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Total safety by design: Increased safety and operability of supply chain of inland terminals for containers with dangerous goods

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ABSTRACT

In recent years, there has been a considerable increase in the international transport of containers with dangerous goods, increasing the risk of seaports and surrounding cities together with the introduction of inherent environmental and security disaster risks. Therefore, there is an increasing interest in seaports that are more socially inclusive, addressing the storage of containers of hazardous goods to safe inland terminals. An appropriate design of inland terminals for containers with dangerous goods (ITDGs) may contribute to the achievement of a sustainable development and the minimization of risks, avoiding disasters such as Tianjin. The objective of this study was the analysis of the criteria used for the design of safe, secure, cost efficient and greener ITDGs by applying the multicriteria decision theory AHP (analytic hierarchy process). Criteria regarding safety and security, environmental care, productivity and information and communication technologies (ICT) have been considered simultaneously into a total performance management system.

1. Introduction

Inland terminals for containers with dangerous goods (ITDGs) are suggested to resolve some of the current drawbacks related to seaport or river port facilities in a seamless supply chain. The social vulnerability of the surrounding areas involves the "physical" impact of an event where people are located and the ability for key institutions to respond and manage the event effectively to cause minimal disruption to exposed communities (Nogal et al., 2016). Vulnerability is related to the sensible geographic location of these facilities with respect to environmental, safety and security risks (Ambrosino and Sciomachen, 2012). The use of ITDGs as multimodal facilities allows seaport social inclusion in cities, making them safer facilities. Moreover, traffic jams and congestion in cities due to port activities may be relieved to some extent.

The sales of chemical products produced in the European market from 2003 to 2013 increased from 1326 trillion euros to 3156 trillion euros (CEFIC, 2015). As a consequence, statistics indicate that the traffic of dangerous goods transported in containers is increasing to record levels by the different methods of transport (road, railway, maritime transport over short distances and inland waterway transport). Dangerous goods are products such as materials, including bulk substances and packed ones, that have the properties indicated in the IMDG code (IMDG 37-14) or ADR code (UNECE, 2015), as well as any other substance that may constitute a threat to the security in the port area or its vicinity and require special treatment. Thus, the storage requirements of dangerous goods at seaports should consider not only the safety and environmental issues but also the high social impact. The increasing demands of the decongestion of the seaports and the cities where they are located (Wiegmans and Louw, 2011) require innovation and studies of the technologies and processes involved in the supply chain of containers with dangerous goods. The development of seaport–dry port dyads plays a key role (Bask et al., 2014), and the promotion of intermodal freight transport through dry ports has attracted increasing interest (Hanaoka and Regmi, 2011; Clott and Hartman, 2016), giving room to the port regionalization concept (Monios and Wilmsmeier, 2012).

Unfortunately, the risks associated with hazardous materials have not been completely avoided by means of intermodal dry port solutions. Those risks are associated with drayage to a significant extent, and current research lines address this topic (Romero et al., 2016). These efforts are also reflected in European policies (MT, 2015) committing to the development of solutions for

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sustainable transport and trying to reduce the road transport of those goods by means of synchromodal transport (Zhang and Pel, 2016). In a complementary way, the risks associated with ITDGs should also be minimised, achieving infrastructures and networks more resilient to extreme events (Axelsen et al., 2016; Zhang et al., 2015), consequences of climate change (EEA, 2014), terrorist attacks (Argenti et al., 2015) or accidents as Tianjin (Huang and Zhang, in press). For instance, 1400 sudden leakage accidents occurred in China from 2006 to 2011 in dangerous goods handling and storage facilities (Li et al., 2014). 13% of the major fire accidents that occurred in the USA also happened in storage facilities (Badger, 2010). In the context of infrastructure systems, resilience can be defined as a function of the vulnerability of the system to potential disruption and its adaptive capacity in recovering to an acceptable level of service within a reasonable timeframe after being affected by disruption (Mansouri et al., 2010). Therefore, it is essential to integrate the vulnerability to extreme weather events and accidents into the decision making process involved in the design of logistically efficient multimodal facilities through identifying, analysing and prioritizing adaptation options (FHWA, 2012). On the other hand, as Lu and Yang reported (2010), greater safety leadership will lead to good safety behaviour and further reduce accident occurrences.

The design of ITDGs is a complex problem that must consider a variety of factors (Beresford et al., 2012) such as safety, protection against intruders, environmental concerns, equipment performance, costs, business intelligence (BI) and information and communications technology (ICT), while managers seek to achieve more inclusive terminals with less noise, lower emissions and lower risks during the process of management. We can find in the literature some publications focused on decision making methods for inland terminals, although the problem has thus far not been addressed comprehensively. There are papers considering the geographic location of an inland terminal (Portugal et al., 2011), the container-handling equipment (CHE) (Gambardella et al., 2001); plant distributions (Kim and Kim, 2002); the collection of follow-up information to prevent thefts of commodities (Tsai, 2006); reductions in the consumption of energy (He et al., 2015) and regarding procedures for the concession of port terminals to private operators (Monios and Bergqvist, 2015). Despite these pioneering works, the study of inland terminals still remains underdeveloped, at least in comparison with that on seaports. This can easily be verified in scientific databases of peer-reviewed scientific literature (Scopus, 2016).

Thus, there is a need to consider the problem of terminal design from a global point of view, especially for ITDGs. This paper focuses as a novelty on criteria to be considered in the design and management of safe ITDGs from a global point of view, taking in consideration the hazards inherent to dangerous goods. Consequently, the main aim of this investigation is to describe these relevant criteria and to prioritise them using the multicriteria decision theory. This purpose is aligned with the European policy that promotes methods of re-design and re-engineering adapted to new needs and ensures greater efficiency. The methods of design and innovative construction must be environmentally friendly, flexible and with low maintenance costs (EC, 2016). Research should try to address the emerging challenges of society. In that sense, we have considered criteria such as equipment reliability, flood risk, preventive measures and emergency response procedures that are directly aimed to achieve safer, greener and more efficient inland terminals for containers with dangerous goods (ITDGs).

1.1. Analytic hierarchy process (AHP)

To achieve the main purpose of our research, it is necessary to apply a suitable technique for the structuration and organization of the design procedures from the earliest stages of the project (Aragonés-Beltrán et al., 2014). Although we assume according to Bask et al. (2014) that there is no dry port solution that suits all needs, we take on the challenge of achieving a commitment situation that satisfies multiple requirements in a holistic way. The application of models based in cost-benefit analyses (CBA) for decision making processes for transport facilities could sometimes hinder the application of sustainable solutions (Flämig and Hesse, 2011) and criteria that may be introduced on the basis of multicriteria analysis (Cullinane et al., 2006; Palacio et al., in press). MultiCriteria Decision Analysis (MCDA) and Multicriteria Decision Making (MCDM) methods are especially useful techniques when several criteria ought to be considered to achieve a goal. The common aim of the diverse available techniques is to be able to evaluate and choose between alternatives based on a systematic analysis considering the limitations observed in group work decisions. The distinct methods vary in the method of evaluation of the criteria and the combination of results necessary to attain a general evaluation. Some techniques establish a ranking of criteria, others identify the best alternative, and others differentiate between acceptable and unacceptable alternatives (Linkov and Ramadan, 2004; Vaidya and Kumar, 2006). Specifically, we addressed the problem by applying the analytic hierarchy process (AHP) tool for decision making, proposed by Saaty for the first time in 1980 but continually updated (Saaty, 1980, 2013, 2016). One of the concrete advantages of the method is that it allows a criteria prioritisation, even for subjective criteria. In fact, rather than producing a precise decision, the AHP helps decision-makers find the solution that best fits their objective and their knowledge. AHP instruments provide a structured analysis for the design of ITDGs that allows establishing a hierarchy of criteria that can be scientifically contrasted by means of a rigorous mathematical procedure. The method organizes a hierarchy in a tree diagram, where the main goal is decomposed into criteria organized on different levels. The AHP method received some criticisms in its early stages (Holguín-Veras, 1995), mainly related to the theoretical foundation of the method or the possibility of the method suffering from rank reversal, but the main criticisms were overcome, and the AHP method is now widely accepted and applied by governmental agencies, corporations and consulting firms (Al-Harbi, 2001) .

Tramarico et al. (2015) made a bibliometric study of the utilization of multicriteria methods applied to the supply chain management. The authors showed that the most used MCDA method in the publications from 2011 to 2014 was the AHP method, with 1872 articles, followed by the ELECTRE method, with 201 articles, and MAUT, with 61. Wider studies such as that of Wallenius et al. (2008) also enhance the use of the AHP method.

1.2. State of the art

AHP methods have been successfully used in comparative studies between different available ports considering the criteria of services in ports, services in the terminals of containers, economic factors and geographic location (Teng et al., 2004; Yeo et al., 2008). Yang et al. (2014) used the AHP method to prioritise the criteria of sustainability, establishing a comparison between several Asian ports and noting that transport companies and seaport managers have different perceptions of the criteria of sustainability.

Multicriteria tools that have been applied to the design of terminals of containers have mainly been focused on the improvement of the performance (Bruzzone and Signorile, 1998; Seyedalizadeh et al., 2009) and to determine the optimum number of automated guided vehicles in each terminal (Liu et al., 2002). AHP has also been used to prioritise the factors that influence the equipment conveyors of containers in the port terminals (Peilin et al., 2012; Yang et al., 2014). The authors concluded that