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Fostering truck platooning deployment: a systems approach**

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ABSTRACT

Concerns regarding climate emergency and road safety are driving technological innovation in the domain of freight transport using driving automation as means to achieve safer and more efficient transport. Truck platooning has emerged as a solution for achieving both Vision Zero and Zero-emission goals by 2050. Even though there have been important technological advances, perceptions regarding technology readiness hinder the deployment of the technology.

From the literature and focus groups sessions, we have identified a feedback loop where regulators see an opportunity for road safety improvement, but are waiting for the technology to mature, while OEMs require regulatory guidelines to select future investments.

To support the deployment of truck platooning technology, we propose a mixed methodology building on Service Science and Systems Approach methods. Our goal is to identify key actions that act as external forces in the freight transport ecosystem, breaking the loop between regulation and technology. After mapping the transport ecosystem and identifying key stakeholders, we developed a System Dynamics model by designing four causal loops diagrams. From the analysis of the diagrams, we selected key actions to break the cycle and reconciling the goals of each stakeholder.

Keywords: Truck Platooning, Systems Approach, Strategic Decision-making, Policy Design, System Dynamics, Causal Loop

INTRODUCTION

Truck platooning (TP) technology is being advertised as a solution for most of the challenges for freight road transport, providing economic, environmental, and safety benefits [1]–[3]. The technology, based on vehicle automation and vehicle-to-vehicle (V2V) communication systems such as cooperative adaptive cruise control (CACC), suggests that gaps between trucks can be reduced, and trucks can travel together in a synchronized convoy [4]. Although the idea first appeared in the 1990's [5], developments in advance driving assistance systems (ADAS) are making it possible to start testing the feasibility of the concept. Nonetheless, the advantages offered from the platoon set up come from a full automation scenario where distances are extremely low, no drivers are required and V2V communication happen in real time. For now, platoons must rely on current automated driving capabilities (i.e., intermediate automation levels that require driver supervision).

Similar to other technologies, TP faces the challenge of the acceptance from its users [6], but in a more complex system. First, it is possible to identify a multilevel acceptance as freight companies will adopt the technology in their business operations, but drivers will be using them in their work tasks. Second, regulators and road operators are responsible for enabling technology deployment and adoption. Although perceptions about the technology tend to be positive for full automation scenarios, uncertainties remain regarding lower levels of vehicle automation, where drivers take driving responsibilities [7].

In this context, this paper recognizes that the deployment of TP requires a multidimensional and multi-actor approach to ensure that technological advances offer real value to key stakeholders. Consequently, the configuration of the freight transport ecosystem presents an opportunity for applying a Service-dominant (S-D) logic together with Systems Dynamics methods. S-D logic offers a theoretical setting to analyse multi-actor systems [8] while system dynamics provide models in real-world scenarios such as decision-making and production tools [9].

Taking on previous work where we identified the main stakeholders and their objectives, we now develop a system dynamic model to identify decision variables upon which regulators can act. From the causal loops we select external actions that enable the system to move forward and conclude with a proposition for a roadmap of TP deployment.

RELATED WORK

Technology adoption studies in complex systems have been developed using theoretical frameworks based on Systems Approach and System Thinking [10], while Service Design methods have been the foundation for the development of technology-based services promoting collaboration and reconfiguration of complex ecosystems [11]. These frameworks have in common their systemic approach to a multi-actor and multi-objective settings, making them appropriate for study of the freight transport sector. On the one hand, adopting a service-dominant logic can facilitate the analysis of the actor and their interaction through the understanding of their value exchanges. On the other hand, systems dynamics can help understand the dynamics of those interactions and the causal relations between the different goals. Considering that actors were identified in previous studies, we focus the next section on System Dynamics model's application and structure.

System Dynamics model structure

System Dynamics (SD), as outlined by [10], is a methodology and discipline, which studies the modelling and understanding of dynamic systems, emphasizing the complex balance between system structures and their evolving behaviours. At its core, SD visualizes systems as networks connected with feedback loops, defined by stock and flow variables, which underline

their inherent feedback mechanisms. This perspective, with its emphasis on continuous processes, sets SD apart from other modelling techniques like discrete event modelling and agent-based modelling.

In SD modelling, the fundamental structures are represented through loop diagrams comprised of positive and negative feedback loops. Ylén and Hölttä [9] explain that these loops illustrate the interplay of variables within a system. These feedback loops, in conjunction with flow and stock structures, form the basis of system dynamic models, being the flows the variables causing changes in the stock variable. The simplicity of these model structures hides their complexity in generating various system behaviours.

System Dynamics application

Although SD provides a robust framework for systems analysis, [12] suggests its application in the transportation sector, demonstrating its versatility. The methodology, enriched by its focus on causal cycles and actors, goes beyond conventional modelling approaches. These causal loops represent the interaction between the system's components, outlining how they mutually influence outcomes, either reinforcing them (positive feedback) or regulating them (negative feedback). Such insights become crucial for modelling complex system behaviours, defining potential challenges, and evaluating various design implications. Furthermore, the essence of SD goes beyond mere technical interrelationships. It integrates the human dimension, recognizing actors as vital entities within the system. Although SD may not explicitly list these actors in organizational contexts, the principles behind the model reinforce their crucial roles and interactions [10], [12]. Therefore, a holistic analysis of SD requires the recognition and understanding of both technical and socio-human elements, ensuring comprehensive system assessments.

Abbas and Bell [13] emphasize that, to build a system dynamics model, it is essential to have a deep understanding of the subject being modelled, highlighting the importance of multiple iterations and extensive studies. This suggests that modelling is not only a result but also a method for deepening knowledge about the subject. The method proposed is outlined by presenting crucial phases for the study of this subject: problem identification, problem definition, variable generation, model development, system verbalization, system conceptualization, computational programming and simulation, and system analysis. The complexity and dynamism of transportation systems are justified by their complex and dynamic nature, distinguishing them as intricate and evolved systems. Ghaemi and Hadji Hosseinlou [14] present arguments emphasizing that, in the context of transportation, understanding behaviours and designing effective solutions for optimal performance is a challenge due to these characteristics, which deviate from simple and linear relationships. Consequently, original and creative approaches become essential for their analysis. To address these challenges, it becomes essential to cultivate systems thinking, establish the limits of mental models, and utilize compatible tools capable of comprehensively understanding the structure and behaviour of complex urban freight transport systems. On the other hand, System Dynamics (SD) offers a comprehensive framework for analysing specific systems, fostering researchers' confidence in the generalization of the model across diverse contexts and conditions. By encapsulating the dynamics of real-world events within a specific system, SD allows observation of how various variables interact to produce specific results, thus facilitating comparisons between systems. However, to ensure reliability, such models must be validated using real data specific to each system under consideration.

METHODOLOGY

The work presented was carried out in three stages. First, the objectives from each group of stakeholders were extracted from a qualitative analysis of focus groups transcriptions, together with possible decision variables, aligned with existing literature. Second, with the results from the qualitative analysis, four causal loop diagrams were developed, representing the four main objectives identified. Finally, we mapped the relations of the stakeholders in the ecosystem represented in an actor-to-actor map and propose a Power-Interest Grid.

Regarding the first stage, a total of five sessions were analysed: two from Portuguese regulators, and three from road operators. The analysis was performed using *NVivo* software, where transcriptions are categorized by stakeholders and subjected to coding. Codes help identifying possible variables such number of drivers, shift duration, and fuel savings, with relevant excerpts allocated accordingly. Additionally, a word count was performed to identify key recurrent terms during discussions, resulting in a word cloud that displays variables emerging from both groups.

To complement the analysis from the focus group, a scoping review was performed targeting leading industry manufacturers (OEMs) aiming to capture press releases and news articles that explored their perspective on TP investments. Companies such as Volvo, DAF, Daimler, Iveco, MAN, Scania, and Ford Otosan were included. Furthermore, the current developments of TP are brought to the discussion by examining information related to projects like Ensemble, European Truck Platooning Challenge, Sweden 4 Platooning, and the Electronic Drawbar – Digital Innovation (EDDI).

For the development of the System Dynamics model, four causal loops were designed – one for each objective identified previously. The causal loops were built by connecting the variables found in the analysis, and adding more variables as needed. The analysis of the diagrams showed what actions can accelerate the deployment of truck platooning. By mapping the actors and their roles in the ecosystem, we have identified the key actions each actor can assume to not hinder the process. This is demonstrated in a Power-Interest Grid, where we placed the actors, representing their position towards the new technology.

RESULTS

Focus groups outputs: objectives and variables

The objective of the qualitative analysis was to extract the objectives of each group of actors and the possible variables. The objectives are considered objective functions that can be minimized or maximized, but cannot be directly act upon, while the variables are related to decisions to be made by the decision-makers. For instance, the regulator can impose a lower limit to the gap between vehicles, influencing safety and fuel consumption in opposite ways.

First, we defined a set of four objectives, associated with the main dimensions impacted by the introduction of the technology: safety, environment, costs, operations, and labour. The objectives were defined as the following:

1. higher fuel savings (or lower emissions from lower fuel consumption).
2. lower number of road crashes;
3. better working conditions;
4. and lower operational costs.

Then, from with the literature and the analysis of word frequency from the focus groups transcriptions, a set of 14 variables was selected (Table 1). Note that one variable can appear more than once, if more than one group can decide on it (e.g., platoon length).

Table 1. Decision-makers and their decision variables.

	Regulators	Road operators	OEMs
1	Vehicle automation level	Number of lanes	V2V communications
2	Vehicles per platoon	Presence of dedicated lanes	V2X communications
3	Platoon length	Distance between exits	V2I communications
4	Distance between vehicles	V2X communications	
5	Number of drivers	V2I communications	
6	Drivers' training level	Platoon length	
7	Shift duration		
8	Mandatory resting periods		

Causal loop diagrams

To build the causal loop diagrams, the variables were linked to an objective. The link was established if there was a clear relation between a variation of the variable and a consequent variation in the objective. To start building the model, we first built individual feedback loops, totalling 21 loops (Figure 1). The causal loops were then grouped around the objectives to which they were related.

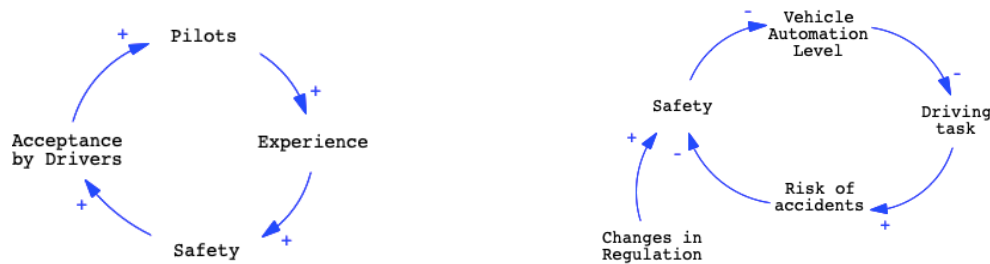


Figure 1. Examples of individuals causal loops.

Figure 2 presents the dynamics around the fuel savings objective. This objective was analysed together with the goal of lowering emissions. Since they are highly correlated, achieving one meant achieving the other, and the variables required are the same. The option of representing the model around fuel savings resulted from this being a positive perspective, thus required building positive loops.

At the centre of the diagram, we observe that manufacturers play the leading role of achieving this objective as investing in V2V will allow for shorter distances and in consequence, higher fuel savings. The model also demonstrates how other road users can be targeted since lowering emissions can increase the acceptance of the general public.

At a macro level, we had identified that regulators did not know the capabilities of the technology, hence they could not regulate accordingly. However, the scoping review on OEMs' investments showed that uncertain and unclear regulations were causing lower investments on research and development of this technology. Therefore, a change in regulation becomes the main external factor for pushing for new developments and breaking the loop between regulation and technology. This type of analysis was used to identify key actions and the stakeholders responsible for the external factors that can promote the deployment.

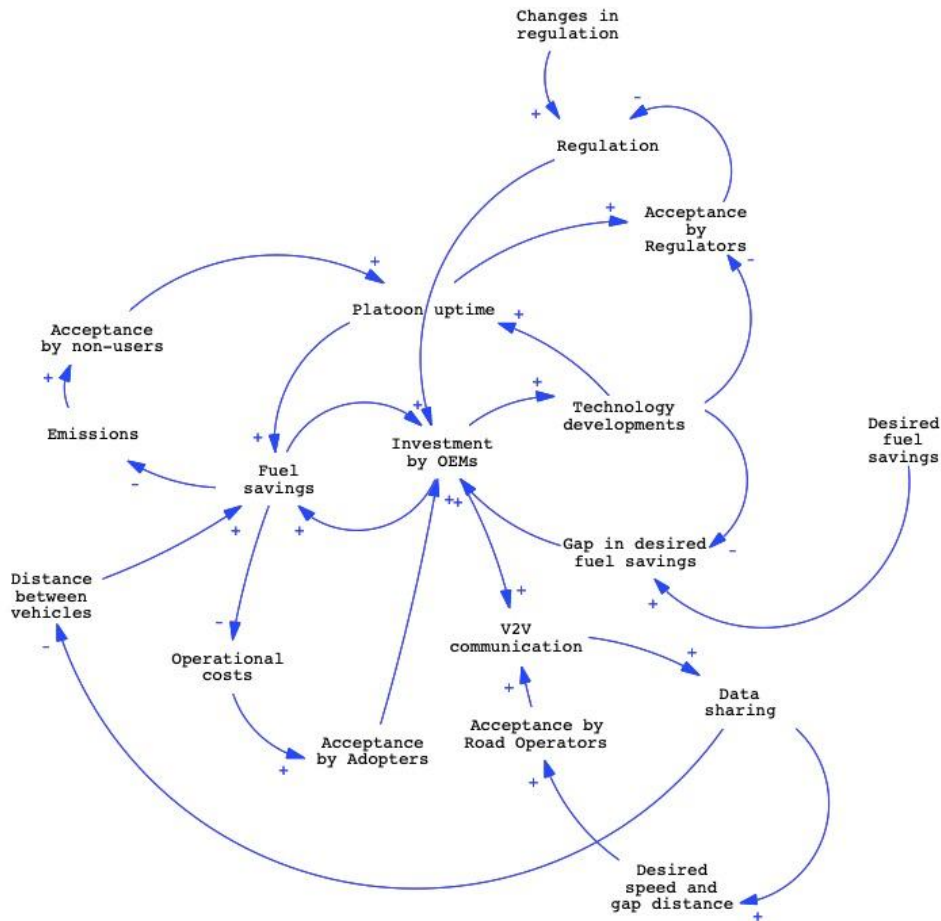


Figure 2. Fuel savings dynamics.

Power-Interest Grid

The Power-Interest Grid serves as a relevant tool for understanding the roles and influences of various stakeholders, helping to categorize stakeholders based on their level of power and interest regarding a particular issue or project.

Stakeholders are categorized into four groups: *players*, who have both high interest and high power; *subjects*, who have high interest but low power; *context setters*, who have high power but low interest; and the *crowd*, who have low interest and low power. In this work, we used an adapted version featuring key stakeholders, those to be kept satisfied, those to be kept informed, and those requiring minimum effort. To provide an overall view of the system we added drivers (users) and companies (adopters) to this analysis.

The main stakeholders studied in this work are all positioned in the right upper side of the grid Figure 3 as explained below.

1. **Regulators (High Power, High Interest)** are the ones capable of approve and enforce a regulatory framework with limits to labour, requirements for safety and environment. Their strategic positioning in the grid means they are key players whose decisions directly influence the feasibility and safety of TP.
2. **Road Operators (Moderate Power, High Interest)** are responsible for providing upgraded and well-maintained infrastructure where TP can be operated. While they have a high interest for reducing congestion and improving safety, their power is limited to

the infrastructure and depend on the regulations set and on the operations of freight transport.

- OEMs (High Power, High Interest)** advance technology, preparing vehicles for real-world usage. They have the second most power as they install driving systems that make platooning possible but are limited by regulations. They are highly interested in developing this technology, not only for business reasons but for research as well.

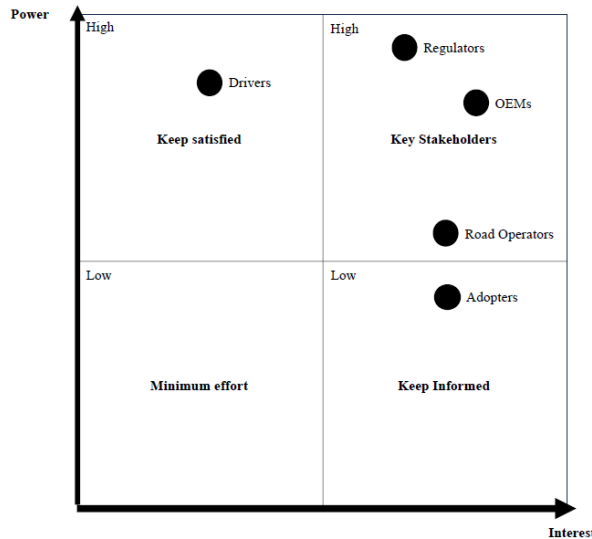


Figure 3. Power-interest grid analysis

The adopters mentioned in the image represent freight transport companies such as carriers and third-party logistics. Their position in the low-power, high interest region is justified by their dependence on market ready vehicles and labour regulations. The only power they have is related to vehicle acquisition and transport operations. As for their interest, they are eager to use any technology that grants lower operational costs and improves efficiency. Finally, drivers were assigned a higher position in the power axis since they can reject technology usage. For that reason, we believe drivers' acceptance must be guaranteed before deployment, hence the need to "keep them satisfied".

CONCLUSIONS

The adoption of a systemic approach to the freight transport ecosystem provides an overview of possible barriers to the deployment of the technology, helping decision-makers in strategically planning the next steps in an integrated way, targeting the different stakeholders' groups. This systemic approach was implemented using system dynamics models through causal loops analysis. The causal loops were developed using the decision-makers objectives as a starting point and the decision variables were added to the loop to map their influence in achieving each objective. By employing a S-D Logic the works emphasizes the value co-creation between stakeholders (regulators, road operators, etc.) and highlighted the interdependencies between them. The objectives set encompassed four dimensions of the ecosystem (emissions, safety, labour, and operations), differing in importance according to the role of the stakeholders.

Together with the power-grid proposed, the causal loops provide an overview of possible actions to be taken from the key stakeholders in order "break the loop" and promote the deployment of the technology. In sum, the main contribution of this study answers the question

“who goes first?”, suggesting who should take the lead in creating the conditions for deployment.

Namely, it was observed that OEMs are called to mature technology, followed by regulators to change on traffic regulations allowing for pilot tests, and after ensuring regulatory updates labour and operations in platooning systems. Only after can the road operators work with OEMs in preparing the network with V2N communications. At the end, companies will follow by developing new business models. An important note is to be made about the role of regulators, and even if the technology is mature, companies will not innovate on business models if labour regulations do not change.

Moreover, by integrating system dynamic tools with service science principles, we contribute with an innovative methodology in the field of freight transport, providing a deeper understanding of stakeholders' connections.

By offering a structured perspective of the next steps towards deployment, this work also presents the ground for future research, such as the analysis of new business models that allow for horizontal collaboration between carriers in order to share platooning benefits and the impact of large platoons on traffic management.

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