A Systems Thinking approach to the analysis of economic impacts related to transportation shutdowns: the ATTACS project

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Abstract

Closing down a transportation system for one or more days due to a potential terrorist attack is not a measure that decision-makers tend to take lightly. However, despite its importance, the EU currently has no common framework or an organization, to deal with such issues in the transportation sector. The ATTACS project aims at providing a tool that will help decision-makers to evaluate the effects (direct and indirect and under economic terms) of a public transportation system closedown. The aim of this paper is to present an initial qualitative mapping of those effects. The approach that will be used is System Dynamics, since it offers a lot of advantages in comparison to other methodologies. The ATTACS project will account for effects in different sectors (transportation, economy, business and the public), across different time horizons (short- and long-term), across different spatial dimensions and for different types of events (terrorist attacks and terrorist threats). The provided CLDs are an initial evaluation of those effects and how they are (or might be) related. They will serve as an initial framework and will be validated and expanded in Group Model Building sessions with experts. The final objective of the ATTACS project is to create a Decision Support System that will facilitate decision-makers to reach better decisions on a subject that cannot be easily specified in advance, can change rapidly and its effects can be cascading and of great magnitude.

Keywords: System Dynamics, transportation system, Causal Loop Diagram, ATTACS, qualitative mapping

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1. Introduction

Transportation infrastructure is a crucial lifeline for society. Dependence on the transportation sector is increasing, thus growing the demand for travel for an urban population that is increasing (Miller-Hooks, Zhang, & Faturechi, 2012). The significance of the transportation sector is not only in the services it provides, but also in the positive influences it renders in other economic activities (Abbas, 1990). Its efficiency is based on an open and accessible design. However, this design is also the sector's biggest vulnerability, since it allows for disruptive (natural or man-made) events to affect its operations and produce domino effects (intentionally or not) to the society (Miller-Hooks, Zhang, & Faturechi, 2012) and to the inter-connected critical infrastructures (Cavallini, et al., 2014).

Surface public transportation is considered the most vulnerable, since apart from its open access points, it also accounts for a very large amount of users during peak hours (Rohlich, Haas, & Edwards, 2010). Reduction in demand due to a disruptive event, depends on how governments, media and the general public react to, for example, a potential terrorist attack: even an unsuccessful one, could generate similar reactions from the public, resulting in image losses and related business. For those reasons, closing partially a transportation system for one or more days is not a measure that decision-makers tend to take lightly (Lave & Apt, 2006).

Nonetheless, there is currently a lack of legal basis for a European Union action as well as a lack of an institution (similar to the International Civil Aviation Organization), which could deal with such an issue. However, the significance of public transportation security and the effects it could generate if impacted by natural events, attacks or normal disruptions, is ever increasing. As a testament to the fact, the EU has funded a large number of projects the previous years (an indicative list can be found in the Appendix) that address the specific issues.

In this context, the ATTACS project (*Assessing the economic impacts of **T**errorist **T**hreats or **A**ttacks following the **C**lose down of public transportation **S**ystems*) aims to create a simulation tool that will facilitate decision-makers to evaluate the effects (direct and indirect and under economic terms) of a public transportation system closedown. The aim of this paper is to provide an initial qualitative mapping of those relevant effects, based on a multidisciplinary research on:

- Structure and functioning of the urban transportation system
- Impacts of public transportation shutdown
- Existing transportation models

The rest of this paper is organized as follows: Section 2 provides a literature review of the use of System Dynamics on transportation systems. Section 3 describes the effects of transportation system close-down with the use of a Causal Loop Diagrams, while in Section 4 some conclusions are presented.

2. Literature Review

Transportation systems are inherently complex; they consist of different modes that interact with each other and with their surrounding environment. The human aspect is also significant for transportation systems, since the individual choices are those that determine demand for a specific mode of transportation, and thus the system's structure and function. Moreover, from a strategic point of view, decision-making with regards to transportation systems, is dynamic; it requires more than one decisions, decisions are interdependent and the environment changes over time (either as a result of the decision or regardless of the decision or both) (Edwards, 1962).

Thus, the methodology to be used in order to investigate and understand the effects that a transportation system shutdown will have, must offer the possibility to model complex relationships of complex components in a dynamic environment. System Dynamics (SD) offers a number of advantages for modeling transportation systems:

- SD can model large and complex systems, especially in terms of their structure
- Nonlinearities, delays and feedback loops are incorporated in the models (Abbas & Bell, 1994)
- It offers an increased insight from a strategic point of view
- It can be used to test policies and what-if analyses in a safe environment (Abbas, 1990)

More specifically for the transportation sector:

- Socio-economics and demographic indicators are included in the model and are not external variables
- Aspects that are not easily parameterized, can be accounted for
- The holistic view it offers is easy to communicate and non-experts can use the models easily.

The ATTACS project will adopt a holistic view of an urban environment- with the transportations system at its core- with the purpose of investigating the effects that a transportation system close-down would have in that urban environment. As such, the ATTACS project must account for different aspects of that environment (for example, the transportation system and the business sector), must connect components with different notions (economic terms with the functionality of the transportation system), account for aspects that are not easily quantifiable (for example, human behavior and how it shapes the demand for transportation) and finally the entire effort must be communicated to non-experts and decision-makers. For those reasons, the System Dynamics methodology seems appropriate for the ATTACS project.

Before moving to the main body of the analysis, a literature review was performed on how System Dynamics has been used to model the transportation sector. This review will serve as the basis for the (future) development of the quantitative model of the ATTACS project.

For a more comprehensive approach on the usefulness of SD in modelling transportation systems, the reader is referred to the work performed by Abbas and Bell (1994), who created a survey on how SD has been used in modeling transportation systems in relation to:

- Studying the long-term effects that the structure of the transportation system could have to its own function and to the environment
- Forecasting economic, trip-forecasting scenarios
- Modeling the interaction between transportation and land use

One of the first attempts to explicitly model a transportation system with SD was performed by Scaeffer and Sclar (1975). Their attempt was focused on exploring the relationship between a transportation system and the evolution of its structure.

Jifeng et al. (2008) proposed a model to simulate the urban transportation system and analyze the external forces that influence it. Their conceptualization of the relationships and behavior of the transportation system is shown in Figure 1.

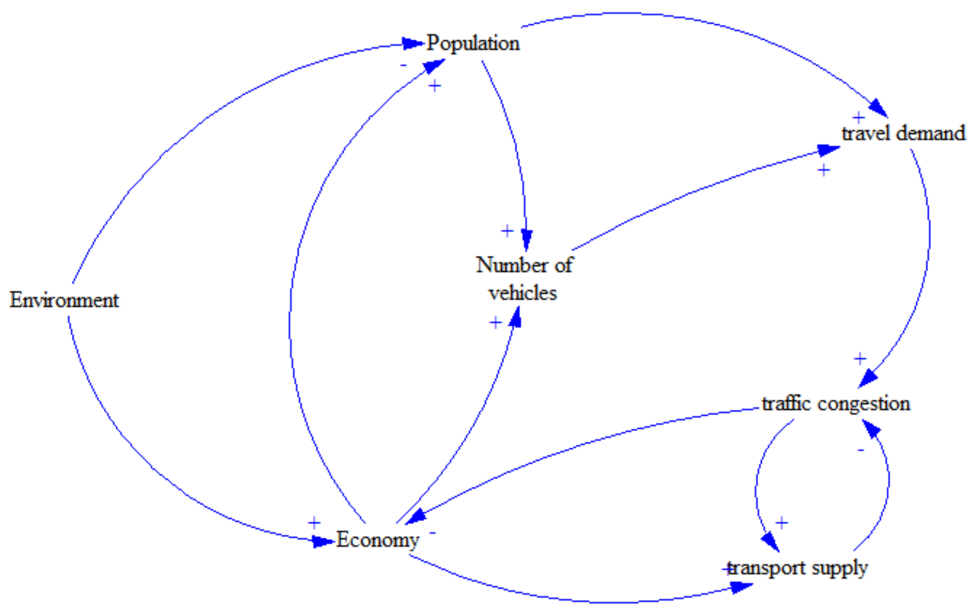

Figure 1 Conceptualization of transportation system according to Jifeng et al. (2008)

Raux (2003) combined SD and econometric models and designed a travel demand sub-model, which deals explicitly with trip generation by purpose, time of day, origin and destination. A more detailed analysis of passengers' behavior was conducted by Chao-Zishan (2013) for the Shanghai transportation system. In this study, the different means of transportation were separated by type and the authors investigated the effects of passenger behaviour on roads, traffic flows etc. A more multi-method approach was used by (Springael, Kunsch, & Brans, 2002), who combined SD with multi-criteria decision analysis to model the traffic crowding in cities.

Armah et al. (2010) dealt more specifically, with the effects of traffic congestion on the environment (air pollution). Finally, Sivilevicious (2011) composed a general Transport system and a list of criteria for transport classification. Six levels of interactions were distinguished:

- Interaction of transport elements with their own internal parts
- Interaction among the elements

- Interactions with the external environment
- Interaction of transportation modes
- Interaction of the transportation system with the economy and the non-productive sector
- Impact of the transportation sector on a country's Gross Added Value.

A recent issue of the *System Dynamics Review (2010 Volume 26 Number 3)* offered the latest developments of the use of SD on transportation modeling (Shepherd & Emberger, 2010); (Bivona & Montemaggiore, 2010); (Fallah-Fini, Rahmandad, Triantis, & de la Garza, 2010); (Walther, Wansart, Kieckhafer, Schhnieder, & Spengler, 2010); (Pfaffenbichler, Emberger, & Shepherd, 2010); (Fiorello, Fermi, & Bielanska, 2010).

One recent research project (funded by the EU) that made use of many of the above contributions of SD to transportation modeling, is the CRISADMIN project. The CRISADMIN project took into account the first four levels of interaction, as described by (Silevicius, 2011) and the basic structures and logic of the papers described thus far, and incorporated them into a greater context, where the transportation system was only one part of the interdependent critical infrastructures. The purpose of the project was to investigate those interdependencies in the face of a critical event (flooding and bombing attack) (Cavallini, et al., 2014).

The ATTACS project is a conceptual continuation of the CRISADMIN project. The CRISADMIN project demonstrated that the transportation system is extremely important for the other critical infrastructures (Cavallini, et al., 2014), however its scope did not include the importance of the transportation sector for the rest of the urban environment- with special attention to economic effects. The ATTACS project as a continuation of the CRISADMIN project, will focus solely on the transportation sector and on the effects that a close-down will have on the entire urban environment, thus addressing the latest two of the levels by (Silevicius, 2011).

Finally, the two projects will serve as a comprehensive study of the Critical Infrastructures –with a focus on the transportation sector- their interdependencies and their interactions with the urban environment. Thus, decision-makers can utilize the two projects in order to reach better decisions in the face of complexity, uncertainty and unintended consequences.

3. Causal Loop Diagram

In the context of the ATTACS project, the transportation system will serve as a basis to study the effects that its potential close-down (due to a terrorist attack or just in presence of a threat of it), partially or entirely, will cause on the urban environment. The effects of such a disruption can play out quickly and over long periods of time. Immediate effects are visible, but long-term effects are more difficult to trace. However, creating models to study both is very important to decision-makers because:

- Models of short-term effects help decision-makers to prepare and improve countermeasures and contingency plans

- Models of long-term effects provide a way to evaluate policies that might be beneficial in the short-term, but have counterintuitive/undesirable effects in the long run (Brown, 2007).

The situation becomes even more complex due to the fact that the ATTACS project must study the effects of a transportation system close-down of an attack or a threat of one. To tackle those issues the ATTACS approach will be manifold:

- It will account for different time horizons to study both the short- and the long-term effects
- It will account for both a threat and an actual attack.

Despite the complexity of the various inputs/structures of the model, a qualitative mapping/CLD offers a basic framework for understanding and structuring the problem. The general conceptualization of the system is presented in Figure 2, below:

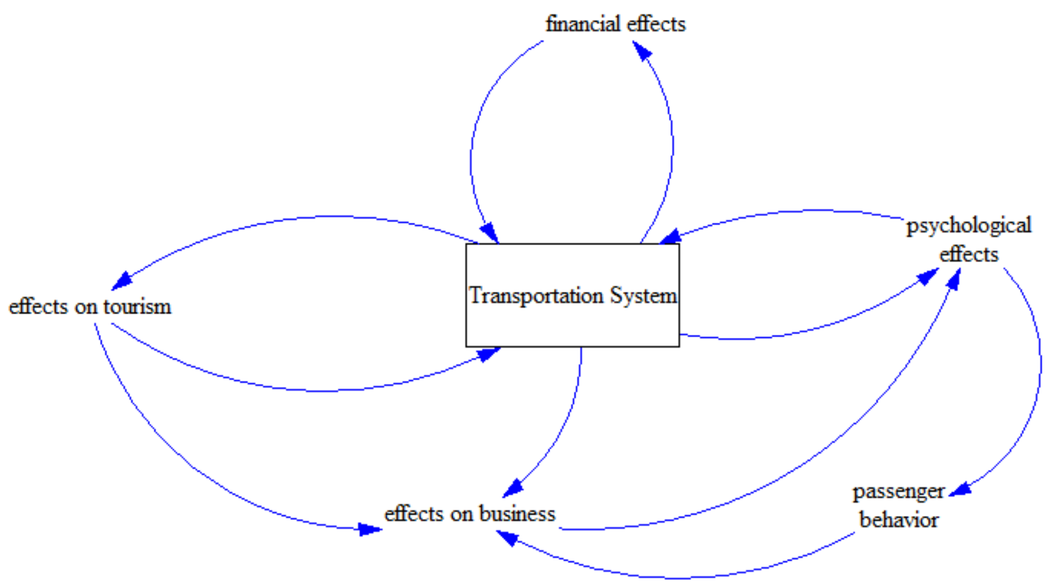

Figure 2 Conceptual map of the ATTACS project

A closed-down transportation system will, firstly, change the state of the system itself. New routes and means of transport will be sought. This effect will be more permanent in the long-run especially if the attack effectively occurs. The new state of the (specific) transportation system will affect its finances. The revenues – for example, in the form of sold tickets - will be reduced and, in the case of an attack, there will be extra losses such as property loss, constant loss of revenues (due to demand of passengers for other means of transportation) and costs related to new security measures.

The state of the transportation system will change because the passengers' behavior will also change and vice versa. Passengers will in fact search for different means of transport and if the attack occurs their trust towards the system that was hit will diminish, in turn severely affecting the demand for that particular mean of transportation.

Moreover, effects on the businesses of the urban environment will be considered. A change in the state of the transportation system will for example be able to affect delivery times, workforce scheduling, wages of the employees etc. In the case of an effective terrorist attack, and not just a threat, there will also be an effect on the tourism demand. An actualterrorist attack is in fact usually a sufficient deterrent for tourists to visit the specific urban environment.

Of course we plan to account also for those ripple effects that do not originate from the transportation system itself. A change in the transportation routine of, e.g., commuters (people who travel for work) might affect their productivity, thus affecting the operations of business. Moreover, a decline in the number of tourists will also have an effect, through for example the reduction of sales, which in turn might cause a feedback effect on commuters (layoffs, reduced wages etc.). Consequently, the behavior of passengers changes once more, thus affecting the state of the transportation system and its finances.

In the beginning of this section, the approach that will be used in the ATTACS project was described. It is now important to add another element: the effects - that were just quickly described - will differ in different zones of the urban environment. For example, they will be different in the part of the city, where more nodes of urban transportation are concentrated, rather than in the outskirts. As a result, the ATTACS model will also try addressing the spatial nature of these effects.

In the following sub-sections, the general CLD developed so far (see Figure 2) will be expanded and explained in more detail.

3.1 The transportation system

The closing down of a particular transportation system/mean will result in a decline in the service level and a loss of credibility for the specific system. Moreover, the credibility of the specific system will further decline due to the decline of the service level. The service level and credibility will be considered among the most important factors for determining the attractiveness of different transportation modes. Thus, the attractiveness of other means will increase-since service level and credibility are declining. For example, it has been observed that during strikes in the public transportation system, an increased demand for taxi services occurs (Anderson, 2013); (Blumstein & Miller, 1983).

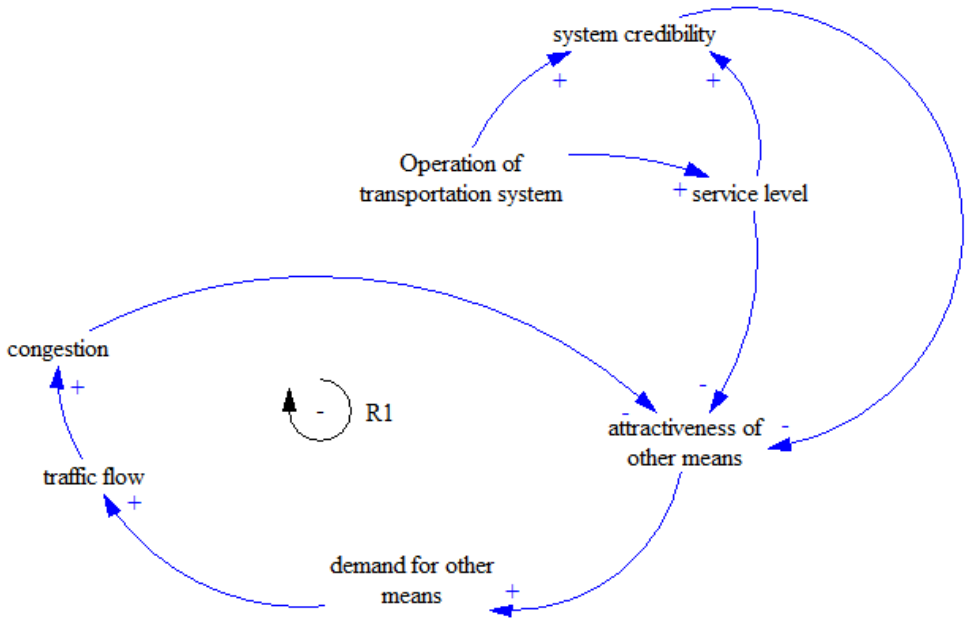

Figure 3 Causal Loop Diagram of the transportation system

It is important to note that choosing different modes of transportation means a change in traffic patterns. This will increase the traffic flow, thus in turn increasing the possibilities of congestion (congestion could mean either traffic congestion due to the larger number of circulating vehicles or passenger congestion in the metro stations for example, if a central road is closed down). Thus, the negative loop is closing, driving the system to a new equilibrium. In the case of a terrorist attack, the effects will be more severe and in the long-term the changes in travel patterns will be permanent (Ito & Lee, 2005); (vanExel & Rietveld, 2001).

3.2 Financial effects on the transportation system

The attractiveness for other means of transportation will result in decreased revenues for the transportation system/mean that was closed-down, while in the already standard costs of that system/mean, other costs are added. In the long-term and in the case of an actual attack, the situation becomes more complex. Apart from the fact that the aforementioned effects will be permanent, extra pressure will be applied by damage repairs, loss of property value and the cost of extra security measures.

The extra costs combined with a permanent decrease in the system's credibility imply that the profits would be severely affected. As a result, the cost of transportation for passengers related to the specific mean will be increased, which would have an effect on its attractiveness. Finally, the permanent change in travel patterns could have an effect on the environment - especially in the case of an increased number of circulating vehicles - due to an increased emission of air pollutants (Armah, Yawson, & Pappoe, 2010).

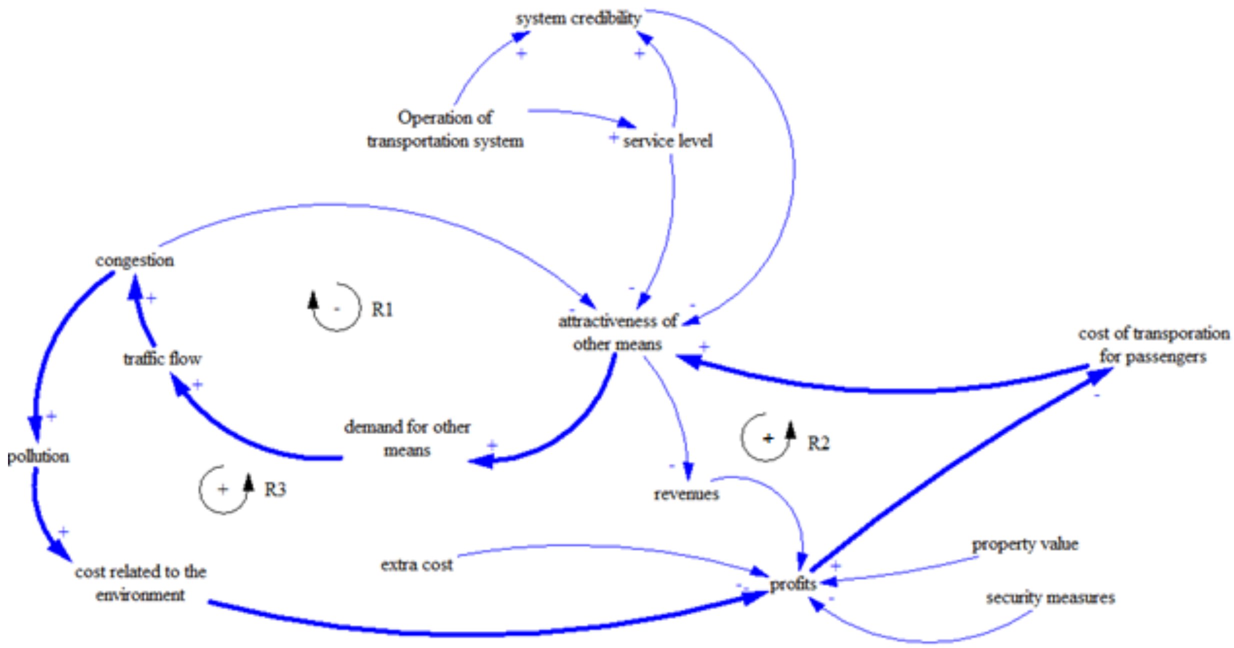

Figure 4 CLD for the finances of the close-down transportation system

Two more loops are affecting the attractiveness of other means of transportation: the loop R2, which increases the attractiveness as the cost of transportation (of the close-down system) for passengers is increasing; and the positive loop R3 (thick blue line in Figure 4), which reinforces the attractiveness of other means of transportation through congestion and the reduction of profits.

3.3 Effects on business

As it was stated before in this document, a close-down will result in a change of the travel patterns of passengers. Those passengers are divided into two types:

- Passengers who travel for/to work
- Passengers who travel for leisure

Thus, an increased congestion will affect businesses in three ways:

- Increased delay times (for the delivery of raw materials to production and the delivery of end-products to consumers)
- Changes in the work scheduling because of the delays of employees
- Changes in sales/services because of the delay of leisure passengers (Gordon & Richardson, 2008).

It should be stated that the spatial dimension is very important for these effects (Minegishi & Thiel, 2000); (Özbayrak, Papadopoulou, & Akgun, 2007). In the long-run, there will be extra costs because of additional drivers and trucks for longer travel times, increased number of "rescue drivers" used to avoid missed deliveries (due to unexpected delays), productivity changes, and reduced market accessibility.

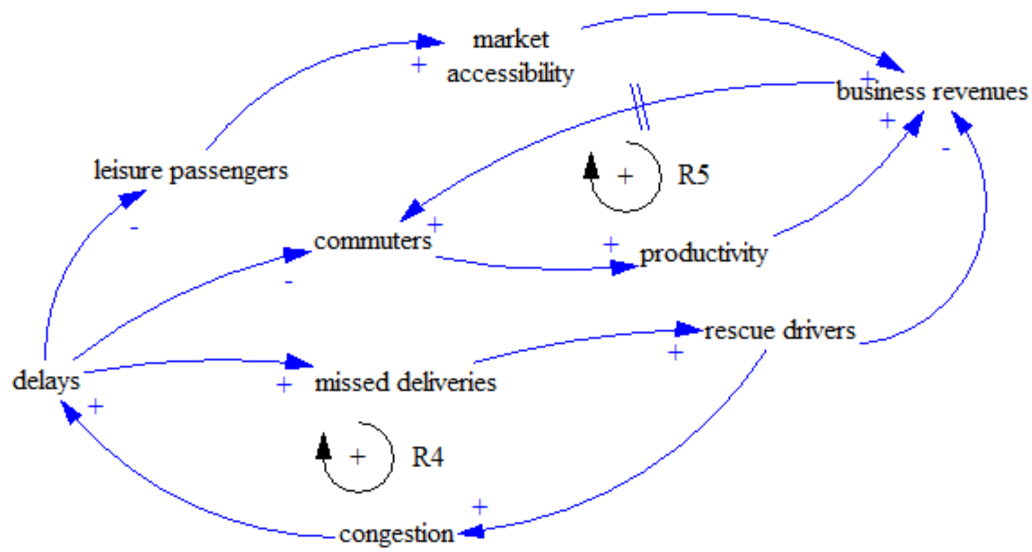

Figure 5 CLD of the effects on business

Thus, two positive loops are created in the business side of the model (R4 and R5). The importance of those loops and hence, the impact on the business sector will be more prominent in the long-run and if the attack occurs.

3.4 Psychological effects and effects on tourism

The close-down of the transportation system will result in a change in the patterns of everyday travel. This might be just inconvenient if it happens only once, but repetitive close-downs or a terrorist attack affect the psychology of the passengers, which in turn can have consequences in the entire system (as a consequence, this section is more focused on the long-term and in the case of a terrorist attack).

An effect that can be observed both in the short- and the long-term is a reduced trust in the system that was closed down and/or hit and an increased attractiveness for other means of transportation. Thus, this part of the psychological effects has already been include in the CLD of Figure 3.

In the event of terrorist attack however, the psychological effects are more severe. The stock of fear increases, which has cumulative effects on several parts:

- People show an overly risk-averse behavior, affecting their consumption patterns and thus the operations of business
- Increased stress, which leads to repeated absenteeism from work, thus creating an extra (and sometimes secret) cost for businesses (London Chamber of Commerce and Industry, 2005); (Mueller & Stewart, 2011). Hence, loop R4 is amplified.

- In the transportation system in general, a decline of demand will be observed. Especially for the mean that was hit by the attack, the decline will be more severe (and extended). Thus, it can be stated that in the long run, the accumulated fear will lead passengers to other means of transportation.

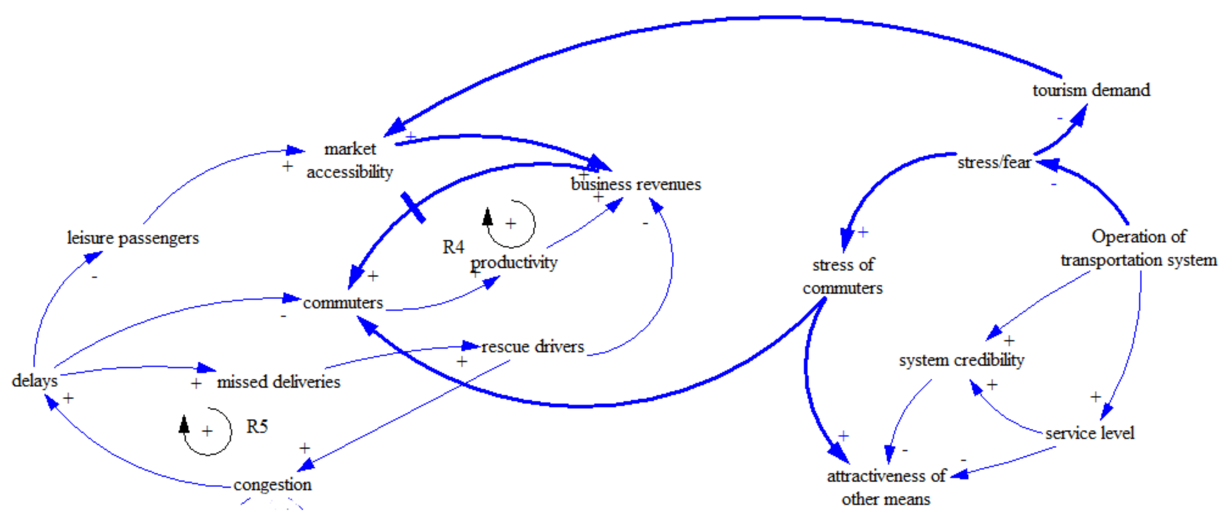

Figure 6 CLD of psychological effects and effects on tourism

The psychological effects and the effects on tourism, although represented with only three new variables, they affected every loop that has been created so far. That is the reason that it was decided to include those effects in the ATTACS projects; not easily quantifiable aspects can have great (economic) effects.

3.5 Concluding remarks

The qualitative nature and generality of the causal-loop diagrams do not diminish their value (the full CLD can be found in the Appendix). It will serve as a tool for framing and understanding the problems under study as well as for the development of quantitative simulation models that will support in evaluating the effects (direct and indirect) of a transportation system close-down due to a terrorist attack or a threat of one. The simulation model will allow an analysis that escapes the narrow scope of a cost-benefit or a statistical analysis – which have been widely used – in this field. Moreover, the investigation of the effects will run across several sectors, across different time horizons and different critical events (threat of a terrorist attack and an actual attack).

A Group Model Building Session was held on the 9th of June, 2015 in Rome. The purpose of the session was to gain insights from the knowledge and experience of experts in the fields of transportation, security and terrorism and System Dynamics.

In the session, the experts validated the CLDs described thus far, and also provided more details to clarify several notions in the process. First, several variable names were clarified and updated to capture more clearly their meaning. For example, the term "Operation of transportation system" was one of the central variables in the original CLD and its purpose was to capture the notion of a specific transportation system's closedown. However, it was deemed necessary to change the name to "Capacity of specific transportation system". That way, if an attack occurs – for example - the capacity will be reduced.

Furthermore, the effects of the closedown to the tourism industry were mapped more clearly. As a result, Figure 6 was updated and became more detailed in the tourism section.

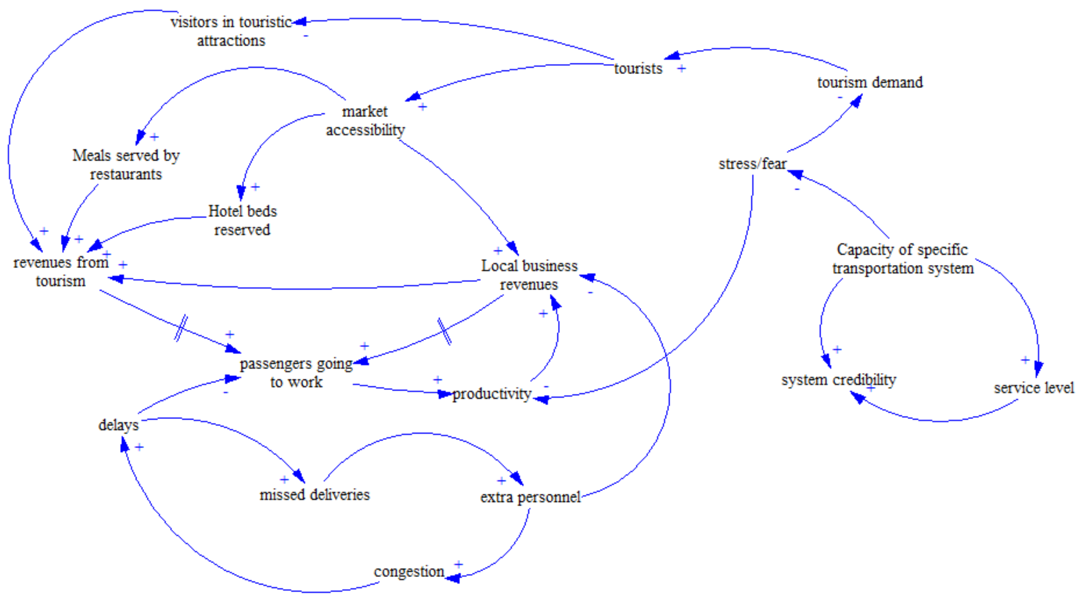

Figure 7 Expanded CLD of the tourism industry

The level of fear in the environment due to an attack (or even the threat of one) will reduce the number of tourists. Less tourists means less revenues from the tourism industry because of the reduced sold tickets to attractions (museums etc.), less revenues for the hotel and entertainment industry. Consequently, less revenues for the industry will result in fewer employees going to work (after a delay).

Moreover, the delays due to congestion will result in missed deliveries for the business sector, which will increase the number of extra personnel needed to meet the missed deliveries (like "rescue drivers"). However, the extra personnel will add to the congestion level, which closes the loop by increasing the delays.

Finally, a recommendation was made by the experts to increase the level of detail for the health sector. Healthcare expenditures will increase due to deaths and injuries because of the attack, injuries from accidents due to the increased flows and congestion and with a delay, expenditures due to the problems created by the increased pollution.

The overall CLD is presented in the Appendix.

4. Conclusions and next steps

The importance of the transportation sector, for both providing services and stimulating the economy, has moved front and centre in the interest of decision-makers in Europe. The ATTACS project aims at addressing this issue and more specifically at assessing the consequences that a close-down of a transportation system - due to a terrorist attack or a threat of one - could have. The methodology that will be used is System Dynamics, which offers many advantages.

It can account for nonlinearities, feedback loops and time delays. Moreover, it can be used to model different time horizons, both short- and long-term, while aspects of human behavior that are not easily quantifiable can be included in the model. Finally, System Dynamics allows for easier communication and use for and by non-experts

As a result, a numbers of attempts –in the form of research papers and projects – have used System Dynamics to model transportation systems. The ATTACS project will use this research as a basis for modeling the transportation system itself.

Furthermore, a manifold approach will be used:

- Different time horizons (both short- and long-term) will be considered
- Both a terrorist attack and a threat of one will be taken into account
- The spatial dimension on the system will be taken explicitly into account.

The effects that will be studied run across several sectors: on the transportation system itself, on its finances, on the business sector, on the passengers' psychology and behaviour and finally on tourism. The qualitative mapping and CLD of the effects that have been described will serve as a framework for the development of several small models. Hence, the research about transportation, security and effects of terrorism will escape the narrow scope of a cost-benefit or a statistical analysis - which have been widely used on the subject - and provide a more general view of the entire system. The final objective/aim of the ATTACS project is to facilitate decision-makers into gaining increased insights into the transportation system and its importance and to test for policies and countermeasures across different types of events, time horizons and sectors.

The CLDs were validated and expanded in a Group Model Building Session with experts from various fields related to the project.

Subsequently, the quantitative models will be developed, tested and various policies will be designed and simulated – again with the help and contribution of experts. The final objective of the project will be to develop a Decision Support System that will allow decision-makers to gain insights into the inter-dependencies of the transportation system, on how passengers react to crises and the role of communication and information technologies. Having a better understanding of those issues will help decision-makers to design and implement better policies, hence be more prepared in a time of crisis. Finally, the Decision Support System itself can serve as a new tool for governance issues and model-based decision-making.

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Appendix

A list of the funded by the EU projects related to the issue of transportation security

Table 17FP funded projects on Land and Maritime transport security

Acronym	EU financial contribution	Project total cost
ARCHIMEDES	1.353.848 €	1.534.245€
CASSANDRA	9.958.749€	4.813.514€
CONTAIN	10.044.904€	15.600.818€
DEMASST	956.558€	1.840.549€
IMCOSEC	930.718€	1.142.591€
ISTIMES	3.113.460€	4.367.950€
LOGSEC	753.372€	800.047€
PROTECTRAIL	13.115.064€	21.775.289€
SECTRONIC	4.496.106€	6.948.326€
SECUR-ED	25.468.072	40.187.354€
SERON	2.246.110€	2.942.113€
STAR-TRANS	2.105.588€	3.195.188€
SUPPORT	9.920.607€	14.629.279€
Total	**83.109.310€**	**128.243.024€**

The overall CLD with all the sectors included, is presented in Figure 8 below:

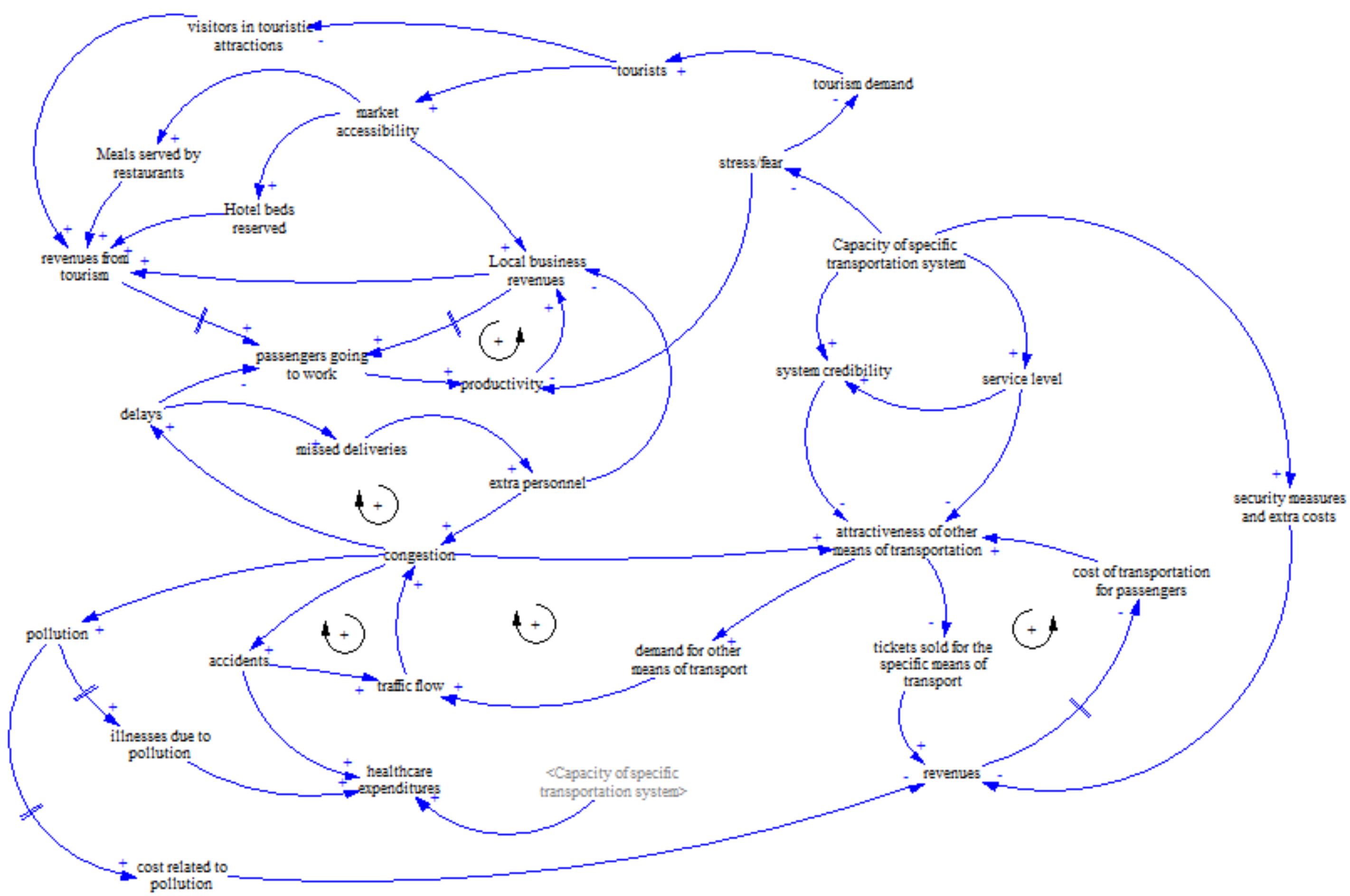

Figure 8 General CLD with all the sectors included