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Requirements For An IoT-Lock Enabling Asynchronous Physical Handovers Of Semi-Trailers In Road Freight Relay-Transport

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Abstract

In long-distance road freight transport, capacity utilization of semi-trailers is less than 30 % due to mandatory steering and rest periods. Truck parking spaces are overcrowded while resulting parking search traffic leads to additional emissions. At the same time, the acute driver shortage and customers' expectations of ever faster functioning supply chains force the highest efficiency in transport means and personnel. Multi-carrier relay-transport represents an approach to solving these problems and exploiting untapped efficiency potentials: Via a digital platform, long distances are intelligently divided into short route sections which are distributed among different carriers. At predefined switching points, the asynchronous handover of semi-trailers to rested drivers takes place. To enable a secure cross-company physical handover, IoT-locking mechanisms play a crucial role. This paper details the asynchronous handover process and introduces the technical design of an IoT-lock which provides effective theft protection while the trailer is parked and reliably connects tractor and semi-trailer during transport. Based on an analysis of stakeholder requirements, software functionalities and mechanical properties of the IoT-lock are derived, which ensure effective theft protection as well as real-time data transmission for relay transports. These form the basis for digital handover protocols that record the condition of the freight and trailer during the handover process.

Keywords:

Road Freight Transport; Relay-Transport; IoT-Lock; Asynchronous Handover; Semi-Trailer

1. Introduction, problem statement and solution

The road freight transport in Europe is facing a variety of challenges. In Germany alone, it is assumed that a lack of approximately 60.000 to 80.000 truck drivers exists [1]. In addition, transports are interrupted to comply with driving and rest periods. Truck parking spaces are occupied in the process, whereby Germany lacks 23.000 parking spaces for tractors/semi-trailers [2]. This phenomenon is accompanied by the fact that a parking lot expansion is progressing very slowly and at high costs – costs for comparatively small parking lots have risen significantly to about 80.000 EUR per space with a construction time of several years due to dramatic shortages for suitable land. [3] Road freight relay transport seems a feasible approach to address the described challenges. However, it must be considered that most of the German shipping companies (73 percent) have less than 100 employees (11 on average) [4]; therefore, internal relay-transport cannot be integrated cost-efficiently. Additionally, stolen trailers and lost freight due to theft and robbery translate into potentially high costs as well as contractual penalties for delivery delays, repairs, and lost sales as a result of production downtime.

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The interruption of transports can be avoided by securing trailers with an IoT lock at the end of the driving time and then handing them over to rested drivers. The research project 'STAFFEL' investigates a safe, cross-carrier relay-transport: on an internet platform, long distances are to be broken down into partial routes with the help of CI algorithms, which are then mediated between carriers and freight forwarders via a driving time marketplace on the basis of real-time data (e.g. traffic, infrastructure, IoT, telematics). The asynchronous handover of semi-trailers takes place at predefined switching points

Based on internal calculations comparing the driving time of a single truck running in conventional traffic (9 h/day) to a truck running in relay traffic (theoretically up to 24 h/day as only the tractor is parked due to mandatory resting hours for the drivers)., this approach can reduce the transportation time by up to 62 percent while increasing truck utilization rate by up to 163 percent. Waste of driving time, empty runs and parking search traffic are reduced. The need for truck parking spaces is reduced by up to 65% if the semitrailers are handed over and only the tractor units have to park. At the same time, attractive, self-determined work models are created for truck drivers, who can drive more regional legs and be at home more often. It quickly becomes clear that relay-transport holds a multitude of potential advantages for the transport of goods by road. However, it also becomes clear that only an asynchronous transfer protected and supported by an appropriately designed IoT-lock makes this process possible in the first place. Such a lock will be derived in this paper with regard to the system architecture.

2. Theoretical background: Fundamentals of relay-transport and IoT-applications

2.1 Road freight Relay-transport

Multi-carrier relay-transport describes the intelligent division of long transport distances into short route sections which are distributed among different carriers. The distance of the newly calculated route sections is congruent with the time that truck drivers are allowed to drive without exceeding their driving times [5]. At predefined switching points, the asynchronous handover of semi-trailers to rested drivers takes place. This approach can massively reduce the transportation time, because it eliminates the need for overnight stays by the carrier, hence resulting in lower costs. The asynchronous handover supported by an IoT lock minimises the risk of otherwise lengthy wating times caused by traffic jams or other complications which only occur on one side of the interaction. The planning process of the relay transport will be executed by an algorithm, which intelligently subdivides transportation routes of long distances into shorter sections. A distribution among different carriers and the asynchronous physical handover of semi-trailers requires a platform to orchestrate the process digitally.

2.2 IoT-applications and IoT-locks

The IoT-technology describes physical devices (e.g. locks or sensors) which can be accessed and uniquely identified through a network and can also be represented in a virtual depiction. The device can be controlled and tracked in real time. It is critical that the devices can share information via the network with other connected devices to guarantee an intelligent and well-functioning process [6]. The number of IoT devices is rising and might triple from 9.7 billion in 2020 to mora than 29 billion IoT devices in 2030 [7].

The IoT-lock within the relay transport is the central enabling technology for this approach. It provides theft protection, accessibility for authorized users and allows traceability of the trailers through real-time data transmission [7]. Improved data transmission enables effective communication and connectivity between the various parties in the supply chain, which is pivotal for relay transportation planning. Besides that, it also allows a digitalization of processes such as the typically paper-based handover protocols [8].

With regard to the state of the art in intelligent securing technologies in road freight transport, it should be noted that very few IoT securing mechanisms are currently in use. So-called "smart locks" exist without reference to road haulage, among others e.g., for securing house doors. In the field of securing semitrailers, conventional kingpin locks with keys are offered. [9] There are currently no cyber-physical security systems on the market. Either related solutions are "purely digital" and passively record the position of the trailer or they are purely physical (including a king pin lock). An exception is the trailer immobilizer, which is not a lock in the traditional sense, however, but controls the air brakes. An exception to this is the trailer immobilizer. Hence it secures the trailer by controlling the air brakes it cannot be seen as conventional lock. This system is therefore easier to manipulate than a heavy-duty lock.

3. Research Approach

This paper's scope is the definition of product features of an IoT-lock which enables the implementation of the above-described relay-transport through a digitally supported physical handover of semi-trailers. In order to achieve that, a methodical process has been chosen to ensure a complete description of the needed functionalities of the product. Figure 1 shows the steps that have been applied. After this a list of product requirements can be formulated, which are based on the identified process and the access authorizations of the users. Additionally, a derivation of technological product properties can be made to ensure that the previously identified functionalities can be fulfilled. In a last step a system architecture can be set up.

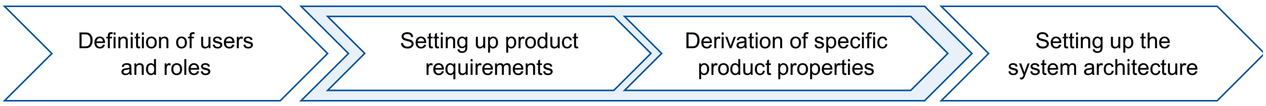

Figure 1: Methodological approach

The identification and characterization of the roles denotes the first step of the procedure in the chosen methodological approach and is based on internal discussions with the project team. In particular, the roles that are directly or indirectly involved in the use of the lock were described. A further distinction was made between authorized and unauthorized users. Consequently, four user groups could be differentiated, which are described in more detail below.

First, those users who carry out the intended physical handover of a semitrailer can be identified. The truck drivers are either those who park a semi-trailer at a predefined location or who couple the trailer. Both roles are so called authorized users, but due to the deviating processes in the two operations, it is necessary that these two roles are differentiated from each other. A third role can be described as a higher level or superior participant. This user-group is the administrative layer which organises and orchestrates the transportation processes. In particular, this group relies on planning routes, transmitting appropriate destination data, and receiving data on the location of the tractor-trailer. In this user category you could find a fourth logistics party (4PL) or other forms of service providers. A fourth group of users is the unauthorized person. Within the context of thievery, a lock must be designed to ensure an adequate theft-protection.

4. Results

4.1 Requirements and product properties

In the following a set of requirements based on the predefined roles will be presented. The basis for using a lock is the locking system itself. The driver locks the mechanism after uncoupling the semi-trailer. The system must be able to recognize and display the current status of the device (locked or unlocked), a visual display is particularly necessary. Technological components for this can be an LED, a reed contact and the corresponding coupling to the motor position of the lock-mechanism. In addition, a corresponding display in the app is necessary.

In a lot of situations, a basic network connection is existing and needed. The driver and the administrative users must have the option of accessing the lock remotely. Possible component functionalities for this are

LTE (GSM as fallback), Sigfox, LoRa or NB-IoT/ LTE-M [10]. Furthermore, it must be possible to run updates of the system. This is ensured with the help of Over The Air Updates (OTA). Since the driver parks the semi-trailer at various locations and a risk of an insufficient or lacking internet connection is given, the lock must be opened offline and independently of the internet connection. Discussions within a project workshop showed that this could be realized by an RFID chip, Bluetooth LE or a Bluetooth Beacon. In principle, it must be possible to carry out updates to the system. This is ensured by means of over-the-air updates (OTA).

Another requirement is that the system must be able to determine the exact location of the semi-trailer so that this position data can be made available to the administrator. Here, a solution using LTE or GNSS is also suitable. In terms of distinguishing between authorized and unauthorized users, the system must be capable of recognizing the authorized driver. RFID, Bluetooth LE or an app control in combination with a Bluetooth Beacon can be used for this purpose. A corresponding alarm or theft protection can be ensured by integrating a buzzer that emits an acoustic signal. Also, to be derived in this context is the requirement that a corresponding event can be forwarded on the system side and sent to the user (e.g. push notification). With regard to anti-theft protection, a corresponding system-side detection of the transaction is also relevant. Requirements can be derived that the system must be capable of detecting unauthorized access to a trailer and identifying tampering with the kingpin lock (e.g., mechanical action). These requirements can be ensured using sensors, including accelerometers, distance sensors, or a thermal sensor.

With respect to unauthorized access, in addition to mechanical security, care must be taken to prevent unauthorized access to the IT system and to ensure adequate data security protection. Cybersecurity can be implemented with appropriate end-to-end encryption and secure protocols. However, further system-side development of these components is not included in this paper.

When the driver of a tractor performs the coupling of a semi-trailer, it is important that an incorrect opening of the locking system is detected. Consequently, the system must be capable of providing feedback (e.g., alarm) if the lock does not retract during coupling to prevent damage to the trailer and tractor. This can be visual feedback (e.g., via LED) or an acoustic signal (buzzer). The corresponding feedback of an error code as well as the display of a warning message in the app communication should be ensured.

Another requirement is that malfunctions are prevented while the vehicle is in motion. This can be ensured via magnetic bolts, an advanceable automatic latch, and appropriate dimensioning of the motor. Additionally, the lock should be designed in such a way that no removable components (e.g., keys) must be dismantled. The driver should not have to take any other components into the cab for reasons of convenience and quick coupling and uncoupling of the semi-trailer. In addition to the above-mentioned design conditions the asynchronous transfer of a semi-trailer can lead to longer idle times. In this case, the power supply must be ensured for the entire period so that the driver receiving the trailer can carry out the coupling process. For this purpose, a battery pack must be provided which has a connection to the semitrailer power supply. The charging process can then take place when the semitrailer is reconnected to the tractor unit.

The above-mentioned requirements can be distinguished into four categories; theft protection/ cyber security, data transmission/ tracking, operability and authorization and other functions (see figure 2).

Theft protection/ cyber security	Data transmission/ Tracking	Operability & Authorization	Other functions
▪ Unauthorized access is detected ▪ Authorized driver is detected ▪ Tampering with kingpin lock is detected ▪ Adequate protection against unauthorized access to IT system ▪ Adequate overall data security ▪ Access history is logged ▪ Triggering of emergency alarm ▪ Theft protection against conventional tools	▪ Determination of the exact location ▪ Software updates via radio interface (over-the-air update)	▪ Access without active internet connection ▪ Remote access possible (hotline) ▪ Temporary disconnection without loss of access authorization ▪ Emergency access for emergency services ▪ Access authorization for up to two trailers (one driver per trailer) ▪ Unlocking without detachable components	▪ Playback of an acoustic signal ▪ Feedback in case of incorrect coupling ▪ Visual feedback on the status of the lock (open/closed) ▪ Prevention of malfunctions while driving ▪ Charging via external power supply possible

Figure 2: Results of the requirements analysis

4.2 System architecture

The system architecture describes the basic structure of the IoT lock by showing the system components and their interdependencies in aggregated form. A distinction is made here between input and output and the processing layer. Figure 3 shows the below described architecture.

Opening and closing the lock is described as an input and is accomplished with the help of the smartphone. The user interacts with the user interface of the app (UI/ UX) and initiates the desired process. Bluetooth is used as the technology for data transmission in order to ensure a robust process without the need of an active internet connection. Due to the need for further modification of the trailer, RFID technology is not used here. The process of opening or closing is also forwarded to the back end of the system in the processing layer.

After the process has been triggered with the help of the smartphone app, the backend initiates the process using a gateway and LTE transmission technology and the signal is forwarded to the interlock or reed switch and the lock is opened or closed. If LTE communication fails due to a missing internet connection, it communicates with the Bluetooth receiver of the lock to open or close it. The sensor communication or the network setup takes place here via LTE-M and NB-IoT with an option for GSM as a fallback. This enables low-power communication and easy integration of new sensors into the network. GSM is used as a fallback when communicating with the backend. If the process was completed with the opening or closing of the lock, a corresponding signal is returned and the LED lights up. The state of the lock is transmitted to the backend.

As LTE communication is used within the architecture of the lock, LTE is preferred for localization of the trailer. Nevertheless, GNSS (Global Navigation Satellite System) is used to support the system whereby feedback on the trailer location is sent back to the backend, thus enabling continuous tracking of the lock.

If the lock is tampered with, if an error occurs during coupling or if the trailer is accessed, these events are registered with the help of an accelerometer and other sensors. It should be noted here that sensor technology is already present on the trailer. It still needs to be examined to what extent these can be integrated into an anti-theft system. Depending on the sensor feedback, a visual and acoustic signal is triggered (LED, buzzer) and the corresponding process is reported back to the back end.

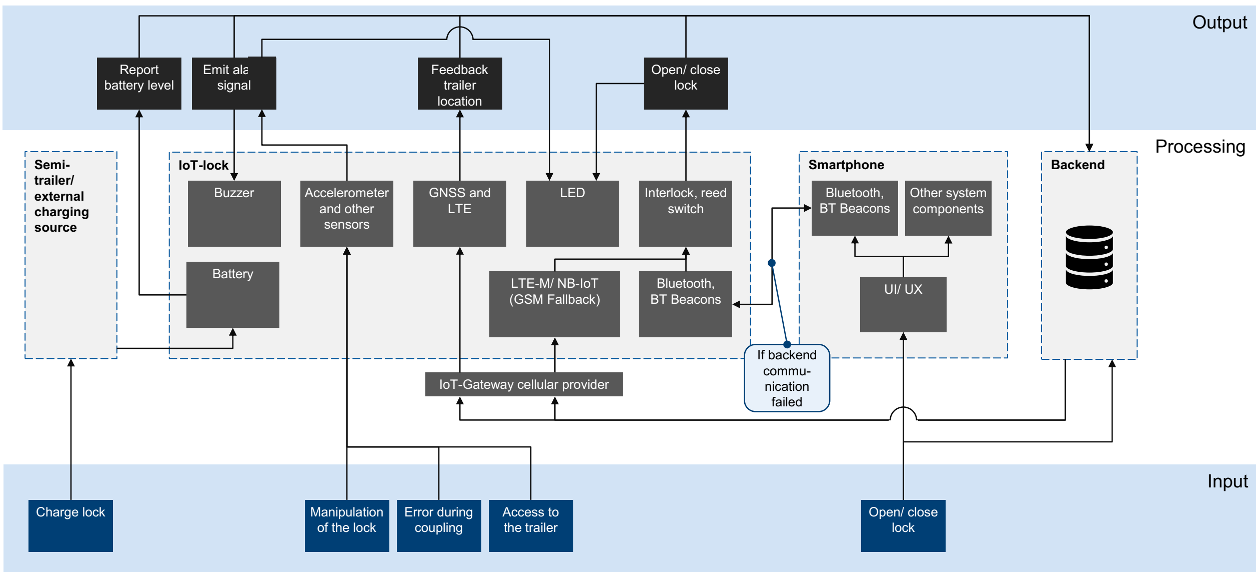

Figure 3: System architecture of the IoT-lock

The charging of the IoT lock is ensured with the help of the power supply from the semi-trailer or its external charging source. A corresponding report on the battery level is transmitted to the back end. When selecting the battery, it is to be ensured that a minimum runtime without external charging source of seven to 14 days can be achieved.

No cyber security considerations have yet been taken into account in the system architecture. In this area, too, it must still be clarified whether sensitive data is exchanged and to what extent it must be protected. Further research effort is necessary.

5. Summary and outlook

Within this paper and based on a definition of roles and users within a relay-transportation, a list of requirements for an IoT-lock has been conducted, which can be used for an asynchronous physical handover of semi-trailers. Based on those requirements, it was possible to derive necessary technological components that ensure functional fulfilment. These components and the corresponding relationships between them were also described. As a result, it was possible to draw up a system architecture that represents the functionalities of the IoT lock. Based on input factors the processing layer shows interdependencies and signal operations of the components and presents the outputs.

Further research is particularly needed in the development of the system architecture and the prototypical testing and validation phase. Since the system architecture is to be understood as a guideline for developement, possible barriers in the practical implementation of the concept must be identified. The IoT lock should serve for a safe and smooth transition of the trailer from one driver to another driver. The data exchanged in this process must be complete and meet the requirements in every situation. In addition, the extent to which sensitive data must be protected under data law and how this is ensured by the corresponding system architecture should be examined in more detail.

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References

[1] Verkehrsausschuss, Deutscher Bundestag, 2022. Gemeinsame Stellungnahme des Bundesverbandes Deutscher Omnibusunternehmen (bdo) e. V. und des Bundesverbandes Güterkraftverkehr Logistik und Entsorgung (BGL) e. V. https://www.bundestag.de/resource/blob/911288/6d79e1ce0be1bc517c93bdd2a5f4bd35/Stellungnahme-BGL-und-bdo-data.pdf Accessed 2 November 2022.

[2] Irzik, M., 2018. Lkw-Parksituation im Umfeld der BAB, Schätzung der Nachfrage 2030. Bundesanstalt für Straßenwesen, Bergisch Gladbach.

[4] Deutscher Speditions- und Logistikverband e.V. (DSLV), 2015. Zahlen, Daten, Fakten aus Spedition und Logistik 2015, p. 22.

[5] Amtsblatt der Europäischen Union. Reihe C & L (früher: Amtsblatt der Europäischen Gemeinschaften ; früher: Amtsblatt der Europäischen Gemeinschaft für Kohle und Stahl). o. J. EurLex. http://eur-lex.europa.eu/JOIndex.do?ihmlang=de.

[6] Gokhale, P., Bhat, O., & Bhat, S., 2018. Introduction to IOT. International Advanced Research Journal in Science, Engineering and Technology, 5(1), pp. 41–44.

[7] Statista, 2022. Number of Internet of Things (IoT) connected devices worldwide from 2019 to 2021, with forecasts from 2022 to 2030 | Statista. https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide/ Accessed 25 October 2022.

[8] Anandhi, S., Anitha, R. & Sureshkumar, V., 2019. IoT Enabled RFID Authentication and Secure Object Tracking System for Smart Logistics. Wireless Pers Commun 104, pp. 543–560.

[8] European Commission, Directorate-General for Mobility and Transport, Piers, R., Giannelos, I., Swart, L., et al., State of play and barriers to the use of electronic transport documents for freight transport : options for EU level

policy interventions : final report, Publications Office, 2018, https://data.europa.eu/doi/10.2832/39079 , S. 7. Accessed 2 November 2022.

[9] M. Shanthini, G. Vidya, R. Arun, "IoT Enhanced Smart Door Locking System," 2020 Third International Conference on Smart Systems and Inventive Technology (ICSSIT), 2020, pp. 92–96.

[10] Linnemann, M., Sommer, A., Leufkes, R., 2019. LPWAN-Netze. In: Einsatzpotentiale von LoRaWAN in der Energiewirtschaft. Springer Vieweg, Wiesbaden.

Biography

Janis Simons, M.Sc. (*1994) is an industrial engineer and has been a project manager and doctoral candidate at the Institute for Industrial Management (FIR) at RWTH Aachen University since 2022. In his current position in the department of Production Management he supports companies in various industries in the fields of selection and implementation of IT systems. He also participates in different research projects.

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