RoPax/RoRo: Exploring the Use of Simulation as Decision Support System

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Abstract — Several challenges of port/terminal and/or ferry company managers pertain to decisions for the justification of investments and concurrent operational tasks of roll-on/roll-off passenger (RoPax) and roll-on/roll-off (RoRo) systems. This paper explores the possible uses of Modeling and Simulation (M&S) techniques as a decision-support aid for a RoPax/RoRo system managers. A number of use cases are described and analyzed to inform possible desirable simulation capabilities allowing for resolution of management concerns related to operational and strategic levels. Different simulation methods and their integration in the context of RoPax/RoRo analysis are described. A description of development of a sample simulation model is used to facilitate better understanding of the possible solutions. The paper is mainly directed toward the exploration of RoPax/RoRo system to facilitate understanding of M&S techniques as a possible solution to multiple correlated concerns of stakeholders. The provided overview is based on the current state of the art of M&S and gives a look ahead at future solutions that M&S can facilitate.

Index Terms — Port, simulation, RoPax, RoRo, simulation methods, multi-method, terminal operations, decision support system, short sea shipping (SSS)

I. INTRODUCTION

RoPAX/RoRo is classified as short sea shipping (SSS) mode of transport. SSS are often considered as environmentally friendly due to a reduction of traffic congestion, accidents, air pollutions, noise, and road damage [1], yet the environmental competitiveness of SSS was also deliberated as problematic [2]. SSS may be considered as competitive, but also complementing and enabling for other modes of transports e.g. road, rail, air, depending on geographic dependencies and current regional infrastructure [3].

RoPax features include RoRo capabilities (carriage of private vehicles, commercial vehicles, trucks, trains, and other types of cargo) with the addition of space for a large number of passengers that enter on foot. This variety of cargos imposes additional technical and passenger safety requirements for terminals due to the different construction of RoPax ships as compared to RoRo. Competition between ports and with other modes of transport drives system performance requirements [2, 4]. Increased complexity of this system is observed due to entwined cargo and different stakeholders e.g. port owner, ferry companies, shipping companies, and private customers. Those stakeholders often have different objectives, interests, and priorities. Special attention to operations of port terminals is required as they were identified as the weakest point of supply chains [5, 6]. Reliable RoPax/RoRo terminals are vital components, influencing their competitiveness within multimodal supply chains, while their resilience should allow for a quick response to any disruptions of services [4].

The management of RoPax system may have limited information about actions, ongoing development plans, and constraints on the complementary side of the system i.e. ports and ships. This may lead to friction and lack of trust between stakeholders. Despite that, all service providers of SSS systems should have a good interest in collaborating to create a good image and reputation for SSS. Failure to providing competitive services because of focus on quick profit and lack of necessary investments can hurt long-term demand. SSS businesses should realize that providing superb services in comparison to competing modes of transportation is their path to success. Because the growth of SSS in large depends on quality and satisfaction for their customers, system managers need to learn how to provide reliable, high quality services. This in turn can facilitate the long-term sustainability of their business.

Sauri Marchán, et al. [4] developed a framework for RoPax/RoRo terminal that included a taxonomy of disruptive events including their causes and a numerical assessment of the real consequences in terms of frequency and severity. This static probability-based analysis indicates high level of system complexity and uncertainty related to the number of factors involved and their multiple interdependences. Unfortunately, the static approach do not allow for conducting dynamic “what if” experiments that explore different scenarios within the system with complex interactions between terminals, ports, and ships to get insight leading to improved decision making processes. Modeling and Simulation (M&S), on the other hand, enables these powerful capabilities e.g. by infusion of disruptive events into operational view to examine system behavior. Additionally, because governments evaluate the value of money spent toward growth of SSS to decide the level of support for future investments [1], managers could increase their chances for obtaining government funding when backed by solid business plan that includes simulation-based analysis.

Flawless interaction between port/terminal and ship is...
critical to success of RoPax/RoRo mode of transport, yet complexity of the system and risks associated with decisions to be made by terminal and/or ferry company managers are significant. This situation calls for potential application of M&S techniques that allow testing different alternative decisions before implementation.

Literature pertinent to simulation models in the RoPax/RoRo context is limited. Assumma and Vitetta [7] developed Discrete Event Simulation (DES) that focused on simulating RO-RO loading and unloading operations. The simple simulation model helped to estimate time to complete loading and unloading containers during normal and perturbed conditions. Mathew, et al. [8] proposed a more advanced object oriented hierarchical architecture that can be used to simulate flow of cargo through a network of seaport terminals and between ports, with the potential to be extended to additional modes of transport to represent the whole supply chains. This architecture is further developed as a simulation tool called SEELS, and it was used for modeling the impact of security and crisis/disaster response on cargo operations [9, 10]. Lättläi and Hilmola [11] developed a simulation that focused on important aspects of ports relevant to RoRo/RoPax terminal operations: forecasting of long-term seaport demand. The past work related to simulation of port and terminals mostly focused on passive view of entities e.g. cranes moving containers facilitating insight into system performance [12-17]. This view may be insufficient when considering large spectrum of stakeholders’ concerns related to the different levels of analysis that causally overlap.

Classical DES simulation primarily focuses on operational perspectives allowing for evaluation of alternative system configurations pertaining to resource utilization and different time-based analysis. This requires collecting or assuming input data, which directly affects the outcome. The high variability and desire to understand causality of RoPax/RoRo system input parameters renders requirements of Independent Identically Distributed (IID) data constraining insight into long-term evolution of the system. On the other hand, statistically reliable evaluation of point estimates will not be possible if inputs are described based on assumption of holistic causal dependencies without extensive empirical validation of theoretical assumptions.

The remainder of this paper is structured as follows: Section 2 examines main drivers and reasoning behind the use of simulation-based analysis of RoPax/RoRo system. Section 3 describes our methodology. In section 4 a process for developing a sample model of RoPax system will be presented, focusing on aspects of simulation methods and approaches that can serve different purposes. Finally, we conclude the paper in Section 5.

II. THE NEED FOR A SIMULATION OF ROPIX/RORO

The high complexity of RoPax system lends itself to the use of M&S techniques. A simulation model can facilitate understanding and decision support of complex problems related to resource allocation and processing activities at the operational level, this informs strategic level decisions when this view is projected onto long-term performance metrics. For instance, at the strategic level we may want to understand and quantify how reliability influences long-term sustainability and profitability. Consequently, the oversight of RoPax/RoRo systems should take on a collaborative and integrative nature based on a high level understanding of the combined sub-systems (ports, ships). Advances in Commercial of the Shelf (COTS) simulation software facilitate change in the perception that only big corporations and government agencies can afford to create such complex simulation-based decision support systems. Nonetheless, a simulation model that supports both operational and strategic level using current state of the art M&S approaches is still a challenging task due to considerable development and validation times.

Effective operation of a RoPax system is critical to its integration into multiple independent supply chains (multimodal). In addition, some ports or ship owners participate in multiple supply chains, which lead into high complexity where simulation-based approach may be the only approach to analysis. While individual port managers must focus on their operations, the overall RoPax system governing the structure that oversees the bigger picture of the systems involved could also be beneficial by providing guidance related to all systems. This is natural for large businesses that own or control several ports or ships, however smaller businesses may not be as concerned with all the factors that relate to the whole industry and requirements that facilitate a positive image and reputation for the RoPax mode of transport.

Our review of relevant literature identified potential cases that call for application of simulation based techniques in the context of SSS. The possible applications of simulation described below are not meant to be exhaustive, but to facilitate further discussion. The following RoPax/RoRo considerations were initially analyzed and projected onto simulation perspectives:

1) A high level of ship utilization drives changes in terminal operational policies and infrastructure needs. SSS is often perceived as an old-fashioned mode of transport with insufficient external connectivity, entangled administrative procedures, and low frequency of departures [3]. The last factor can be especially important for passengers utilizing RoPax on regular basis. Limited available terminal space poses constraints on throughput [18], and requires a significant number of resources to control the flow of cargo. Both factors influence the need to redesign terminals and reconsider operational rules. The efficiency of ports/terminals, their external connections, and quality of provided services is a must, especially in case of competitive dependencies with different modes of transport [19]. A simulation can be used to assess current bottlenecks and evaluate performance of proposed solutions, e.g. viability of dedicated SSS terminals or quays, specific handling equipment, investments in information and communications technology (ICT) [3] and training of personnel. The evaluation of different options can be based on a view of terminal(s) dynamic processes.
augmented with an economic perspective. For instance, reduction of loading and unloading times will increase the possible number of ships serviced and/or ship’s flexibility to adjust speed, which is a significant factor in transport cost [20]. Representing this improvement via simulation model can support evaluating the proposed changes in terminal layout and operational rules, and pinpoint the weakest components of system. Multimodality of SSS can be explored via simulation models by providing the necessary data to support investment options that will facilitate incorporation of SSS into supply chains, integrating infrastructure, transport, operators, and facilities [3].

2) Understanding RoPax stakeholders, their relationships and objectives are important determinants for growing use of this mode of transportation. Satisfaction of customers can be a major factor for a long-term profitability. Their satisfaction can depend on availability, quality, and reliability of services, which is often directly related to waiting times, total processing time, arrival time, (in comparison to other means of transport e.g. bridges), among other factors [21, 22]. Understanding of customers, their needs and priorities, will allow responding accordingly and selecting necessary improvements. Development of a model that captures needs of different customers also facilitates insight into estimating future demand for SSS. Resulting output could be used as input to sub-models at operational and strategic levels.

3) A long-term change of demand can have significant effects on profitability of SSS services. Realistic values for the future profits can be estimated by the effects of demand on operational parameters of terminals and ships. Decisions concerning flexibility versus specialization pertain to long-term demand assessments and depend on commercial and technological strategy [23]. The ability to investigate strategic decisions concerned with flexibility of ports infrastructure allows responding to the market situation accordingly. A simulation model can serve as a virtual laboratory for examining such options.

Financial and political support for SSS systems are a key, for example, for grants and aid provided by local and federal governments. Political influence due to social costs of road transport mode e.g. congestion cost, environmental cost, and infrastructure cost [3] play a role in influencing policies that encourage investments and/or direct funding to enable modifications of infrastructure and startup of new services. The social aspect of the system based on environmental and infrastructure problems related to the highway transport mode can drive the development of new ferry connections that in turn may create competition between ports, ship owners etc. Some businesses may experience a decline whereas others will adjust, improve their operations by investing and winning competition with competing ports and other modes of transport. Simulation can support government investment decisions by providing insight into the viability of proposed terminal layout, operations, and business factors. Ability to evaluate a high-level view using simulation-based analysis in this sector could be especially valuable at governance or strategic management level.

4) Security and emergency related considerations [9] can also be addressed using simulation models e.g. uses of real time situational data to evaluate recovery strategies for ports and terminals, or as unforeseen events that can be expressed as component of system reliability estimations [24].

A simulation model can help to identify and evaluate options for achieving individual sub-systems objectives and overall system objectives. Performance of RoPax terminal should be monitored using identified metrics. Performance monitoring combined with a simulation model will allow port managers to more proactively identify and assess areas needing their attention, investigate redundant or unnecessary components of terminals, and the long-term impacts on demand. The use of a real system data within simulation model should provide short-period predictive analysis and decision support, mitigating or avoiding possible problems. Development and validation of a long-term simulation model is substantially more difficult, because it usually includes theoretical constructs to support system evolution over time.

The uses presented above can be correlated, making the solution space complex. Different types of customers and different stakeholder’s needs for use of RoPax e.g. cars, trucks, and people, make the process intertwined. This situation lean itself to the use of M&S, but the potential uses of simulation techniques require further analysis. Different M&S or analytical methods can be used for different types of problems. The usefulness of the integration of different methods could be also evaluated as possible solutions allowing for handling diverse problems within a single simulation framework. The operational and strategic cases for employing a simulation model are correlated and investigation of implementation as a reconfigurable simulation framework needs to be explored.

III. METHODOLOGY

The exploratory character of this study required an iterative approach. The authors distinguished two main parts of the exploratory: theoretical, and implementation. The theoretical portion of the methodology is shown in Fig.1.

![Diagram of Methodology](image)

The initial purpose and problem required identification of phenomena involved. Once the phenomena and system are assumed to be holistically defined, a selection of an appropriate method or methods is made. Different types of
simulation methods carry different assumptions, constraints, and serve different purposes [25, 26]. System Dynamics (SD) is especially suitable for capturing dynamic complexity, representing internal causality, holistic views, and representation of feedback loops [27]. Agent-Based Modeling (ABM) is unique in representing complexity arising from individual behavior and interactions, providing insight into emergent behaviors and investigation of adaptive systems [28]. DES supports well “black box” process complexity based on flow of passive entities [29]. Bayesian Based Methods (BBM) offer a unique probabilistic view, where posterior probabilities can measure the degree of belief based on evidence. BBM can be used to represent decision making processes and beliefs of agents [30, 31]. Fuzzy Based Methods (FBM) allow for capturing the vagueness of phenomena systematically [32] and can be useful in modeling social aspects within simulations [33].

Perception on usefulness and applicability of simulation methods to solve different kind of problems evolves as new practices and functionalities are established and implemented into software tools.

The choice of a modeling method or methods is a very important step within a simulation-based study or project. If the system is complex and identified problems span many levels of abstraction, different method or a set of methods should be considered. Balaban and Hester [34] proposed a decision support process to aid in determination if a multi-method approach is a desirable. Accordingly, the choice to use a multi-method M&S approach is based on the structure of the phenomena being modeled, a concept of system realization, methodological soundness of the simulation with coupled methods, and a human dimension. Initial concept of phenomena structure and system realization can dictate more than one method which can be further supported by identifying criteria that expose the methods’ distinctiveness, complementary character, and a need for dynamic interaction of methods during model execution. Different sets of criteria were investigated [25, 35–41]. The abduction risk [40] should be considered when mixing methods in a specific methodological context. Human related factors provide the final layer of consideration. This subjective layer includes considering the skills of the modeler, stakeholder acceptability, expectations of insights related to perception of method usefulness, and other personal circumstances e.g. software concerns.

The implementation portion of the methodology converts theoretical concepts into appropriate formats using considered approach. This requires procedures for mapping concept to software, which depends on the methods used. In this phase, the model is implemented using a software tool. AnyLogic® was selected for this work is called because it allows for combining M&S paradigms: SD, DES, and ABM. While this paper covers considerations related to initial implementation of theoretical concept related to RoPax system, it is important to be aware of required V&V efforts throughout a simulation-based study by detecting and eliminating errors, limitations, testing logical validity, and considering usefulness of the proposed model in addressing the study problems.

IV. Sample Model

Based on the analysis from section II and methodological guidelines described in section III the authors implemented a sample proof-of-concept model of RoPax system to evaluate the feasibility of a simulation-based approach.

A. Purpose/Problem and proposed solution

The cases identified in the section II spans various levels of abstraction, different periods, involve high complexity, and significantly overlap. This means that a decision support system (DSS) based on a simulation model should not only capture a singular problem space, but also a holistic view of the system to test dependency of the identified problems. Simulation-based experimentation platforms should allow assembling reconfigurable experimental settings to deal with a particular problem or sets of problems via reusable and reconfigurable components. A simulation model of a RoPax system with a goal of holistic representation must include its main components: ports, ships, and customers, and should allow for representation of their dependencies and interactions.

B. Phenomena definition

The following phenomena are identified as important for a simulation-based DSS related to SSS system:

1) Demand

Demand can be defined as customer’s desire and willingness to pay a price for a specific good of service [42]. Demand in this work is tailored for SSS and conceptualized as divided by two main dimensions at a high level: type of customers and geographical locations of customer as shown in Fig. 3.

SSS long-term sustainability depends on demand. Seasonal and weekly fluctuation of demand and the variety of cargo types in RoPax terminal makes predicting demand for services especially challenging. Demand for ferry transport can be affected by factors external to the port e.g. GPD, population density, location attractiveness, and factors internal to ports e.g. competitive advantage with other modes of transport e.g. prices, customer satisfaction, and image. Different factors with different magnitudes may influence demand for commercial and private customers, therefore it seems reasonable to consider related groups separately. Each type of cargo e.g. commercial trucks, bicycles, and cars may have to be considered individually when estimating demand. For an initial effort, the general view of private and commercial entities is assumed. The required individual data is collected.
based on information provided by customers e.g. when purchasing tickets by providing incentives in form of discounts or free services. Accurate data (knowing the customer) is important for calibrating and validating a model.

2) Customer satisfaction

Juran [43] defines customer satisfaction as conformance to requirements and value as perceived by them. Maital and Seshadri [44] describe customer satisfaction in terms of feelings and emotions toward solutions, and experience with innovations supplied. Customer satisfaction depends on proper serving of existing demand and is often an indication of enterprise innovation [45]. Profit from RoPax system depends on the quality of services offered to customers. Long-term organizational innovations can influence the quality of those services. A study presented by Ellis [46] revealed that end users’ satisfaction was a function of usefulness, aesthetics, quality, reliability and service, but was not correlated with cost competitiveness. SSS provides services to private or commercial customers whose satisfaction will likely be dependent on distinct factors. If a decision to use SSS is made by the managers of the company of supply chain, and if it is based solely on financial calculations, satisfaction of commercial drivers’ may not be the most important factor to consider. Private customer satisfaction is often related to availability, quality, and reliability of services, which is directly related to time-based measures like total processing time, timely arrival, frequency of ferry departure [21, 22] etc., and which could most likely be improved by various services available at terminal and onboard ship.

3) Image

Image can be associated with a product, a service, a combination of products and services, or the operating company serving as an umbrella for a brand [47]. Dobni and Zinkhan [48] described brand image as the concept, mental model of the brand held by the consumer, formed by interpretation, reasoned or emotional. Whetten and Mackey [49] described organizational reputation as the reciprocal of image, providing feedback from its stakeholders regarding the credibility of the organization’s claims. Image of SSS as a mode of transport and image of a particular company providing the shipping services can be useful to explain customers’ preferences to choose it and may affect demand.

4) Reliability

Reliability is defined as the probability of a system performing its intended function under stated conditions without failure for a given period of time [50]. Reliability of a RoPax system is difficult to assess because of limited available data. Gaonkar, et al. [24] developed a model to estimate reliability of maritime transportation based on a fuzzy method. Considered factors related to port, ship, transit conditions including weather, and human element. A more detailed view on terminal disruptive events, including their causes and consequences in terms of frequency and severity, was developed by Saurí Marchán, et al. [4].

The phenomena considered are initially structured to provide a holistic phenomenological view that allows for an initial conceptualization of methods needed as shown in Fig. 4. Demand is an overarching phenomenon that integrates with other phenomena. This may require different methods in order to capture internal characteristics and dynamics of phenomena at desirable levels of abstraction. Conceptual model development step (section D) integrates phenomenological and systemic views and provides more elaboration about methods chosen.

C. System concept description

Based on the phenomenological view, a sample system and scenario is proposed as a base for development of a proof-of-concept simulation model. The proposed RoPax system main components include two ports, n-number of ships, and customers as shown in Fig. 5.

Two ships operate between Port A and Port B. These ships are under schedule constraints correlated with speed of vessels required to support the schedule. The cost of ship operation is largely dependent on fuel economy [20] that is a function of ferry speeds during transit. The transit reliability depends on port, ship, and transit conditions, which includes weather, and the human element. The unforeseen variability of ship transit could be potentially compensated on the terminal side of the RoPax system by higher capacity for cargo, more time efficient loading, and unloading processes, which supports punctual arrival at the destination. Moreover, time flexibility during transit will lower fuel consumption and hence the cost.

Cargo and passengers are aware of the schedule and are prompted to arrive x amount of time before the ferry departs, but not later than y. The timing requirements are different for private and commercial cargo. Customers must decide what time to arrive before departure, and this decision can affect congestion during processing at the terminal. Customers arrive at a port and are processed to an access area, where they wait for permission to enter the ship.
After loading, a ship departs e.g. Port A. Transit conditions can generate speed fluctuations. A ship has a back ramp for vehicles, and side ramp for passengers. A loaded ship arrives at the terminal of Port B, moors, its ramps are deployed, and terminal cargo operations begin. Alternative sequences of cargo loading and unloading can be tested. When all cargo is unloaded and loaded, the ship prepares to departure by closing its ramps and sails back to Port A. The cycle repeats based on the scheduled daily departures. The customer is modeled throughout round-trip, and can decide on mode of transport during each phase.

D. Conceptual modeling

The causal conceptual model of RoPax system is shown in Fig. 6. Demand drives the rest of the system. The customer decision to choose SSS mode of transport is vital for RoPax business; it can be indirectly influenced by system managers. The primary dynamics of a simulation model are conceptualized as both reinforcing and balancing feedback loops. Demand is reinforced by higher profits, allowing for investments that increase reliability, customer satisfaction, and the image of the SSS mode of transport. On the other hand, demand is balanced by technical constraints that pertain to a facility and ship, improvements above some threshold level may be infeasible at the given time.

Evaluation of method selection was conducted based on a process developed by Balaban and Hester [34]. Complementary features of methods can be useful to represent different phenomena within an integrated system view and may prove effective during integration of both theoretical and descriptive elements [51].

SD or regression model should be able to provide a way to estimate market potential characteristics as they can impact port demand [11]. Demand for transport between areas is derived at aggregated SD level, because the holistic view of RoPax system is the focus, but the individual customers should also be considered, especially if there is an option for choosing the mode of transportation. ABM could also be used to characterize the population of customers, but computational limitations will not support this approach for large populations in order to run experiments effectively. DES is conceptualized as especially valuable to describe terminal operations because it allows for easy and detailed representation of complex processes, including terminal layout, car movements, or stochastic disruptive events affecting reliability.

Long-term terminal profit depends on not only processing efficiency of entities, but also on the customers’ perspectives that have “soft” characteristics. Such perspectives are difficult to represent within a descriptive view of passive DES entities. ABM agents allow for representing elements at individual customer level, and this is the desirable choice for representing individual behavior of customers. This approach makes, at least in principle, it possible to estimate effects of environmental stimuli on “soft” phenomena e.g. customer satisfaction. Additionally, use of BN within agent offers a unique approach to inferences that can enhance representation of their behavior [31], especially when designed based on theoretical concepts of human behavior [52]. Cognitive architectures can also be used for more accurate agent representation [53, 54]. Aggregated SD view of customers, individual level agents, and entities are conceptualized in Fig. 7.

Ships are also conceptualized as individual agents because they are controlled by humans driven by their conflicting goals e.g. minimize the fuel consumption versus avoid delays. Results from the model can be integrated with external decision-making module using a Bayesian Network (BN) layer. Translation of a simulation model output into qualitative information supports a set of decisions, which will be more comprehensible by decision-makers.

E. Development considerations

Only chosen parts of the model are described due to space limitations and are a work in progress. The separation of components allows for easy configuration and addition of components and changes to the logic.

Customers are represented as agents progressing through different stages during the simulation run. The implementation of private vehicle logic is described as an example. Commercial vehicles and passengers are driven by the same overall concept, but with processing differences. Example of private vehicle agent logic is shown in Fig. 8. For consistency, the representation of a private vehicle called an agent pertains to ABM and called an entity when the DES process is considered. SD module generates potential daily demand. An agent can decide to go one way or choose a round-trip. The round-trip option is described here. If the agent chooses to use a RoPax system instead of bridge, it will be added to the list of...
agents traveling. An agent can choose between three daily departures. According to the terminal arrival rules, an agent decides at what time to arrive at terminal. This is modeled using a probability distribution function (PDF) within the time frame allowed, but this rule can be changed depending on model assumptions (e.g. late arrival). The arrival’s PDF can be derived by collecting data from an actual system and scaling the shape of the PDF to the model’s demand values. When the agent arrives at terminal, it creates a car entity (Anylogic® Road Library) within the loading process and binds with it. This allows for easy representation of high fidelity loading process of private vehicles including size of car, acceleration, deceleration, and speed factor. The process of car entry is finished when car logically enters ferry, as permitted by the terminal and the modeled ship logic. At this time the car’s sink block adds the agent to a ship object and terminates itself. Next, the agent is transported by ship to the other port. Upon arrival, and when allowed by the terminal and ship logic, the agent again creates a car entity within unloading process and binds with it. Upon completion of unloading, DES entity terminates itself. The agent waits until the return time and makes the trip back following the same logic given that the ferry transport is chosen.

A ship has also two layers of representation within the model. An agent captures persistent representation of the ship covering transits between ports, while a ship entity mimics terminal operations. Both elements are bonded to each other. An agent consists of two dynamic models of ship movement that allows representing proactive behavior patterns of ship transit (Fig. 9). A pair of dynamic models allows setting desired ship velocity based on distance from the port and simulates dynamic adjustments to external situations e.g. ships late departure, desire to save fuel, or bad weather conditions causing delays during the transit. Once the first model is used to simulate speed required for the desired time of arrival, the second model monitors the progress and adjusts actual speed. If unforeseen circumstances arise, the ship can adjust its required velocity after situation is resolved based on the reference model, this provides difference of ship’s “lost time” that must be compensated by velocity increase to keep up with the schedule. One could also implement this using lookup tables but that would limit the possibility to control both models programmatically. This can be important for overall model purposes that require mimicking a ship’s internal behavior and external rules that reflect different processes affecting the ship e.g. level of information integration with the shore side. An entity representation of the ship is modeled within the terminal and it is used to control and coordinate ship’s interaction with terminal and customers.

The persistence of an agent throughout different processes, and binding of these processes allows for building a frame for experimenting with customer satisfaction. Representation of high fidelity terminal operations generates data reflecting the measured reliability of RoPax system such as missed departures due to ship breakdown, deviations of departure and arrival times, ramp and other equipment based problems, congestions at gates and delays that are dependent on demand, terminal and ship operational rules, and traveling conditions. The data are also fed into theoretical model that aims to predict customer satisfaction.

A customer experience determines their satisfaction, which can be used to model their decision for choosing a ferry mode of transportation. Image phenomenon aggregates the value of customer satisfaction and adds other factors e.g. advertisement. Inputs from events generated by ships and port terminal models are fed into BN representing customer satisfaction as a factor for deciding to choose a ferry as part of their trip plan and possibly during their return journey. The BN can have predefined conditional probability tables (CPT) based on external empirical data, it can be calibrated based on simulated events, or both. Please refer to Fig. 10 during discussion about the concept of mapping quantitative model values into qualitative “soft” levels using BN to represent customer behavior based on a theory of reasoned action [52].

According to Fishbein and Ajzen [55] prediction of behavior $B$ can be expressed based on intention toward conducting behavior $I$, attitude toward behavior $A_B$, subjective norm $SN$, perceived behavioral control $C_B$, and empirically derived weights $w_1, w_2, w_3$ using (1).

$$ B \sim I = (A_B)w_1 + (SN)w_2 + (C_B)w_3 $$

Behavior would be defined differently for private and commercial customers e.g. for private customers it can be defined as “my choosing a ferry for my travel”, and what follows “I intend to use this ferry.” First step requires identification of beliefs that contribute to attitudes, norms, and perceived control toward the behavior when applicable, and
outcomes that relate to behavior e.g. “I believe the price for the ferry is reasonable when compared with a combined bridge toll and gas expenses, or I believe transportation on the ferry is a pleasant experience.” In the next step, sample scales were devised that maps quantifiable model factors to qualitative believes e.g. delays threshold values, i.e. if the ship arrival time is delayed more than \( x \) sets node state to significant, if less than \( y \) sets node state to insignificant. Do not set the node value if the ship is delayed between \( x \) and \( y \) amount of delay time. Similarly, wait at entry gates, wait at exit gates, and loading time are mapped. Updates of the BN represent changes in the customer’s context variables (delays, ship breaking) during simulation run, which influences customer’s attitudes, and controls estimation of intentions toward given behavior. Design of CPT should support capturing initial customer attitude but do not change until possible delays and technical ship problems occur. Alternatively, different BNs can represent a range of possible situations.

At the aggregated level, demand is estimated separately for each cargo type modeled as the number of customers who consider transportation service offered by RoPax system per day. The SD model used to estimate the demand of private customers was adopted from the bass diffusion model described by Sterman [27] and shown in Fig. 11.

Overall considered population based on area and population density can also fluctuate dependent on external factors like GPD, exchange rates, and can be incorporated into the model by using statistical methods [2]. This would be especially useful for evaluating demand for commercial customers. Adoption rate represents the number of potential customers who decide to travel to the area, and which could involve use of ferry or other mode of transport. Rate of travelers, the season, and weekly cycles affect the final estimate. Special dates like holidays could also be added. Estimated daily number of potential customers is then used at the individual customer level as described in previous sections. It should be emphasized that demand models of different types of customers will depend on a particular relationship between the areas connected by ferry transportation.

**F. Discussion and future work**

Overall, possible throughput of RoPax system depends on the number of ships with their capacities, and the infrastructure of terminals. Both parts of the system support customer demand for transport between ports. If the demand is not supported or reliability of service is low, a loss of customers occurs. This “equation” is not constant and can depend upon management decisions. The idea of evaluating the co-evolution of demand and capacity of RoPax system presented in the example model is very appealing, but the methodological aspects for development of validated DSS need further research. Each component of the simulation has value on its own, but the integrated version allows dynamic mapping between phenomena. Theoretic-based simulations influenced by the descriptive operational model can help managers understand and select a course of action that will provide a reliable and successful business based on appropriate decisions. Challenges in the accurate mapping
between phenomena determine usefulness of the holistic view of the simulated system. The final predicted outcome is also affected by variability and assumptions of each sub-model, which should be taken into consideration. The lengths of simulation run and available data have a significant effect on types of problems that may be addressed with sufficient confidence. Empirical validation of theoretical concepts that capture holistic view of RoPax system is the ultimate goal of the model, which in turn will generate highly accurate predictions.

V. CONCLUSION

We have identified potential cases that call for the application of simulation-based DSS in the context of SSS at both strategic and operational level. A conceptual model of RoPax system was proposed and discussed. The proposed model supports discussion and reflection about which simulation capabilities are needed. An agent view with added BN provides more flexibility in representing individual customers and their behavior, whereas a processing view simplifies representation of high fidelity cargo flow through terminals. SD was used to estimate high-level demand. Combination of different modeling methods can provide inputs at aggregated and individual levels facilitating funnel-like effect for estimating demand of particular types of customers.

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