7, we summarize main conclusions.

2 GUIDANCE ON SIMULATION CONCEPTUAL MODELLING

In recent years considerable research efforts have been put in improving guidance for the analyst in specifying simulation conceptual models, meant as a precursor for model coding and experimenting. Robinson (2008a) distinguishes three basic approaches on simulation model development: principles of modelling, methods of simplification, and modelling frameworks. Most research efforts, however, concentrated on the development of modelling frameworks (Robinson, 2020). Modelling frameworks go beyond other approaches by specifying what to model. To do so, they provide a procedural approach for detailing a model in terms of its elements, their attributes, and their relationships. Several modelling frameworks have been developed, differing in intended field of application (for example, health, operations systems or the military), scope (including or excluding model inputs, outputs and modelling objectives) and process support (help in exploring the problem situation). For overviews of modelling frameworks, see Robinson (2008a, 2020), Karagoz and Demirors (2011), Van der Zee et al. (2011) and Furian et al. (2015). So far, however, frameworks proposed lack guidance on how to address specific challenges in modelling emerging technologies being implemented in operations systems.

3 CASE: USING EVTOLS FOR EMS IN THE FRISIAN LAKE AREA

The Frisian Lake area in the northern part of The Netherlands is a sparsely populated (130 inhabitants per 1000 km²) (Cybo Company, 2022) rural area. The area is part of a larger region, the province of Friesland, being served by an EMS provider. The area has a complicated road infrastructure due to many lakes and water canals, delaying ground transportation (Turcanu, 2012), see Figure 2. EMS serves the area by five stations, located in Bolsward, Sneek, Koudum, Joure, and Lemmer. Each station operates one ambulance 24/7. In addition, the station located in Sneek, operates one ambulance during a late shift (3-11PM) and a night shift (11PM-7AM). Each ambulance is staffed with a nurse and an ambulance driver. Dutch EMS providers employ nurses to staff ambulances, while internationally many ambulance services employ paramedics.

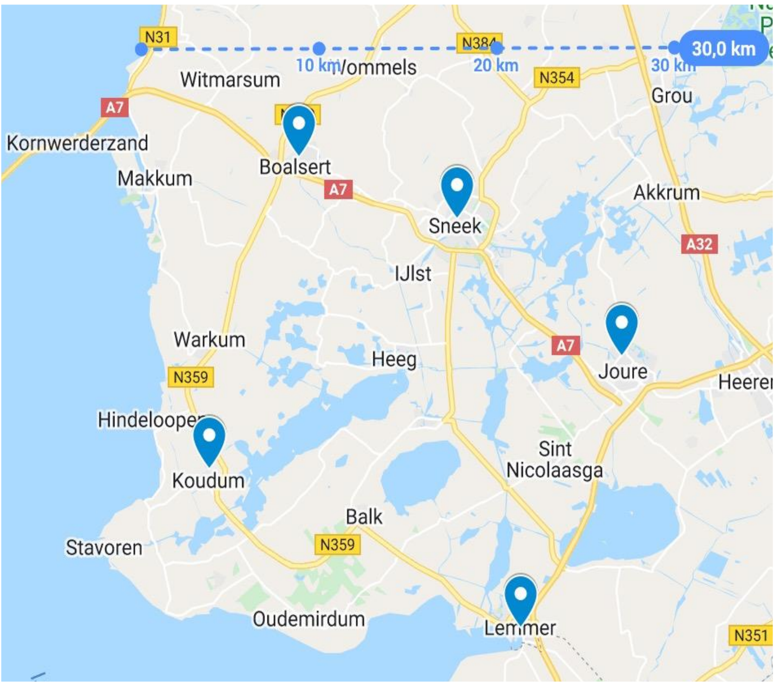

Figure 2 *Map of EMS system in the Frisian Lake Area (Source: Google Maps)*

On a province level, 95% of urgent (A1) calls must be served (i.e. reached by a medical professional) within 15 min, according to Dutch norms. In the Frisian Lake area, the performance has been below this threshold for the past 4 years, see Figure 3. Moreover, the performance has become significantly worse in the previous 2 years, partly due to extra safety measures in relation to the Covid19 pandemic but also due to a lower average speed of ambulances. It must be noted that the Frisian Lake area is a challenging area due to its geography implying that a performance of 95% is harder to reach than in other areas of the same province. At the same time, being part of a larger region some tolerances were allowed with respect to norm settings, as worse performance may be "compensated" in other subregions of the Friesland region, especially urban regions for which adherence to norms may be easier to realize. Nevertheless, the observed deviation from the norms for the area underpins the need to explore possible interventions.

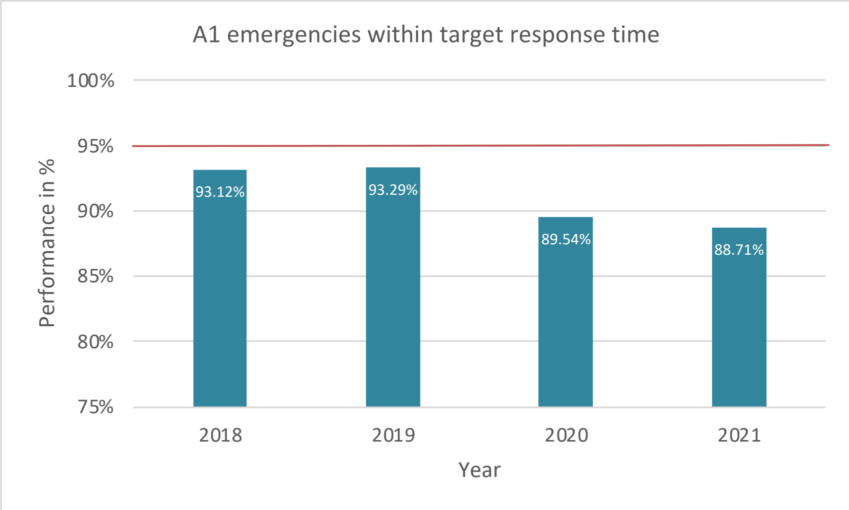

Figure 3 *EMS Performance in the Frisian Lake Area 2018 - 2021 (Source: UMCG Ambulancezorg)*

Additional ground units and eVTOLs have been considered as solutions to improve the performance in the Frisian Lake area. Extending the EMS system with additional ground unit(s) is perceived as too labor-intensive, due to existing staff shortage, and as inefficient due to an expected underutilization of the units. On the other hand, an eVTOL unit can cover a far greater area than a ground unit (within the same time) because of travelling in a straight line bypassing the limited road infrastructure. Therefore, eVTOLs were deemed to be more resource efficient and operationally viable. However, more insights on system performance gains and the parameters influencing these were desired.

4 SIMULATION STUDY

4.1 Extending the EMS System Using eVTOLs

The simulation study did go together with an engineering effort in EMS systems (re)design, given its extension with eVTOLs. Essentially, the engineering effort resulted in clarity with respect to changes required to current EMS operations when implementing eVTOLs and choice of EMS system configurations with eVTOLs to be studied (Tables 1,2). Table 1 captures required changes as assumptions – to be reflected in model content. Table 2 specifies alternative system configurations through design parameters, acting as simulation model inputs. Together with various sensitivity analyses on eVTOLs specifications these were underlying experiments.

Adoption of eVTOLs would imply an extension of the existing ground-based system (base line, see Section 3) towards a hybrid system operating both ambulances and eVTOLs. While various uses of eVTOLs for EMS could be distinguished, it was chosen to restrict use of eVTOLs to a role as so-called rapid responders. As such, eVTOLs would be used to bring nurses to the scene, offering a fast alternative for ground transport. Hence, EMS performance on responsiveness would be expected to improve. However, patient transport from scene to a hospital, if deemed necessary, was still to be executed by a ground ambulance, called by the nurse that arrived by eVTOL on the scene. Further refinements of uses eVTOLs as rapid responders were considered by studying alternative dispatching rules. For example, "what if the eVTOL was primarily used as a backup for ground ambulances if these cannot arrive in time". The choice of restricting the role of an eVTOL to a rapid responder was motivated by the state of art in eVTOL technology, suggesting patient transport not to be feasible before 2030 (Mihara et al., 2021).

4.2 Study Results

Using simulation the various configurations (Table 2) were put to the test. See Figure 4 for an overview of main study outcomes relating to experimental factors. It shows how implementation of eVTOLs may have a relevant impact on system performance. For further details, including sensitivity analyses on

Table 1 *Assumptions on eVTOL Operation in a Hybrid EMS system*

Subject	**Assumption**
Regulatory Framework	The framework for eVTOL operation is in place (European Union Aviation Safety Agency, 2022).
Infrastructure	Infrastructure elements such as charging facilities and vertiports are in place and corresponding regulations (for building and operating these) exist
eVTOL specifications	eVTOLs can carry a pilot and one medical specialist.
eVTOL specifications	Take-off time is constant and is 2 minutes (UMCG Ambulancezorg, 2022).
eVTOL specifications	Landing time is constant and is 3 minutes. This includes finding a landing spot and the landing procedure (UMCG Ambulancezorg, 2022).
Personnel	Pilot licensing for eVTOLs is possible (European Union Aviation Safety Agency, 2022).
Personnel	An eVTOL is staffed by a licensed pilot and a nurse with the same qualifications as nurses in ground ambulances.
eVTOL operation	The approximate response time for each vehicle in the system (ambulance and eVTOLs) can be estimated by the dispatch center and it is the basis for assigning a vehicle.
eVTOL operation	An eVTOL must be charged after every ride. The charging time is constant and is 15 minutes (Liu et al., 2021)
eVTOL operation	eVTOLs will first operate during daytime. This means they can be dispatched after sunrise and until 45 minutes before sunset (UMCG Ambulancezorg, 2022).
eVTOL operation	At any given time, there is a 1% chance that an eVTOL is not able to launch due to poor weather conditions (UMCG Ambulancezorg, 2022).

Table 2 *Design Parameters for a Hybrid EMS System with eVTOLs*

Design Parameter	**Values**
Dispatch rule	Various dispatch rules, for example: "An eVTOL is dispatched if the estimated response time of a ground ambulance would exceed 12 minutes".
Location of eVTOL Station	Current locations of stations, additional eVTOL station in the center of the region.
Number of eVTOLs in system	1 eVTOL
Type of eVTOL	Average cruise speed of 180km/h, minimum range of 150 km.
Operation mode	24h, day time only

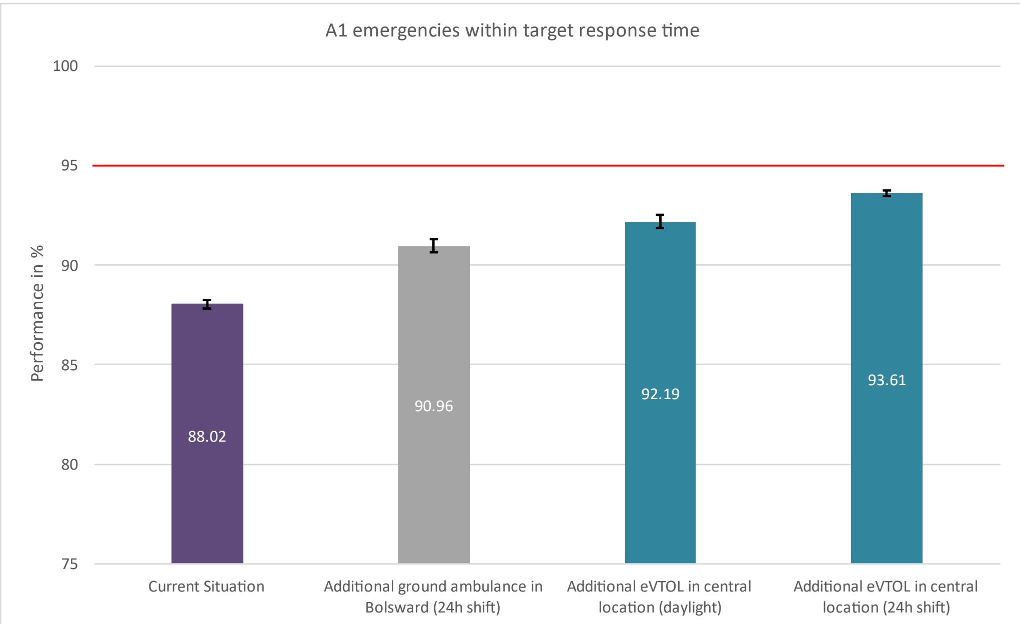

Figure 4 *EMS Performance in the Frisian Lake Area for Selected Configurations*

eVTOLs' speed, take-off and landing time, charging times, and availability due to weather conditions see Degel (2022). Clearly, progress made with respect to the latter aspects may further enhance system performance.

5 EXPLORING REQUIREMENTS ON CONCEPTUAL MODELLING OF EVTOLS

In this section we explore specific requirements on conceptual modelling of eVTOLs for EMS use (Table 3). We do so in three steps:

1. Modelling of new technology as a part of the conceptual model: determine the way eVTOLs have been represented in the conceptual model. In doing so, we adopt the Robinson (2008b) modelling framework, implying modelling objectives, model inputs, outputs, and content to be components of a conceptual model. See Table 3; only those model elements being specific for eVTOLs are included, i.e., being different from straightforward resource extensions using ground ambulances.
2. Scrutinize modelling decisions: assess choices with respect to which components to include or exclude, assumptions and simplifications, paying attention to the (many) uncertainties on eVTOLs' specifications, their effective use and performance. Which trade-offs does this imply with respect to quality criteria for a conceptual model (i.e. validity, credibility, utility, feasibility)?
3. Assess implications for organizing the modelling process: who is involved (expertise, roles), characteristics of modelling activities (efforts, nature, team set-up) , and information sources.

6 DISCUSSION – EXTENSIONS OF MODELLING FRAMEWORKS

6.1 Relating Simulation Modelling to Technology Development and Use

Strategic decisions on emerging technologies to be adopted in business set a specific context for a simulation study, bringing technology adopters and developers together. Ideally, context specifics are reflected in organisational aims motivating the study, as well as modelling objectives that should contribute to these. Next to establishing potential of a new technology in terms of performance improvement or even optimization, the simulation study may contribute to (realizing) innovation agendas by answering "what does it take", i.e., exploring changes to current operations to be realized to successfully embed the new technology. Moreover, modellers and models may act as linking pins between technology developers and potential adopters. Starting from this role they may facilitate discovery of promising use cases by linking model-based estimates on systems' operational performance to technology specifications – thereby highlighting enablers and barriers yet to overcome.

6.2 Modelling & Engineering

As technology is emerging, simulation modelling efforts go together with engineering efforts or may sometimes even trigger these, compare the development of dispatching rules for allocating eVTOLs, see Section 5. Note how the latter example also illustrates how engineering efforts may result from existing and new technology working together. Furthermore, modelling requires assessing future engineering contributions to operational performance. For example, eVTOLs speed and range may be expected to improve considerably over time.

6.3 You Cannot be Certain: Need for Sensitivity Analysis

New technologies go with a clear need for sensitivity analysis. Key uncertainties may be in infrastructure, resource specifications, availability and use, staffing, and regulatory frameworks. Clearly, scope and detail of sensitivity analysis has to be weighed against needs suggested by technology development stage and innovation agendas.

Table 3 *Exploring Requirements on Conceptual Modelling of eVTOLs*

Step 1: Elements of conceptual model (excerpt, focus on use of eVTOLs)

Organisational aims

- Assess potential of eVTOLs as rapid responders for EMS in terms of their responsiveness to calls for help, and costs and sustainability of their use (gains to be expected).
- Identify key decisions to make for adapting current operations for eVTOL based rapid responders and changes implied for its system configuration and operation (what does it take).
- Set a time path for eVTOLs implementation as rapid responders for EMS (how to plan to make it happen).

Modelling objectives

- Explore potential of eVTOLs as rapid responders for contributing to EMS responsiveness, measured as the percentage of calls for help met within 15 minutes, taking into account existing eVTOL technology and their developments in the near future (5 years horizon). Dutch EMS standards require at least 95% of urgent calls to be addressed within 15 minutes at a regional level. However, deviations to this norm may be acceptable at a subregional level, if compensated by other subregions.

Model inputs

- Dispatch rule
- Location of stations
- Operation mode
- Number of eVTOLs
- Type of eVTOLs
- Sensitivity analysis: speed, take-off and landing time, weather conditions, charging times

Model outputs

- % of calls served within 15 minutes
- Average response time to call for help
- Number of yearly missions per eVTOL

Model content (assumptions, see Table 1)

- Activities
    - Dispatch: dispatch rule, availability overnight, weather conditions
    - Travel to patient: flight time model
    - Treatment of patient: determine need for ambulance transport to hospital
    - Handover of patient: time required to hand over patient to ground ambulance
    - Return to station: flight time model + 15 minutes (charging time)
- Resources
    - eVTOLs: location

Step 2: Scrutinize modelling decisions

Organisational aims

Apart from insights in EMS performance the study has a relevant role in strategic resource planning in (1) underpinning decisions to make and (2) actions to undertake and setting a timeline for these. The inclusion of new performance criteria on sustainability adds to the strategic nature of decision making.

Modelling objectives

The many uncertainties going together with emergent technologies classify the study as explorative. Both significance of technology developments expected and the investment horizon make peaking ahead to future eVTOL technology relevant as an input for the study. Model accuracy (validity, credibility) has to be interpreted according to the technology development stage – allowing for wider tolerances in earlier stages.

Model inputs

Next to common decisions to be made on transportation vehicles (location of stations, number) specific decisions concern the “operation mode” and “choice of dispatch rule”. The operation mode is determining eVTOLs availability (daytime, 24h). Day time use is assumed in the first years of eVTOLs operation. After building experience on eVTOL use and securing its safe operation, 24h use would likely be allowed. As eVTOLs are part of a hybrid solution, including ground ambulances, dispatching rules have to be adjusted, clarifying call priorities in allocating eVTOLs. Such adjustments imply an engineering effort – as such rules are non-existing.

Key operational uncertainties concerning eVTOL specifications are its speed, time required for take-off and landing, vulnerability to weather conditions, and battery charging times. Hence, a need is acknowledged for sensitivity analysis on respective factors.

Model outputs

No specific model outputs relating to use of eVTOLs vs. ground ambulances have been defined. One may wonder about outputs related to eVTOLs use, like percentage of calls being allocated to eVTOLs, in explaining its contributions to specific system configurations.

Model content

Set-up of operations has changed due to use of eVTOLs (compare Table 1). Main differences are explained by the facts that (1) eVTOLs travel by air (vs. ground transport) requiring a flight time model and setting restrictions to their availability (weather, overnight), and (2) solutions are hybrid (entailing eVTOLs and ground ambulances) requiring more advanced control logic (dispatching rules).

Table 3 (continued) *Exploring Requirements on Conceptual Modelling of eVTOLs*

Step 3: Implications for organizing the modelling process
Modelling & engineering The modelling of the system did go together with engineering efforts concerning changes of EMS operations and their control (dispatching rules), compare Tables 1,2. Concerting activities was required. Information sources on system set-up and operation - Information was found also outside the business context, i.e., aircraft manufacturers, researchers, and literature. - Roles of domain experts were extended in exploring future settings. For example, helicopter pilots were asked to assess eVTOLs' operations. Business context The project had to be linked to a development stage in eVTOL implementation. Choice of interventions and precision (model accuracy) were to be related to this stage (maturity level). In principle, the earlier the stage, the less accuracy is accepted. Project team composition An analyst did both the modelling and engineering activities – safeguarding their concerting in this way. Inclusion of the manager of the EMS helicopter team and EMS innovation manager guaranteed easy access to relevant domain experts (especially pilots, and ambulance nurses) and alignment with project objectives and EMS agenda on innovation. Finally, information on state-of-the art of eVTOLs was easily accessible through the EMS project manager being involved in research projects concerning new transport modalities.

6.4 The Process Matters!

Success of modelling efforts cannot be considered loose from the modelling process. Modelling emerging technologies sets additional requirements to this process with respect to concerting modelling and engineering efforts, collecting data on system specifications, consultation of domain experts and – overarching – relating simulation project to the companies innovation agenda. Ideally, the project team and set-up reflects these requirements. As far as project set-up is concerned, facilitated use of simulation may be considered in according to which analysts work jointly with the client and stakeholders in model development, adding to model accuracy and identification of feasible solutions (Robinson et al. 2014; Tako and Kotiadis 2015; Tako et al. 2021). We found how facets of such facilitated use – seeking cooperation with both adopters and developers of technology did benefit the simulation study.

6.5 What's a Good Quality Model?

Clearly, this is usually not an easy question to answer. It may be better to ask: "which quality would be acceptable". In answering this question one might consider aspects like technology development stage, including uncertainties on its specifications, timing and size of investments, and estimated performance gains relative to existing system performance. Note how the question on model accuracy (validity, credibility) may be linked to model feasibility: setting extensive demands on model accuracy while modelling uncertainties are high, likely puts a (too) high burden on the shoulders of the analyst due to extensive data collection and/or efforts to be put in experimenting – if possible at all.

6.6 Extending Modelling Frameworks for Emerging Technologies

Issues addressed in 6.1-6.5 suggest a clear need to extend guidance offered by modelling frameworks. Starting from the Robinson (2008b) modelling framework more support is required for "understanding the problem situation" by linking it to a client company's innovation agenda. Moreover, specific attention for "understanding solutions" with respect to their specifications and implications for company's operations may also be of importance. Among others this may be reflected in model inputs, including sensitivity analysis. Finally, to make things work, organizing the process in a collaborative manner and facilitating effective communication among parties involved (Haveman and Bonnema, 2015) in utilizing cross-disciplinary knowledge is paramount – which is scarcely being addressed in modelling frameworks so far.

6.7 Limitations

Our findings are based on a single case study. Clearly, further studies are required to explore issues raised in greater depth. However, the study clarifies how issues are very much present in practice.

7 CONCLUSIONS

In this study we explored specific requirements on simulation conceptual modelling of emerging technologies. Starting from a case study on a simulation project exploring use of eVTOLs for EMS we established needs for extending modelling frameworks to benefit the practice of modelling.

Case study findings suggest that in conceptual modelling of emerging technologies a good understanding of the problem at hand and solutions provided requires the identification of an innovation agenda for the potential adopter. This agenda should be reflected in the modelling objectives and choice of model inputs. Organizing the process of modelling such that (1) reliable information on technology specifications is obtained – to be reflected in choice of model content and inputs, and (2) concerting of modeling and engineering activities is realized, is considered paramount.

Future research is directed towards developing modelling frameworks facilitating interfacing with the engineering scene, while taking due notion of requirements set to the modelling process.

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