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D2.1 – Design of automated wagon loading system (AWLS)

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List of abbreviations

ATLS	Automated Truck Loading System
AWLS	Automated Wagon Loading System
FTL	Full Truck Load
ROI	Return On Investment
UIC	Union International des Chemins de Fer

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1. Introduction

The objective of this Work Package is to design an Automated Wagon Loading System from the ground up. Such a system should be able to load pallets into, and unload pallets out of a rail freight wagon in a safe, quick and easy way, with as few process steps as possible, with optimal control of the over the pallet flow, at low cost and with high reliability. When all these conditions are fulfilled, the resulting system will have the potential of offering an efficient and competitive transport solution for pallets by rail.

A first step in this process is the definition of the functional requirements of such an AWLS. These requirements will determine the scope of an AWLS, as well as the functions it should offer, and they are therefore applicable to any and all implementations of these systems, regardless of the specific characteristics of the cargo flow, the freight wagon or the infrastructure that is being used.

Although the technological solution should fully comply with the desired functional requirements, the project has a higher chance of success when the limitations of the currently available technology are taken into account at this early stage, since existing technologies may be directly applied to this problem, thus winning time and building on acquired experience. For that reason, the functional requirements will immediately be impacted by the current technological limits, and they should therefore be considered throughout the definition of the functional requirements.

This deliverable will describe the iterative process between functional specifications and technological possibilities that leads to the definition of the functional requirements.

2. The specific problem of freight wagons

Automated loading and unloading solutions for trucks have been around for over a decade. ANCRA Loading and Unloading Solutions has an extensive track record in this field, equipping trailers and docks of large corporations with the means to automatically handle pallets. When designing a similar system for freight wagons, it is useful to look at the case of trucks, and to adapt the existing design in a way that fits the special case of the freight wagon. This requires a look into existing ATLS solutions to track down the differences between the two approaches. Table 1 gives an overview of these inherent physical and practical differences between trucks and trains.

	Truck (ATLS)	**Train (no AWLS)**
Load weight	Up to 30 ton	Up to 1500 ton
Load dimension	1 FTL (26 pallets)	50 FTL (1300 pallets)
Loading direction	Longitudinal	Transversal
Loading mode	Full load at once	Pallet per pallet with forklift
Driver present	YES	NO
Manual activities	Parking, opening and closing doors	Opening and closing doors, pallet sorting and grouping, wagon moving
Infrastructure	Loading bay as wide as the trailer	Loading platform up to 300m, level with wagon floor.

Table 1: Functional differences between Truck and Train for pallet (un)loading

Due to their specific nature, the loading and unloading activities are very different between trucks and trains. Merely installing an ATLS on a wagon will not be enough to achieve the goal of automated (un)loading of pallets from freight wagons. A thorough study is required to build the functional requirements for the AWLS from scratch, using inspiration from existing pallet handling systems.

The study will focus on five distinct domains in which the functional requirements will be defined:

1. Safety: The AWLS must ensure personnel safety and cargo safety at all times. Measures need to be taken to avoid injuries and loss of cargo, infrastructure or rolling stock, and to control the entire process.
2. Compatibility: The AWLS must be designed in a way that it remains compatible with manual loading and unloading procedures. Compatibility with other automated pallet handling systems should also be ensured.

3. Flexibility: To the maximum extent possible, the design will be able to handle a range of different infrastructures, wagons and pallets.
4. Performance: An efficient AWLS must be able to perform the loading and unloading of a train reliably and in a short time span. This is the main benefit of an AWLS. While doing so, the quality of the shipment must be maintained.
5. Cost: To be commercially viable, the solution should be marketable with a return on investment in the order of 5 years. The total life cycle cost of the equipment should be relatively low.

This study will result in a set of functional requirements that must be respected by the system. In a next step, these requirements will be translated into technical requirements for the technology that will be selected as the best solution.

3. Defining the functional requirements

The functional requirements for each of the five domains will be defined in this chapter. Each requirement will be explained in full, and codified as follows:

[XXX123], where

- XXX is a short reference to the domain
- 123 is the unique number of each requirement within its domain

A full list of functional requirements is compiled at the end of this chapter, and as Annex A to this document.

3.1 Safety

The AWLS will typically be employed in a rail-connected warehouse where crossdocking or storage activities take place. Although warehouses are gradually converting to automation, the presence of humans in the vicinity of the machines can never be avoided. This is particularly true in the special case of a freight wagon, where personnel will always be needed to open and close the wagon doors, or to move the wagons. The design must therefore respect all relevant regulations for health and safety, and put in place the required mitigating measures to lower the risk of injuries to an acceptable level. These measures must include emergency stop buttons at relevant places, manual override buttons, covers over moving or rotating parts, and the placement of the required warning symbols. This leads to a first functional requirement:

[SAF001]: Take all measures to remove or mitigate the risk of injuries to intervening personnel.

To ensure railway safety, a wagon that is loaded with pallets using an AWLS must respect the UIC loading guidelines[1] for freight wagons. These guidelines impose rules for the weight and balance of the loaded wagon, and rules for securing the cargo in place on the wagon. The system should be equipped with sensors that allow for accurate measurement of load placement, alignment and weight distribution. If a deviation from the guidelines is detected, a warning must be automatically generated to allow for human intervention. This requirement will put in place a monitoring system that focuses on safety, but which must also fully integrate in any existing automated warehouse control center (see also Compatibility).

[SAF002]: Ensure pallet loading according to UIC Guidelines.

[1] Code of practice for the loading and securing of goods on railway wagons, version 01/04/2017

3.2 Compatibility

The development of an AWLS within the framework of the LWL project can be seen as a precursor for the future of pallet transport by rail. As such, the system will inevitably be used in combination with classical loading methods, such as forklifts or manual transpallets, both during loading and unloading operations. The implementation of AWLS-technology on either the wagon or the warehouse infrastructure must never prevent the loading and unloading by classical means.

Backward compatibility has a drastic impact on the design options for the wagon equipment, as well as on the dockside infrastructure. Many of the current (un)loading methods require a forklift to drive into the wagons in order to pick up the rearmost pallets. For this reason, these warehouses have a concrete loading dock that is at the same level as the wagon floor. If backward compatibility is to be guaranteed, the floor height of the wagon may not be increased by the addition of an automation solution. The wagon floor must furthermore remain accessible for wheeled forklift trucks, which implies a flat surface. Equal design restrictions apply to the infrastructure, since that infrastructure must still be able to support loading and unloading operations with manned forklifts or transpallets. As an example, an AWLS that covers the full width of a loading dock, and prevents manned apparatus from moving freely, is therefore out of scope.

[COM001]: Ensure backward compatibility with legacy (un)loading methods and the AWLS wagon.

[COM002]: Ensure backward compatibility with legacy (un)loading methods and the AWLS infrastructure.

While ensuring backward compatibility is a necessary requirement for the AWLS, ensuring forward compatibility with current and future warehousing and crossdocking solutions is even more important. The system will ideally operate as an automatic interface between an automatic or semi-automatic warehouse and the freight wagons. Automation of warehouses is part of the strategy of logistic service providers, so compatibility with these systems is a key factor in the success potential of the AWLS. However, since it is not possible to design a system that is fully compatible with all current automation solutions, the design must be adaptable to fit any pallet handling system, current or future, through a modular interface.

[COM003]: Ensure hardware compatibility with automated warehouse solutions.

Cargo monitoring and identification is also a part of this forward compatibility. The system software should integrate seamlessly with the warehouse management system (if any), so that the warehouse receives the relevant information from the AWLS on each pallet as soon as it is loaded or unloaded. Barcode scanners and standard GS1 SSCC label readers should therefore be an integral part of the solution.

[COM004]: Ensure software compatibility with automated warehouse solutions.

Unlike a trailer, the full cargo space of a freight wagon cannot be accessed directly through the opening of one door. In the case of H-type freight cars, only half of the cargo is directly accessible through one door (see Figure 1). To load or unload these wagons entirely, the doors need to be moved from side to side after each half load. This manual action may either be automated, or the wagon floor may be modified to allow longitudinal shifting of the cargo within the wagon. In both cases, a power source will be needed to power this process. Freight wagons are not equipped with an on-board power source, nor is such a solution part of this project, as it would lead to a considerable rise in CAPEX and a potential loss of time due to the certification process. The use of an external power source is therefore a functional requirement for the AWLS-equipped wagon. This power may be provided by the surrounding infrastructure (AGV's, conveyer belt, auxiliary power unit, …), or by a manual operation. Both options need to be evaluated during the process of translating this functional requirement into a feasible technical solution.

[COM005]: The AWLS wagon will only rely on off-board power supply for all power needs.

Figure 1: Opened Hbbillns wagon showing only half of the cargo

3.3 Flexibility

Pallets, wagons and warehouse infrastructures come in many shapes and sizes. An ideal AWLS would be able to handle any pallet type, on any type of wagon, through any warehouse technology. It would be as passkey solution that interfaces between a diverse range of technologies on both sides (wagon-side and dockside). Although very desirable, such an all-capable system is not realistically feasible when one combines the inherent weaknesses of any automatic system with the enormous diversity of palletized goods, freight wagons and infrastructures, and the stringent safety requirements of rail traffic. Since the system needs to respect the loading guidelines, the only way to limit the technological challenges of the AWLS prototype, is to reduce the diversity of the other intervening elements, thus reducing the scope and applicability of the AWLS.

The specific use case of the AWLS will therefore determine the particular characteristics of each implementation. A specific use case for the prototype has been identified at this stage, but although it will impact the physical realization of the prototype, the overarching functional requirements will remain the same for any implementation. This set of functional requirements towards flexibility of the solution will ensure that any instance of the AWLS will adhere to a minimum required level of interoperability between itself and the range of pallets, wagons and infrastructures that it may face. The AWLS prototype will eventually be designed to load and unload a steady and uniform flow of pallets of the same type, from a wagon of a single type, using a single infrastructure. Commonality between different implementations should be as high as possible, particularly when it comes to the equipment in the wagons themselves, as they may come into contact with multiple dockside implementations. This approach aims at increasing the degree of commonality between the AWLS implementations, which is a necessary condition for the broad implementation of automated loading systems throughout Europe.

Commonality and flexibility requirements are defined in three distinct domains: Wagons, Pallets and Infrastructure:

Wagons – Some 36 different types of H-wagons are available for international rail transport[2]. These wagons range from a simple covered 2-axle flatbed floor wagon to multiple linked 12-axle wagons with hoistable floors and movable intersections. The inner and outer dimensions are rather diverse, as is the maximum loading weight. Some of these wagons have doors that give access to exactly 50% of the cargo space, while other have overlapping door which limit access to about 45% of the cargo. A few wagon types of the L- and S-types are also designed for the transport of pallets[3]. With floor heights ranging from 2.5m to 3.3m, a 'one size fits all'-approach is clearly not an option. At the same time, railside loading docks throughout Europe have been built at the corresponding height for a particular subtype of wagon, so raising the floor of a wagon will directly lead to problems with backward compatibility. Additionally, a higher floor may imply undesirable restrictions for the height of the cargo. From this evaluation, the following functional requirements may be derived:

[FLX001]: The AWLS implementation on a wagon may not increase the floor height of a wagon

[FLX002]: The dockside implementation will be able to adjust for all loading heights that are at or above the level of the dock itself.

Note that [FLX002] implies that the dockside part of the AWLS needs to have at least one degree of freedom.

[2] http://www.goederenwagens.nl/index.php?cat=3
[3] http://www.transwaggon.de/index.php?id=14

Pallets – As with wagons, pallets come in many shapes and sizes, ranging from ISO pallets to EURO pallets and North-American models, along with some proprietary models from specific industries (see Figure 2). The quality and stiffness of these pallets is variable, as is the quality of the loaded cargo. Shipments are often poorly packaged, which leads to unbalanced pallets, skewing loads and unstackable pallets. The plastic wrapping that holds the cargo in place is often loose or insufficient to sustain the accelerations during transport. An ideal AWLS would be able to handle a mix of pallet types, dimensions and loading formats, but this is technologically not possible. An automatic pallet handling system is usually optimized to accept one single family of pallet types, with narrow margins of error. It follows that, in order to be effective, the AWLS should focus on one single pallet type, with a loading that is as uniform as possible (see Figure 3). The specific use case will determine the type of pallet, and the characteristics of the load. The system should be able to detect deviations from the standard pallet size and loading, and act accordingly. Such actions may be to correct the issue automatically (e.g.: rectifying the load), sending a warning to the warehouse supervisor, stopping the process, or any other action that may eliminate or mitigate the detected issue.

A clear distinction must be made between the AWLS-equipment onboard the wagon, and the dockside equipment. The diversity of pallets is most challenging for the automated warehouses to which the AWLS will be connected. As such, the dockside equipment, which is directly linked to the infrastructure, may be designed to handle a specific type of pallet only. The vectors of the AWLS, the wagons, however, should be designed to handle a range of pallets, since this would increase the flexibility of the wagon, and its compatibility with different dockside AWLS-implementations.

[FLX003]: The AWLS must be able to detect deviations from the standard pallet load, and act accordingly.

[FLX004]: The design of the wagon floor should be able to handle a range of pallet types.

[FLX005]: The dockside equipment may be designed to handle a single pallet type.

Figure 2: Diversity of pallets and cargo

Figure 3: Uniformity of pallets and cargo

Infrastructure – On top of the diversity in wagons and pallets comes the diversity in infrastructure. These may range from a minimal infrastructure with a simple concrete floor at rail level in the outside air, to a fully equipped and automated rail-connected warehouse. Again, designing a system that would fit all cases is unrealistic, and would needlessly increase the complexity of the system. Moreover, as the AWLS is ideally the missing link between an automated warehouse and the freight trains, it should be clear that the situation in Figure 5 is the preferred option. This option also has the advantage of providing optimal shelter for the dockside implementation.

Figure 4: Minimal infrastructure

Figure 5: Rail connected, automated warehouse

In any case, the design should limit the physical extent and complexity of the changes to the existing infrastructure, since space isn't always abundantly available, and whatever system is added to the dockside platform will inevitably decrease the space available for manual (un)loading. This requirement will also increase the potential of replicability of the system in a range of infrastructures.

A final requirement, linked with infrastructure, is the accuracy of train positioning. There are two basic modes of operations for the AWLS: either the train moves past a fixed point where (un)loading is performed wagon per wagon, or the train remains steady and a vehicle drives from wagon to wagon. The preferred option is strongly dependent on the available infrastructure and the organization of the warehouse. The case of the fixed point has the lowest impact on the existing infrastructure, but it does put a strong requirement on the accuracy of train positioning. Indeed, for successful (un)loading, each wagon should be halted exactly in front of the fixed point. Because of mechanical wear and play in the wagon buffers, such accuracy cannot be achieved. It is therefore mandatory that the dockside part of the AWLS can move back and forth sufficiently to compensate for the inaccuracies in train positioning.

[FLX006]: The AWLS should have minimal impact on the existing infrastructure.

[FLX007]: The dockside part of the AWLS must be able to compensate for inaccuracies in train positioning.

Note that [FLX007] implies that the dockside part of the AWLS needs to have at least a second degree of freedom.

3.4 Performance

Any automated system is only useful when it outperforms the manual modus operandi. Performance can be evaluated on many domains, but the determining ones are speed and reliability.

Speed – Manual loading or unloading of a freight wagon with pallets using a manned forklift can take up to 15 minutes, depending on the size of the wagon, the type and number of pallets and the surrounding infrastructure. A standard freight train can have up to 30 such wagons, which brings the total time for (un)loading close to 8 hours or a full working day. Any system that can decrease this time may save valuable resources and generate a positive business case. The benchmark for the required (un)loading speed is the performance of an ATLS, which manages to load an FTL in under 8 minutes. Since the aim is to outperform the trucking business, the ambition for this system should be to unload an FTL in 5 minutes.

[PER001]: A loading or unloading operation should take no more than 5 minutes, counted form the moment the wagon is ready for (un)loading (i.e. doors opened and aligned with the AWLS) until all pallets are at their final position.

Reliability – The design, implementation and maintenance of the system must align to yield an AWLS on which the client can depend 24/7 for the loading and unloading of freight trains. As is the case with all mechanical systems, good maintenance is key to good operation. Ideally, the maintenance is performed during planned downtime of the equipment. Ample downtime is foreseen for this system, since the train will often wait in the warehouse to be moved by a railway undertaking. Maintenance will reduce the risk of downtime due to technical issues, but reliability goes further than that. The system should continuously monitor the quality of the pallets, and adjust or alert when necessary. To avoid downtime for these reasons, a redundancy must be foreseen within the system which allows it to temporarily park pallets on a separate conveyer for inspection by an operator. In the meanwhile, the automatic (un)loading process should continue.

[PER002]: Maintenance intervals of the system must be aligned with planned downtime.

[PER003]: The system will not block upon detection of deviating pallet properties.

[PER004]: Overall system availability should be 99.99% over the course of one year.

3.5 Cost

The business case for any automation relies on increased performance, increased safety and reduced manual labor, to either boost revenues or cut expenditures. This improvement should then counterbalance the system's procurement and life cycle cost within an acceptable timeframe. As with many of the requirements for the AWLS, these figures will strongly depend on the selected use case. It is at this stage not yet possible to estimate the financial impact of the system, since the use case it yet to be defined, but it is possible to formulate a goal for the ROI. This goal is neither a functional requirement, nor a go-no go criterion for the system, but it does impose limitations on the cost of the system, which in turn have an impact on the design.

[COS001]: The ROI of the AWLS should not exceed 5 years.

ANNEX A: Consolidated functional requirements

N°	Label	Title
1	[SAF001]	Take all measures to remove or mitigate the risk of injuries to intervening personnel.
2	[SAF002]	Ensure pallet loading according to UIC Guidelines.
3	[COM001]	Ensure backward compatibility with legacy (un)loading methods and the AWLS wagon.
4	[COM002]	Ensure backward compatibility with legacy (un)loading methods and the AWLS infrastructure.
5	[COM003]	Ensure hardware compatibility with automated warehouse solutions.
6	[COM004]	Ensure software compatibility with automated warehouse solutions.
7	[COM005]	The AWLS wagon will only rely on off-board power supply for all power needs.
8	[FLX001]	The AWLS implementation on a wagon may not increase the floor height of a wagon
9	[FLX002]	The dockside implementation will be able to adjust for all loading heights that are at or above the level of the dock itself.
10	[FLX003]	The AWLS must be able to detect deviations from the standard pallet load, and act accordingly.
11	[FLX004]	The design of the wagon floor should be able to handle a range of pallet types.
12	[FLX005]	The dockside equipment may be designed to handle a single pallet type.
13	[FLX006]	The AWLS should have minimal impact on the existing infrastructure.
14	[FLX007]	The dockside part of the AWLS must be able to compensate for inaccuracies in train positioning.
15	[PER001]	A loading or unloading operation should take no more than 5 minutes, counted form the moment the wagon is ready for (un)loading (i.e. doors opened and aligned with the AWLS) until all pallets are at their final position.
16	[PER002]	Maintenance intervals of the system must be aligned with planned downtime.
17	[PER003]	The system will not block upon detection of deviating pallet properties.
18	[PER004]	Overall system availability should be 99.99% over the course of one year.
19	[COS001]	The ROI of the AWLS should not exceed 5 years.