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Performance evaluation of a tracking system for intermodal traffic: an experimentation in the Tyrrhenian area

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Abstract

Monitoring shipments along intermodal chains is crucial to ensuring the fast, reliable and secure transport of goods. In this regard, the paper describes the results of a real-life tracking experimentation carried out in June 2018 in the Tyrrhenian area with a twofold objective: 1) to evaluate the performance of a state-of-art tracking system to effectively monitor Ro-Ro freight units moving along intermodal chains; 2) to get an objective view of the intermodal chains currently connecting the two main Italian islands to the mainland. The experimentation was performed by means of a tracking device using the GSM network for data connection and geographical position detection. In addition, the Automatic Identification System (AIS) data were used to improve positioning during navigation. Quantitative analyses carried out on the recorded tracking data revealed that a significant share of the total transport time of the monitored transport chains is unproductive time that goods spend waiting at the port and logistics nodes. From a technical point of view, the experimentation raised several problems of the tracking technology employed vis-à-vis real-time tracking, continuous monitoring, signal coverage and positioning accuracy. A discussion of the main detected limitations is provided in the paper along with some possible solutions to overcome them.

Keywords: Tracking Technologies; Maritime Transport; Supply Chains Monitoring; Intermodal Transport.

1. Introduction

Tracking and tracing are considered essential tools of Supply Chain Management (SCM) for ensuring customer satisfaction and efficient management of logistics networks (Shamsuzzoha and Helo, 2011; Kärkkäinen et al., 2004). Given the complexity of logistics chains in the global economy, companies have been showing an increasing interest in technologies and methodologies able to improve their monitoring (Artto et al., 1998) and management (Fancello et al., 2018). Particularly, the monitoring of shipments

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along intermodal chains and maritime networks is recognized as one of the crucial factors to ensuring the efficient, reliable and secure transport of goods. In this regard, tracking systems provide not only the position of goods along end-to-end transport chains but also their real-time status. Moreover, they can partially overcome some criticalities of the ships' arrivals forecasting models used to improve port performance (Fancello et al., 2011; Pani et al., 2014) and human resources management (Di Francesco et al., 2015; Serra et al., 2016), both in short sea shipping and in medium-long range container traffic.

This study was conceived as part of an earlier project lying within the scope of MoS (Motorways of the Sea) which the authors worked on during 2017 and 2018. The project, called Go Smart Med (funded under the Interreg It-Fr Marittimo Programme 2014-2020), intended to propose an integrated and optimized network scheme for the Ro-Ro freight shipping services currently operating in the Tyrrhenian basin. The primary aim of the proposed network was to improve the accessibility of island regions while providing an essential contribution to how shipping services can be streamlined to render them more competitive than road transport. The approach used was based on the integration of the timetables and frequencies of the existing freight shipping services and showed the potential positive impact generated by rescheduling and coordinating the existing liner services operated by diverse shipping companies (Fancello et al., 2019). Despite the potential benefits the integration of services can have, the entry into operation of such an integrated system may clash with the reluctance of transport operators to use the proposed integrated services. Particularly, the need to perform transhipment operations can be difficult to accept by transport users who may perceive such operations as potential security threats for their goods. In fact, at intermediate ports, the unaccompanied Ro-Ro unit must first be disembarked from the first ship and then embarked on the second ship to reach the final destination port. When interviewed about this opportunity, most of the transport operators complained about the impossibility of maintaining control of their loads during these operations. In this regard, adopting tracking technologies can provide a useful tool giving users the ability to continuously monitor their goods along the entire transport chain.

The market offers several technologies for tracking goods in real-time, each with its specific benefits and limitations in terms of performance, reliability, usability, cost, and so on. The choice of specific technology may depend on several criteria: user type, environmental conditions, tracking frequency, cost factors, etc. Although the pertinent scientific literature provides a large number of studies with some focus on vehicles tracking for public and private transport, to our knowledge, very few studies deal with performance assessment of tracking applications for intermodal and maritime transport chains. The main reason for this may lie in the traditional reluctance of operators to share any data or information related to their business due to (understandable) commercial sensitivity issues.

In this regard, this study can contribute to the literature in the field by providing a transparent and independent application of tracking technologies for intermodal road-sea chains and by discussing its main results and criticalities. Specifically, this paper intends to investigate the performance and reliability of a state-of-art tracking system to effectively monitor a set of unaccompanied Ro-Ro freight units moving along intermodal Tyrrhenian chains. In doing so, Section 2 provides a brief literature review of studies with some focus on applications of tracking tools for monitoring transport chains. The results of the performed real-life tracking experimentation are presented and discussed in Section 3 together with a description of the main features of the tracking device adopted. The main problems detected concerning real-time tracking, continuous monitoring, battery life, signal coverage and positioning accuracy are discussed in Section 4, along with some possible solutions to overcome them. Section 5 concludes the paper.

2. Literature review

Faced with the growing need to guarantee short and reliable delivery times companies are making significant efforts to implement effective tracking systems able to satisfy manufacturers, suppliers and transport users within the planned logistics networks (Shamsuzzoha and Helo, 2011). However, though monitoring shipments along intermodal chains and maritime networks is recognized to be crucial, to date millions of transport units are still subject to limited control with little knowledge of their real-time status (Martinez-Sala et al., 2009).

The terms tracking and tracing are often used indistinctly both by the industrial and academic communities to indicate the same activity (Kelepouris et al., 2007). The specialized logistics literature provides instead two different definitions. The term tracking is used to define that set of information which enables shippers to determine the current position, or previous positions, of a transport vehicle or product being delivered along the entire logistics chain (Jansen-Vullers et al., 2003). The term tracing mainly refers to the ability to determine the history of the goods throughout their entire life cycle (Van Dorp, 2002). In this study, the focus is on tracking tools.

The market offers several technologies to track goods in real-time, each with its own characteristics. A number of more and less recent reviews of existing tracking technologies can be found in the literature (Budak et al., 2018). Some of the available studies specifically focus on performance assessment of available tracking and tracing technologies (Shamsuzzoha et al., 2013). Others provide a review of the available studies using a technological- or an SCM- perspective (Konovalenko and Ludwig, 2019), while others investigate specific aspects of the tracking problem, such as the signal processing technique in network-aided positioning (Chen et al., 2005) or the individual or combined use of available technologies to enhance the monitoring system's effectiveness (Rooney et al., 2000; Martin-Escalona et al., 2004; Prasanna and Hemalatha, 2012). Some studies distinguish tracking and tracing activities into discrete and continuous (Hillbrand and Schoech, 2007), some deal only with continuous tracking (He et al., 2009) while others propose hybrid methods that combine discrete and continuous tracking technologies (Yang et al., 2010; Papatheocharous and Gouvas, 2011; Kandel et al., 2011).

Although the literature provides a significant number of studies with some focus on vehicles tracking for public and private transport (Chadil et al., 2008; Bojan et al., 2014; Lee et al., 2014; Kishore and Raja, 2015; Rahman et al., 2016), only a few seem to deal with the application and performance assessment of tracking tools for monitoring intermodal supply chains (Hajdul and Mindur, 2015; Hajdul and Kawa, 2015; Olivera et al., 2015). Furthermore, among the analyzed studies, only one addresses the vehicle tracking problem for intermodal transport chains, describing the application of a tracking technology combined with AIS data on a single shipment moving along an intermodal road-sea chain (Shamsuzzoha and Helo, 2012).

In this framework, the primary intention of this research is to investigate more broadly the basic needs and operational challenges for tracking shipments moving along intermodal maritime chains. To this end, the results of a real-life tracking experimentation involving 46 unaccompanied Ro-Ro units moving along Tyrrhenian chains are presented and discussed. By providing a rare and independent application of tracking technologies for intermodal road-sea chains, the intended contribution of the research is twofold:

- to get an objective view of the general features of the intermodal chains connecting the two main Italian islands to the mainland in order to highlight potential inefficiencies susceptible to improvement;
- to provide insights into the application of state-of-art tracking technologies for intermodal maritime chains, by investigating related performances, needs and challenges.

3. Experimentation

This section describes the results of the real-life tracking experimentation carried out in June 2018 in the Tyrrhenian area.

The experimentation involved 46 containerized Ro-Ro units moving along the same number of intermodal Tyrrhenian chains. Each analyzed chain connects one of the two main Italian islands (Sardinia or Sicily) to the mainland. Every monitored chain includes at least one sea leg, one road leg, and two port calls.

The adopted tracking device is equipped with sensors and alarms for humidity and temperature, a triaxial accelerometer, compass, and gyroscope. It is also equipped with a light sensor that informs the user about door closing and opening. The device uses the GSM telephone network for data connection and geographical position detection. It was installed inside the containerized Ro-Ro unit in order to reduce the risk of detachment or breakage during handling operations. The choice of tracking device to be used in the experimentation was based on both cost and operational criteria.

Particularly, when planning the experimentation, special attention was devoted to the concept of "real-time tracking" throughout the duration of the journey considering the two main criticalities related thereto: battery life and data communication. As for the first point, assuming a theoretical two-week observation period, in case of continuous real-time tracking the batteries should have a capacity of around 300 A/h. These batteries are not only significantly more expensive than standard ones (10 A/h) but are also heavier and larger, making the installation more difficult. Similarly, in the case of continuous tracking, data communication would require a relatively costly subscription to a data service provider, making the tracking service much more costly. Besides, continuous real-time tracking may actually be of little practical use, especially when the shipment stops for a long time in one place or during navigation. Taking all these elements into consideration, the problem was to define an optimal tracking interval able to ensure complete monitoring of transport chains while avoiding a high (and costly) frequency of transmissions when unnecessary. Considering the presence of real-time alerts in case of need, a position tracking at intervals of 20 minutes was assumed as satisfactory for the purposes of the investigation.

Information collected by each device includes:

- Event Type – it indicates the type of event that characterizes the precise moment of signal emission: device activation, position, doors opening/closing, device detached;
- ID Device - it indicates the code of the tracked device;
- Occurrence Date - it identifies the date and time of detection;

- Temperature (°C) and Humidity;
- Latitude and longitude coordinates;
- Locality, province and country referred to detected latitude and longitude.

Automatic Identification System (AIS) data was used to improve positioning data during the navigation phase. Table 1 shows an example of an information string.

Table 1: Example of an information string.

Event Type	*ID Device*	*Occurrence Date*	*Temp (°C)*	*Humidity*	*Lat*	*Lon*	*Locality*	*Country*
Position	TBD. 1705xxx096A	15/7/18 9.47	19.89	31.6	39.2147	9.10984	09123 Cagliari (CA)	Italy

Source: Authors.

3.1 Quantitative results

More than 4500 hours of tracking were recorded, corresponding to 189.9 days and an average duration of 4.1 days per shipment analyzed. Using the tracking information recorded, each of the 46 analyzed intermodal chains has been characterized in terms of:

- logistics time: it includes times for loading, unloading, embarkation and disembarkation operations;
- waiting time: it includes waiting times spent at the ports and logistics nodes;
- transport time: it includes travel times referred to road legs only;
- navigation time: it includes travel times referred to sea legs only.

Table 2 gives the average time features of the 46 monitored intermodal chains in both absolute and percentage terms while Figure 1 graphically depicts the temporal characterization of the 46 intermodal transport chains analyzed.

Table 2: Time features of the 46 transport chains analyzed.

	Global balance: 46 transport chains [days]	*Single transport chain [days]*					*Weight*
		Mean	*Median*	*Min*	*Max*	*St Dev*	*[%]*
Logistics Time	41.50	0.90	0.66	0.25	3.67	0.71	22
Transport Time	9.92	0.22	0.17	0.01	0.85	0.18	5
Waiting Time	93.75	2.04	1.45	0.07	12.47	2.22	49
Navigation Time	44.70	0.97	0.88	0.39	2.38	0.35	24
Total Time	189.87	4.13	3.40	1.52	14.23	2.58	100

Source: Authors.

The most interesting element is represented by the Waiting Time variable, which on average constitutes almost half (49%) of the total transport time. Although the corresponding standard deviation value is representative of significant sample heterogeneity (min and max values range from 0.07 to 12.47 waiting days), this value can be indicative of major inefficiencies existing in the current transport scenario and of significant potential for improvement achievable in the connections to and from the islands. In this regard, the results of this experimentation can provide some useful insights to EU decision makers to encourage and promote integrated short sea shipping strategies for improving the overall maritime transport supply in the area with specific reference to the connection of island regions and the mitigation of their isolation.

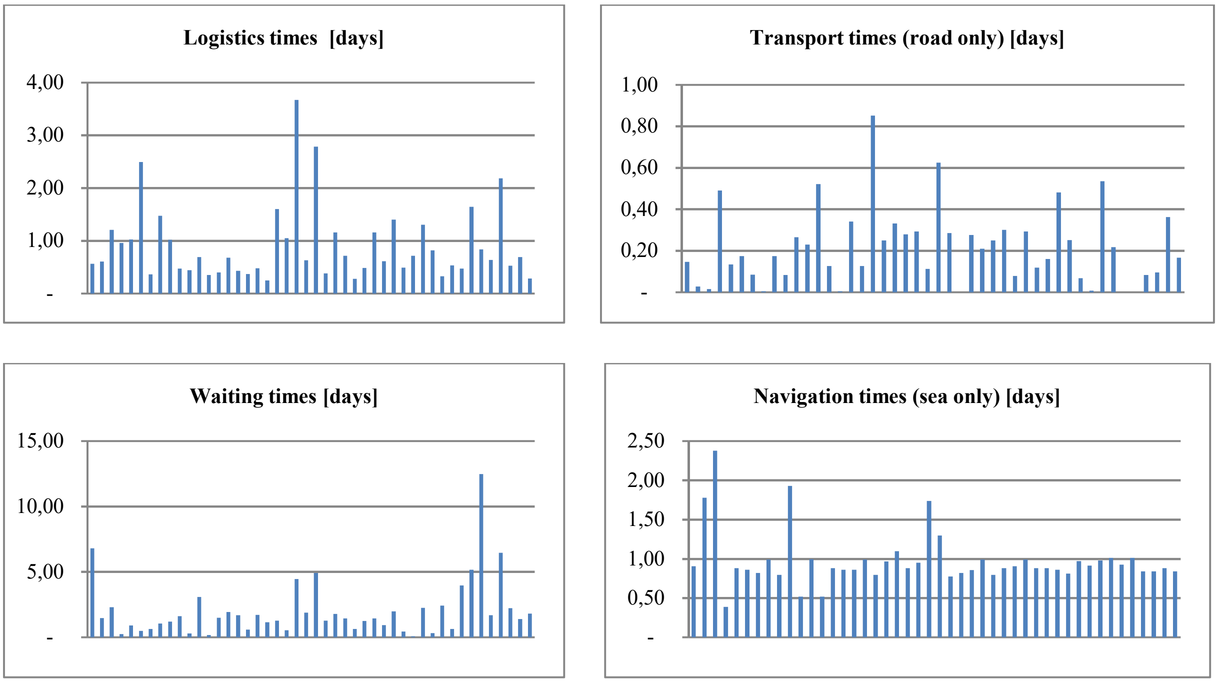

Figure 1: Temporal characterization of the 46 analyzed intermodal chains.
Source: Authors.

4. Critical factors

This section discusses the main outcomes of the experimentation in relation to the second objective of the study: to provide insights into the application of a state-of-art tracking technology for intermodal maritime chains, by investigating related performances, needs and challenges.

The chosen device uses as a positioning tool the GSM signal of all the cells it is able to detect, regardless of the specific operator. On the ground, it generates a quite precise positioning because of the large number of available cells from which to triangulate the signal (the average margin of error is 200 meters). Conversely, during navigation, two main critical issues arise:

- the number of available cells is far more limited compared to the mainland. This means that the device must be activated every time the signal is reached, and requires very high frequency data transmission.
- the distance to reach the signal can be very considerable.

One of the most striking examples was recorded with a device during navigation between Salerno and Palermo, when the signal was detected at the Aeolian Islands, over 60 km away from the actual position. This happened due to two concurrent factors:

- the very high position of the ground-based transceiver antenna on the Aeolian islands;
- the raised position of the container on the outer deck of the ship.

This effect produces major inaccuracies because the signal is recorded very far from the real position and the route seems to follow a zigzag path, or even to pass through land. The tracking does not give sufficiently detailed information to fully describe, if not by interpretation, the evolution of navigation. Figure 2 compares the track given by the device (right side) with the actual track of the ship, obtained through AIS positioning (left side). The zig-zag path between Corsica and the Tuscan Archipelago highlights and confirms a typical and universal problem of location detection via the GSM network: if in one area there is only one signal source, it is impossible to triangulate and therefore the position is assumed with a very high uncertainty around the detection point of the receiving antenna.

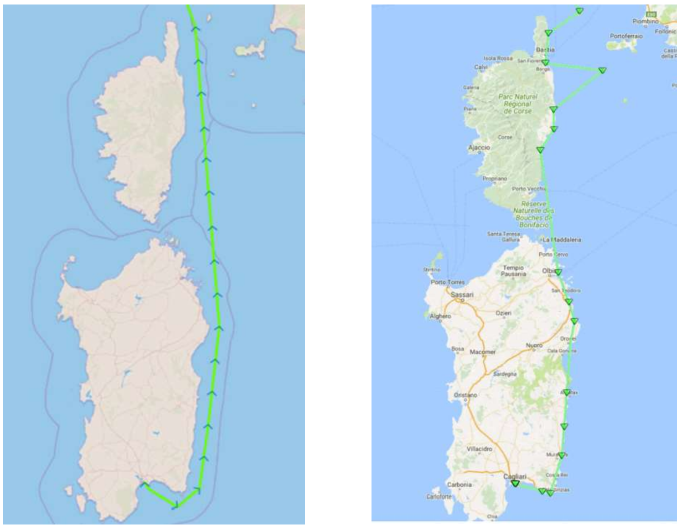

Figure 2: Tracking from AIS data (left). Tracking from device data (right).
Source: Authors.

In order to further investigate the problem, information concerning the positioning and reception of the signal from cellular devices was used to analyze the signal coverage in the area of interest. Information about signal coverage was obtained using maps from opensignalmap.com[1]. Figure 3 shows that the area considered has, according to the opensignalmap website data, a large number of areas covered by the signal. However, when looking at signal strength, it appears to be mainly of weak intensity (red points on the map). In this regard, it should be stressed that the quality of the signal also depends on the positioning of the vehicle/container on board the ship. When it is positioned on an open deck, the reception is maximum and both the positioning and the relative transmission data are recorded. Conversely, if during navigation it is positioned in a hold (thus enclosed by very thick metal walls) and/or surrounded by many other cargo units, it may be very difficult (if not impossible) to capture the signal which may not be fully detected.

Further difficulties included the possibility to effectively detect the exact positioning of the containerized Ro-Ro unit during road transport and accurately identify the moment it was loaded/unloaded onto/from the ship. The first issue can be solved by

[1] Opensignalmap is a service that produces independent coverage maps for mobile operators based on data voluntarily contributed by users.

using a tracking device based on a global positioning system, such as, among others, NAVSTAR GPS, GLONASS, BeiDou, or Galileo. However, these types of devices cannot be used for standard containers because, in order to avoid damage during handling, they need to be installed inside the unit while their receiving antenna must necessarily be positioned outside. Conversely, these tracking devices are the best option for trailers, as they can be easily installed both in the front area (just behind the tractor) or in the lower side, attached to the metal structure.

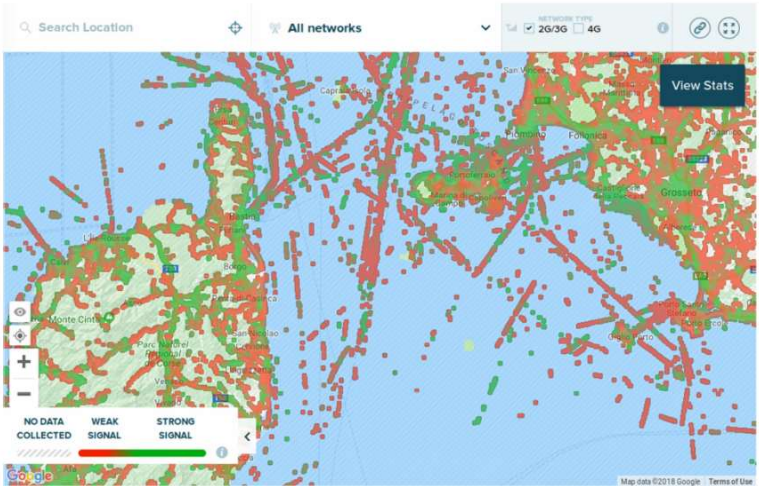

Figure 3. Map of the GSM 2G/3G signal intensity in the Corsica Channel.
Source: www.opensignalmaps.com on Google Maps.

As for the second issue, there exist a number of operational constraints. When a Ro-Ro unit is loaded onto a ship, unless it is parked on an open deck, the positioning signal is usually shielded and the tracking device cannot even detect when the ship is departing. Possible solutions to this issue may include:

- the association of the tracking device with AIS data positioning. This has to be done manually, by identifying the ship of interest and keeping the correlation until disembarkation;
- the use of a ship-based wireless infrastructure for data exchange and transmission;
- recording of the exact boarding time directly involving dockworkers.

Each of these solutions raises important operational and cost challenges and needs strong cooperation by both ship and port operators. Getting a 100% reliable tracking system based on the GSM location is almost impossible without the active cooperation of the sea carriers, who have to allow transporters to interface their tracking systems with the signal repeaters on board. Much work must still be done before these solutions can be effectively and easily applied on a large scale to improve the precise monitoring of intermodal road-sea chains.

5. Conclusion

This paper has described the results of an independent real-life tracking experimentation involving 46 containerized ro-ro units moving along the same number of intermodal Tyrrhenian chains. Quantitative analyses carried out on the recorded tracking data revealed that a significant share (49%) of the total transport time of the monitored chains was actually unproductive time that goods spend waiting at the port and logistics nodes. This value can be indicative of major inefficiencies existing in the current transport scenario and of significant room for improvement in the connections to and from the islands. In this regard, the results of this experimentation can provide useful insights to EU decision makers to encourage and promote integrated short sea shipping strategies for improving the overall maritime transport supply in the Tyrrhenian area with specific reference to the connection of island regions and the mitigation of their isolation. In fact, despite being widely recognized that integrated management policies can yield significant benefits (Fancello et al., 2014), coordinated market strategies are far from being realized, mainly because of the resistance of maritime operators to implement integrated strategies, and of transport users to use integrated services. Particularly, in the unaccompanied Ro-Ro transport segment, the need to perform transhipment operations may be difficult to accept by forwarding agents who may perceive transhipment operations as potential security threats for their goods. In this regard, the adoption of effective tracking technologies may serve as a facilitator tool, enabling users to continuously monitor their goods along the entire transport chain. From a technical point of view, the experimentation has raised a number of problems of the tracking technology used mainly concerning real-time tracking, continuous monitoring, signal coverage and positioning accuracy. Although a number of possible solutions to overcome such criticalities have been proposed, their implementation on a large scale still raises significant operational and cost challenges and needs strong cooperation by both ship and port operators. Much work has to be done both at the technological and management level before these solutions can be effectively and easily applied on a large scale to ensure the precise and accessible monitoring of intermodal chains. To this end, the outcomes of this study can hopefully provide some useful insights for the development of more effective tracking solutions for road-sea chains on the basis of the detected needs and operational challenges.

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