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Dynamic Safety Modelling for Ship Management Performance

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Abstract. Recent development and projection of ship operations as a sociotechnical system is getting more complex. In order to successfully emulate a high-reliability organization with a balance between operational efficiency and safety, the shipping companies have to grab a well understanding of the operating performance. However, because the teams are distributed spatially and temporally, a misalignment of shared situation awareness casually exists. We extended Rasmussen's dynamic safety theory and adjusted it in the context of ship management performance. A modelling study using system dynamics was done to illuminate how the feedback loops construct the interaction between safety, efficiency, and workload. The simulation result shows that the operations behave following the safety and efficiency pressures created by existing goals and boundaries. The model is also able to capture these trade-offs in different variety of operation scenarios. Application such modelling may provide the managers with a better understanding and valuable insight to implement the strategies to sustain safe operations.

1. Introduction

Balancing between efficiency and safety in ship operation is common practice, as well as other general industries. While doing it, each level of the organization's components in ship operation frequently makes a trade-off between efficiency and thoroughness to manage the available resources [1]. Naturally, an organization such as a shipping or ship management company based their decision to pursue optimum cost-effectiveness, but on the other hand, it also prepares the stage for the accident [2]. In a sociotechnical system where safety is viewed as a control problem, an accident occurs whenever this control system cannot handle component failure or external troubles [3]. Therefore, examining the behaviour in each interaction between components becomes more prominent.

Ship management operation has a characteristic of the distributed team between shore staff and onboard seafarers. Different time operations make the team distributed not only geographically but also temporally [4]. Even the accident number in maritime operations is decreasing, human error, especially the failure of situation awareness, remains dominant [5]. The failure to attain situation awareness occurs not only because the difficulty in communicating mental models between the team members onboard, but also between onboard and shore side [6]. The overall situation awareness is perceived differently by an individual based on incomplete and inaccurate information. Such condition makes the team remain locked into a false picture of the situation until accidents or incidents occur [4].

The interaction between onboard seafarers and shore management and its behavior in terms of efficiency, safety, and workload needs to be closely observed in a feedback loop environment.

However, the traditional approach is unable to cover the dynamic behavior of these interactions. To address the challenge, the developed system dynamic model in this study provides a holistic understanding of safety and efficiency pressure allocation in sustaining a safe operation. Modelling with system dynamics focuses on system behaviour made by nonlinear feedback loops [7,8]. It is well used in safety studies for complex systems, where the decision-making system analysis is involved in planning a safety policy [9].

2. Method

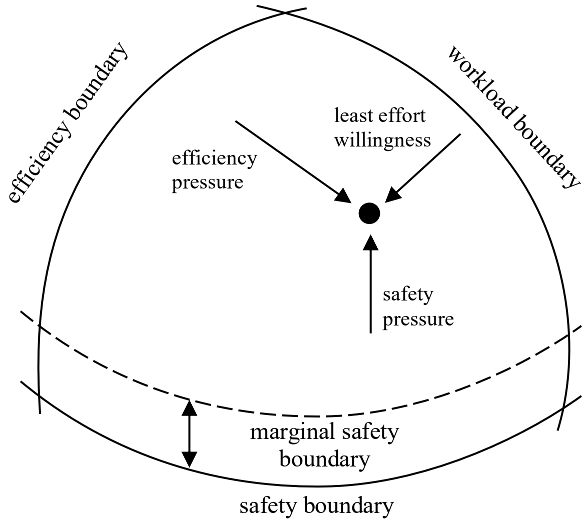

Figure 1. Operating point and three boundaries, as adopted from Rasmussen [2]

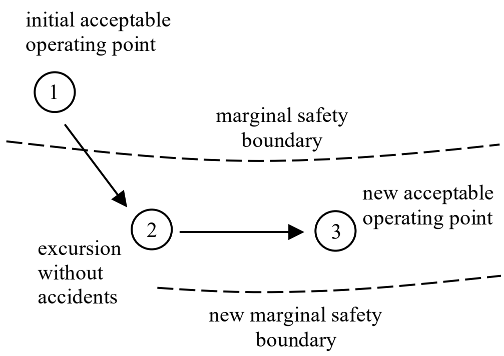

Figure 2. Operating point movement, as adopted from Cook and Rasmussen [10]

We developed a system dynamics model based on Rasmussen's dynamic safety theory [2] and what Morrison and Wears already have formulated [11]. As shown in Figure 1, Rasmussen's theory consists of three boundaries where a sociotechnical system operates: safety, efficiency, and workload. Later, this concept was formalized into the system dynamics model by Morrison and Wears [11] with simplification of the workload and efficiency as a single boundary. We see the model should be extended regarding the ship management operation where the teams are divided into the shore team who act as the management, and the seafarers onboard as the front-line worker. Thus, the constructed model within this paper is based on the previous study [11], together with the related literature in ship operation management. The developed model consists of several loops as shown in Figure 3; its variables construction is explained more extensively in each subsection below.

2.1. Operating Point

The operating point represents the state of the organization's operation from the perspective of three boundaries. The continuous movement of the operating point is made by a trade-off between the management who will apply an effective cost gradient, and the worker who will find an effort gradient. The migration is defined as the management's tendency to find a more suitable position to gain performance. Likewise, it describes the aggressivity of ship management in doing business. Rasmussen explained this practice with an analogy of Brownian Gas movement, where the operating point's variation will randomly move within the available space made by these three boundaries [2]. Further, stability is achieved when movement is small and random [10]. This practice pushes the operating point move away from the efficiency and workload boundary toward the safety boundary. As a result, the migration will likely cross the safety boundary, and an accident may occur.

In Figure 3, the operating point is described as the input function of safety pressure and efficiency pressure to decide its magnitude and direction of movement. The symbol "+" in the arrowhead from loop B1 means the operating point will move to a higher position (greater safety) as the safety pressure increase, and vice versa. Contrary, the symbol "–" from loop B2 indicates the operating point will move to a lower position (less safety) as the efficiency pressure increase. Safety and efficiency work similarly but in a different direction of consequences. The aforementioned management strategy to pursue more suitable operation performance is represented as the excursion. The negative arrow input from the excursion indicates that the operating point will move closer to the safety boundary as the excursion value increase.

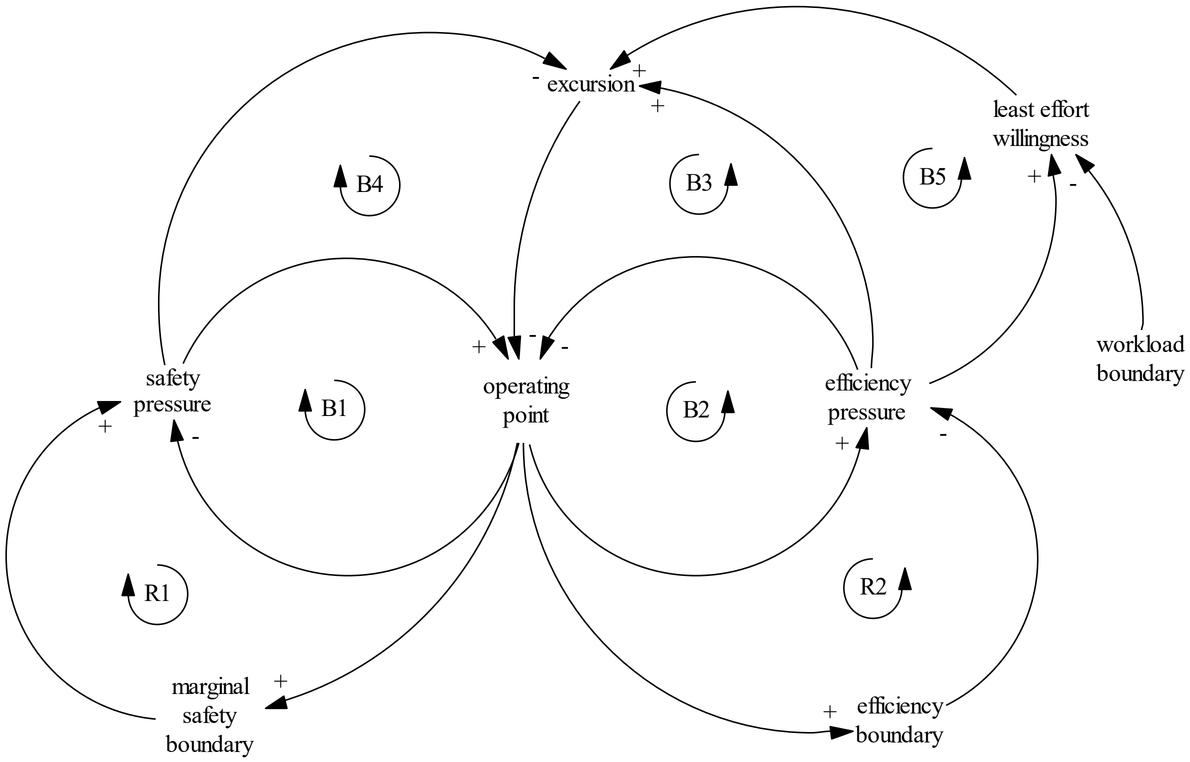

Figure 3. Causal loop diagram of the proposed model

2.2. Safety Pressure

Since the location of the safety boundary is unknown unless the organization is experiencing an accident, the marginal safety boundary is created to estimate and give the margin error from the safety boundary. It is normal if the organization, also in this context, is a ship management company, to operate near the marginal safety boundary given the advantage of higher efficiency and lower workload. Unintentional crossing the marginal safety boundary is recognized as a near-miss since no accident occurred [10]. Immediately an effort is created to bring the operating point move upwards. Crossing the marginal safety boundary also gives the organization a new understanding that the current operation state is acceptable. Hence, the practice of lowering the marginal safety boundary is unavoidable.

Loop R1 explains the safety pressure created by the marginal safety boundary. Illustrated in Figure 2, when the operating point moves beyond the marginal safety boundary, the new boundary value will exist lower than the previous one. The new lower marginal safety boundary generates lower safety pressure since the operating point is more distant from the marginal safety boundary. Operating with lower safety pressure stimulates the operating point to move even lower, close to the safety boundary. Therefore, the feedback mechanism in this marginal safety boundary is categorized as the reinforcing loop.

2.3. Efficiency Pressure

Seeking more profit is the nature of the company in doing the business. It is not uncommon for the organization to cut off safety corners or boundaries to meet operational demand [12]. The manager's job, such as a marine superintendent, is to allocate resources such as budget and time efficiently. Allocating the resources is not without obstacles. Even shore staff have had a long sea experience before, demands to meet the target and performance indicators make the actual situation onboard often remain unconsidered [13]. These are accumulated into the pressure to pursue greater efficiency, but on the other hand, also lead the condition into less safety.

In an extended theory by Morrison and Wears [11], not only the marginal safety boundary that is moveable but also the efficiency boundary will adapt to the recent organization experience and pressure. In the model, efficiency pressure is defined as the exact opposite of safety pressure. Explained by the loop R2, the efficiency boundary will migrate to the lower side, which means more efficiency but less safety because of the feedback from the lower operating point without safety breach or accident. On the other hand, having a lower efficiency boundary means the efficiency pressure will increase and push the operating point even lower. Similar to safety pressure, the mechanism in this feedback is a reinforcing loop.

2.4. Excursion

As explained in Figure 2, an excursion makes the operating point move closer to the safety boundary or to the condition of less safety. The position across the marginal boundary does not immediately trigger an accident, but instead, it states that the current operating point position is acceptable. Further, it made the organization move the marginal boundary to a lower position. Although the direction of the excursion itself was explained by Rasmussen [2], and its magnitude was explained by Morrison and Wears [11], we argue that its magnitude should also be affected by safety pressure and efficiency pressure. In Figure 3, Loop B4 describes that when safety pressure increases, it reduces the excursion. The same balancing feedback explains with loop B3: when efficiency pressure increases, it also triggers a higher excursion.

2.5. Least Effort Workload

Given the circumstances of ship operation where operator onboard and shore management are distributed spatially and temporally, some unintended resources allocation may exist. In large scope, ship companies also consider the efficiency in manning allocation by cutting the number of seafarers onboard; a common practice for some ships not to employ a third mate to save the budget. The implication directly adds the work demand to remaining seafarers [13]. It settles unsuitable conditions to maintain safe operation since the remaining seafarers tend to limit their rest hours and have to work longer. In several cases, as reported by Rajapakse et al., work tasks were assigned to the seafarers onboard sometimes without considering the seafarers [1]. It makes the allocation task not adjust to the limitation of seafarers as a human. A higher workload will make the operators tend to find the strategy to lower it to achieve a suitable workload level. Such a strategy is generally understood as a shortcut or workaround. Moreover, because of the lack of understanding between shore and onboard operators, it is common for seafarers to keep back particular events or activities from the shore-based staff [13]. This deviation in the actual work environment was not recognized by shore management.

The point we want to stress is that kind of additional pressure excursion is the actual condition on the field but beyond management estimation. We argue this matter from the original model and define workload as a separate entity besides economic as efficiency pressure. Explained in loop B5, the increasing efficiency pressure will increase the front-line operator's workload because of the human limitation that defines the workload boundary. Higher workload naturally will make the operators develop a tendency to find the strategy to lower it beyond workload boundary and achieve a suitable workload level. In the loop feedback, this practice brings the least effort willingness more significant, directly increases the excursion, and lowers the operating points (less safety).

3. Simulation Result

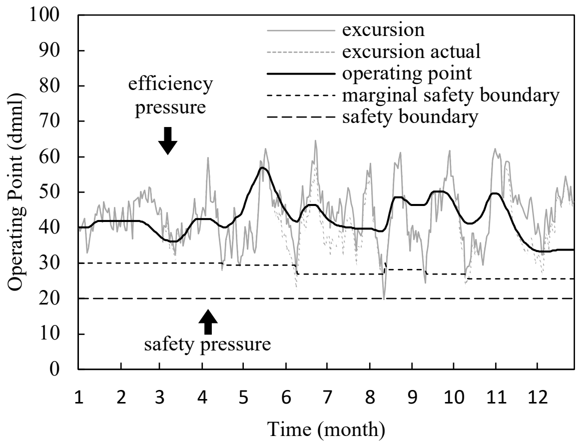

Figure 4. Single running simulation result for Scenario 1

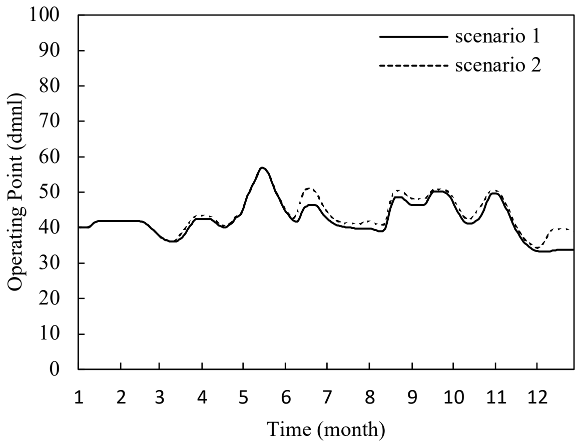

Figure 5. Operating point comparison between scenarios

Figure 4 shows the base model simulated in a one-year period. We followed the Morrison and Wears [11] representation model into one dimension vertical axis. Because this study focuses on the theoretical construction and dynamic behavior pattern, the variables are made on a theoretical basis and assumption, including its unit defined in dimensionless (dmnl). An operation point on the vertical axis, for instance, illustrates the higher value with greater safety and vice versa. The safety and marginal safety boundaries are shown in the lower part. The horizontal axis shows the operating point over the time variable; it demonstrates the objective of explaining the behavior dynamically.

The model starts from the equilibrium initial state, with the operating point being the average function of safety and efficiency pressure. The excursion combined with the safety pressure brings the operating point upward to higher safety, and efficiency pressure balances it to a downward position. When the excursion crosses the marginal safety boundary, safety pressure suddenly increases and brings the operating point upward, but we can notice the marginal safety boundary moved to a lower state. In a condition where the excursion moves further lower and crosses the safety boundary, the system experienced an accident.

In Scenario 1 (S1), the onboard excursion (excursion actual) is assumed not to be noticed by the shore management. Hence, the management only used the partial excursion to decide the operating point's direction and magnitude. While in Scenario 2 (S2), we assume the shore management has sufficient situation awareness about the excursion actual and uses it in allocating safety and efficiency pressure. The different operating point between these two scenarios is shown in Figure 5. Two types of excursion lines indicate the difference between shore side perception and actual onboard excursion affected by the least effort workload.

To test the model's sensitivity, we run the simulation 100 times for each scenario in different simulation duration. Table 1 shows the total accidents on the average and normalized ratio for each running scenario. The most noticeable difference is that Scenario 2 experienced fewer accidents compared to Scenario 1 in all simulation duration. Comparison between different simulation duration also indicates the consistency is established in long simulation duration, but not with the short one.

Table 1. Simulation result

	1 year		4 years		10 years		15 years	
	S1	S2	S1	S2	S1	S2	S1	S2
Accidents (mean)	0.40	0.26	3.12	1.84	8.56	4.99	13.10	7.79
Accidents (SD)	0.65	0.52	1.58	1.16	2.74	1.86	3.68	2.33
Ratio	0.40	0.26	0.78	0.46	0.86	0.50	0.87	0.52
Reduction		35%		41%		42%		41%

4. Discussion

Rasmussen's dynamic safety model has a significant contribution to understanding the influences of safety, workload, and efficiency in a sociotechnical system to determine the position of the observed organization over time. To adopt the theory into the ship operation management context, we extended Morrison and Wears's formulation model. Instead of combining the workload and efficiency into a single effect, we translated the workload as a separate entity that depends on efficiency pressure but still acts upon safety. In adjusting the model, we tried to stay in line with the original theory.

Viewing safety as a control system in sociotechnical, what is needed is a leading indicator; therefore, an act to intervene can be performed before this system's state leads to an accident. The developed system dynamics model in this study attempted to provide an understanding of management strategies in allocating safety and efficiency pressure to approximate that leading indicator. As a result, having sufficient situation awareness of onboard conditions allows the management to put the operating position in a state where accidents are less likely to occur. It amplified the essential of maintaining good coordination between the onshore and onboard teams. The modelling with system dynamics also allows observing this behavior in the long-horizon time span.

As an effort to analyze the system holistically, this paper focuses on behavior prediction rather than point prediction. Validation is limited to model construction, and the test is conducted only with extreme scenarios. Like other models, many simplifications and assumptions were made. Future studies should involve actual data representation as an attempt to represent each dimension into the countable unit. We agree with the previous study that safety, for instance, can define as a risk factor, but the feedback system likely will show a similar behavior pattern.

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References

[1] Rajapakse A, Emad G R, Lützhöft M and Grech M 2019 A study on time constraints and task deviations at sea leading to accidents – a cultural-historical perspective *Maritime Policy & Management* **46** 436–52
[2] Rasmussen J 1997 Risk management in a dynamic society: a modelling problem *Safety Science* **27** 183–213
[3] Leveson N G 2011 *Engineering a safer world: systems thinking applied to safety* (Cambridge, Massachusetts: The MIT Press)
[4] Endsley M R 2012 *Designing for situation awareness: an approach to user-centered design 2nd ed* (CRC Press)
[5] Grech M, Horberry T and Koester T 2008 *Human factors in maritime domain* (CRC Press)
[6] Barnett P M, Gatfield D and Pekcan C 2006 Non-technical skills: the vital ingredient in world maritime technology? *Proceedings of the International Conference on World Maritime Technology 2006* p 11
[7] Sterman J D 2000 *Business dynamics: systems thinking and modeling for a complex world* (Boston: Irwin McGraw-Hill)
[8] Forrester J W 1961 *Industrial Dynamic* (Cambridge, Massachusetts: The MIT Press)
[9] Ibrahim Shire M, Jun G T and Robinson S 2018 The application of system dynamics modelling to system safety improvement: Present use and future potential *Safety Science* **106** 104–20
[10] Cook R and Rasmussen J 2005 "Going solid": a model of system dynamics and consequences for patient safety *Quality and Safety in Health Care* **14** 130–4
[11] Morrison J B and Wears R L 2021 Modeling Rasmussen's dynamic modeling problem: drift towards a boundary of safety *Cognition, Technology & Work*
[12] Reason J 1998 *Managing the risk of organizational accidents* (Aldershot: Ashgate)
[13] Sampson H, Acejo I, Ellis N, Tang L and Turgo N 2016 *The relationships between seafarers and shore-side personnel* (Seafarers International Research Centre (SIRC), Cardiff University)