Understanding and Improving System Safety Through System Dynamics Modelling – Systematic Literature Review

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Abstract. System Dynamics (SD) has been widely used in modelling across a range of applications but its potential has not yet been fully realised as a tool for understanding system safety and supporting relevant strategic decision making. We conducted a literature review of SD applications in safety-critical environments, employing a safety taxonomy framework. The result of our literature review provides an overview of SD modelling application in safety-critical environments, highlighting the existing gap and generating future research questions in this area.

Keywords. system dynamics, literature review, simulation modelling, safety.

1. Introduction

System dynamics is an analytical modelling methodology, its origins of which are attributed to Forrester (1961) in his pioneering work on "industrial dynamics" in the 1960s. SD combines both qualitative and quantitative aspects and aims to enhance understanding of complex systems, to gain insights into system behaviour. The qualitative aspect entails the construction of "causal maps" in which the system structure and the interrelations between the components of a system are explored. The quantitative aspect entails the development of a computer model in which flows of information around the system are modelled and bottlenecks identified.

Whilst SD modelling has gained popularity as a tool in variety of industries (Homer & Hirsch, 2006), its potential has not yet been fully realised as a tool for understanding trade-offs between safety and efficiency and making strategic decisions in safety-critical industries. No comprehensive systematic approach review of the use of SD modelling in safety-critical domains has been published. The aim of this study is to evaluate the extent, quality and value of system dynamics applications in safety-critical domains.

2. Methods

2.1 Literature Search

Systematic approach methods were employed to gather and evaluate relevant papers for this literature review. A range of databases were searched for published articles up to July 2015 on system dynamics and safety. The databases include PubMed, Web of Science, Science Direct and Google Scholar databases. The grey literature was also searched. Papers eligible for inclusion were those that described applications of system dynamics modelling to understand/improve system safety. The reference lists of each article were reviewed to identify additional resources. Articles were selected on the basis of their thematic and content relevance to the inquiry. Thirty-seven papers were identified that reported findings that applied SD modelling in safety.

2.2 Analysis - Safety Taxonomy

We adopted the combination of the Human Factors Analysis and Classification System (HFACS) framework and Rasmussen's risk management framework to identify and classify the SD applications in the selected articles. A new tier was introduced therefore changing the original HFACS framework into an extended HFACS framework with an addition of a new tier called External Factors (regulatory, social, political, environmental, and economic factors).

3. Results

The 37 papers were concentrated in the fields of aviation, construction, disaster-prevention, industrial systems, drugs and terrorism, government, healthcare, military, nuclear and traffic. In terms of which modelling aspect of SD was used, studies applying only qualitative SD (casual-loop diagrams) were 11, whilst those applying quantitative SD (stock-and-flow diagrams) were 14. Lastly, the total paper applying both casual-loop and stock-and-flow diagrams numbered 12.

Examples of applied SD applications are enhancing healthcare safety through estimating potential outcomes, analysing reasons other than cost on why systems safety is failing to though, discussing bottlenecks in critical services. Authors have also improved safety through calling for greater decision-making by basing it on system analysis, analysing past behavioural events in modelling structure to future plan effective safety policies as well as looking at the holistic approach to analyse beyond human error in accidents. These number of examples provide a clear indication on how through the effective application of SD can yield greater results in improving safety in safety-critical industries.

The literature review on existing SD applications to system safety indicated that most of the literature concentrated on improving safety in the higher tiers of the hierarchy whilst a small number of the studies has been dedicated on the operator end or the lower tiers

4. Conclusion

System dynamics has the potential to significantly improve our understanding in areas not well addressed by traditional safety approaches. It presents organisations and management as a tool for discerning the dynamic world of today, and offers insights to the potential trajectories they might encounter once faced with critical decisions that will affect safety. It allows us to see the wider scheme of things and help eliminate subjectivity that may distort vision. The efficacy of system dynamics in simplifying multivariate problems can be employed in demystifying the current state of the system.

The output indicates that majority of implemented SD applications in all sectors are primarily focused to improve the safety of external, organisational and management tiers, not so much in the workplace environment and the operator tiers. As a result, there is a gap in literature where applications of SD are grossly underrepresented in the sharp-end of safety. A future research question would be the utility and feasibility of applying SD to better understand, improve and aid safety amongst operators in the work environment. As evidenced in literature on safety, SD has the potential to contribute to safety in safety-critical domains although it is heavily under-utilised.