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A GENERAL SIMULATION FRAMEWORK FOR SMART YARDS

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ABSTRACT

This paper presents a simulation framework for the logistics operations at Smart Yards. A Smart Yard is a digital and physical system enabling the collaboration of various companies at a logistics hub, e.g., seaport, airport or hinterland distribution center, and characterized by a decoupling point, automated vehicles for internal handling of cargo, and data sharing technologies. The framework is a high-level conceptual model for a hybrid Discrete Event and Agent-Based Simulation, comprising inputs, outputs, assumptions, flowcharts, and agents representing the complex interrelation of stakeholders and shared autonomous vehicles. We illustrate the concept of Smart Yard using three case studies and apply our simulation framework to one of these cases by analyzing the use of a Smart Yard at Amsterdam Airport Schiphol.

1 INTRODUCTION

Logistics companies face challenges regarding shorter delivery times, shortage of drivers, traffic congestion, safety and environmental concerns. Following the trends in digitalization and changes in the transportation system (e.g., automated vehicles and platooning), logistics hubs need to adjust and transform their yards into so-called Smart Yards to improve their operational efficiency and environmental footprint. Our idea of a Smart Yard is that of a logistics hub, e.g., seaport, airport, hinterland distribution center, using data-integration and information sharing technologies, Automated Guided Vehicles (AGVs) for internal handling of cargo, and a decoupling point (DP) to separate the inbound road modalities from the internal traffic, i.e., a pre-gate parking area. In addition, Smart Yards could improve the processes of other logistics service providers by supporting trailer swapping and truck platooning operations. The Smart Yard concept is being developed as part of the CATALYST (Connected Automated Transport And Logistics Yielding SustainabiliTy) project funded by the Dutch government and a consortium of logistics companies.

In this paper, we give a first definition of the concept of Smart Yard and provide a general and flexible framework for simulating them. Our focus is on Smart Yards where multiple independent stakeholders (logistics companies) collaborate through a shared DP and/or a shared pool of AGVs. The goal of the framework is to enable the analysis of internal and external flows of goods in a Smart Yard, considering different levels of data availability, automation, and shared resources. Typical problems as AGV routing and deployment or dimensioning of the AGV system are directly tackled by the framework, with the extra difficulty of managing conflicting interests on the shared use of AGVs. Moreover, it can be used to model and analyze the congestion and safety levels at road intersections, terminals, and warehouses being part of the Smart Yard for any kind of mixed traffic we wish to represent, both in a daily and long-term perspective. We illustrate our framework by describing simulation scenarios using three case studies corresponding with three port areas in the Netherlands, and present simulation results for one of these case studies. The final goal of Smart Yards is to be the cornerstones of an open, global and integrated transport system operated by individual companies, similar to what was envisioned in SETRIS (2017), to achieve a seamless, flexible, and efficient supply chain, connected on a physical, digital and operational level. The seamless connection of logistics service providers and freight modalities requires ample use of Information Technology (IT), meaning shared protocols and standards, and a higher grade of information exchange, as in the definition of Physical Internet by Montreuil et al. (2013). The long-term vision would be that of knowing in real-time the state, position, and arrival time of a shipment, container, or even a product, at any step of the supply chain. Examples of current technologies that can enable steps towards this vision are tracking and tracing, geofencing, and digital platforms. On a product level, tracking and tracing technology is widely used and allows customers and shippers to know past and current locations of goods, as well as receiving notifications on arrival and departures times. On a spatial level, geofencing technology allows the creation of virtual fences to remotely monitor tracked entities entering or exiting an area (Reclus and Drouard 2009). On a network level, digital platforms could be a relevant enabler of collaboration and data sharing inside and outside the port area, especially to support multimodal transport (Ding 2020). Simple multi-sided digital platforms are already being used for the auction of freight transport between shippers and carriers. More advanced cloud-based real-time platforms are being developed, with adaptive planning features for auctions of freight transport, to achieve quicker decision loops and shorten processing times of large trading volumes (Helo and Shamsuzzoh 2020; Kong et al.2015).

Automated vehicles are employed for transportation of material in many environments, e.g., production plants, warehouses, container terminals and external transportation systems (Vis 2006), and showed great potential in reducing costs and increasing the flow of goods at container terminals (Liu et al. 2002). Furthermore, the increase in real-time data availability will greatly benefit the implementation of automated vehicles, allowing better communication between vehicles but also between vehicles and the infrastructure. Following the definition of Wood et al. (2012), we consider any kind of autonomous or self-driving vehicle inside Smart Yards as automated vehicles, due to the connection and collaboration with other entities that excludes a completely autonomous behavior. For sake of simplicity, we use the term AGV to refer to any type of automated freight transport.

We present the concept of Smart Yard and its adaptation to three business cases in Section 2. In Section 3, we outline the general simulation framework. In Section 4, we illustrate the applicability of the framework by presenting a simulation model using one of the business cases. We end with conclusions and directions for further research in Section 5.

2 SMART YARDS

In this section, we introduce the general concept of Smart Yard and use several business cases to illustrate its possible adaptations. We use the term *yard* to refer to any logistics hub comprising various stakeholders, transport modalities, terminals, and warehouses for transshipment operations and value adding services (VAS). Moreover, we use the term *logistics centers* (LCs) to refer to any terminal, warehouse, or area for consolidation of goods. The number and type of stakeholders being part of a Smart Yard differs, but typically one would have several terminals, dozens to hundreds logistics companies (shippers, carriers, warehouses), a port authority, a customs authority, manufacturing and chemical companies, and any other agent usually present at a yard. The overarching Smart Yard system should include all entities that have an effect on the flow of goods, and align these entities through IT platforms to allow for planning of operations, on-line rescheduling, efficient use of pooled resources, etc. To be considered *smart,* a yard needs to make proper use of its data. The main type of information used in Smart Yards is related to logistics operations, e.g., arrival time of modalities and congestion levels. Being *smart* is also about sharing such data between actors inside the yard and to a certain extent over the supply chain. The shared information is then used to plan ahead, re-schedule previously planned operations, allocate resources, etc. Next, a Smart Yard features a DP to better control the internal flow. Here, inbound road modalities can park, detach their trailer or chassis with container, and move to a rest area. Furthermore, additional services might be present at the rest area, such as tank/container cleaning and washing, plugs for reefer containers, showers and restoration areas for drivers, container repairs, or even customs’ activities to avoid bottlenecks at the (un)loading warehouse.

The last smart trait is to employ AGVs for the internal handling of cargo. Automated transport, supported by data and the separation of internal and external flows, can reduce congestion at the yard, increase road safety, and allow for higher utilization of resources by continuous operations.

We distinguish two levels for a Smart Yard: a physical and a digital one. The digital Smart Yard can be seen as a platform to store and share information. Potentially, all incoming modalities, upstream locations in the supply chain, and freight destinations are connected to the digital Smart Yard. The digital level of a Smart Yard could enable functionalities of cyber-physical systems, effectively creating a digital twin of the physical operations (Alam and Saddik 2017). For example, after obtaining awareness on the state of the transport modalities and LCs (the cyber-physical system), an integrated simulation and analysis of future scenarios could be achieved (the digital twin), with the ultimate goal of self-configuration, optimization, and more robust planning of logistics operations. Different AGV routing algorithms could be used by the Smart Yard system based on the current congestion levels and forecasts. Also, (un)loading operations could be rescheduled after being notified about a late shipment. On the physical level, a Smart Yard can be identified with the area of a seaport, airport, hinterland hub, or distribution center, and the transportation movements between these locations. These areas can be open or (semi-)confined, which means control of entities entering the system is harder or easier, respectively. A confined area would ease the separation of traditional and automated traffic, thereby increasing safety, but a complete separation of the two traffic flows is often not realistic. However, using a DP to separate incoming road modalities, could reduce the necessary amount of human-driven vehicles in the Smart Yard area. Our focus is on the movement of freight between LCs, and between the LCs and the DP. Terminal operations and consolidation of goods have been extensively analyzed, both for traditional operations and with automated equipment, e.g., automated quay cranes (Steenken et al. 2004; De Koster et al. 2007). Therefore, we only implicitly incorporate the processes within LCs by the time they require.

To better understand possible uses of Smart Yards in practice, we briefly present different adaptations of the concept to two seaports and an airport in the Netherlands. These ports have common interests in the potential benefits of the Smart Yard concept, namely the reduction of congestion, round-the-clock handling by AGVs, and improved planning using data. Additionally, each port area has a different focus: (i) the port of Moerdijk focusses on the buffering effect of the DP and the use of smaller vehicles inside the yard; (ii) the port of Vlissingen focusses on increased safety and using the extra services at the DP to make them a preferable transit location for truck drivers; and (iii) Amsterdam Airport Schiphol (AAS) focusses on avoidance of disruptions and use of data for creating tighter schedules.

Figure 1: Smart Yard application at Port of Moerdijk.

Figure 1 shows the port of Moerdijk and its Smart Yard adaptation. This port is characterized by a compact layout and a confinable area due to fences and gates delimiting the main port area, which eases the complete decoupling between traditional and automated traffic flows. The port has two container terminals for (un)loading barges, an extensive pipeline network, rails that reach up to the seaside of the port, and many LCs on its area. The main problem for Moerdijk is its lack of maneuvering space at certain junctions inside the port area, which creates congestion at peak times. By creating a DP near the highway, a truck can (i) move directly to its destination, (ii) wait at the DP until prompted to move by the system, or (iii) wait and decouple its trailer or container that will be picked-up by an AGV. This calling system can solve congestion inside the port due to a buffering effect of the DP and the efficient routing, smaller size, and error avoidance achieved with AGVs. The port authority is unsure whether they should transition to a Smart Yard or simply invest in infrastructure. The port authority already conducted studies on infrastructural interventions, thus we plan to support them by providing insights on the potential of the Smart Yard concept regarding congestion and routing of internal handling.

Figure 2: Smart Yard application at Port of Vlissingen.

Figure 2 shows the seaport of Vlissingen, located in the southwestern part of the Netherlands. From a Smart Yard perspective, this port is similar to the port of Moerdijk, except that its layout is not as compact and the area is not as easily confinable, due to its geographical position, shape, and lack of pre-existing fences or gates. This results in less congestion but in more safety issues for drivers resting in the port areas at night. Here, we face mixed traffic consisting of traditional and automated vehicles. For this case, the rest area for drivers is merged with the DP, to achieve a complete Central Gate facility where all inbound trucks would stop, detach their trailer and use the extra services mentioned beforehand. The main goal of Vlissingen in pursuing the Smart Yard concept is to increase road and night safety for truck drivers, and make the port a preferred location for truck drivers, with many indirect benefits for the whole supply chain.

The last case is AAS, as shown in Figure 3. This case is characterized by an environment where passenger transport happens on a daily basis together with various types of freight transport. Therefore, we envision the area as a complete mixed traffic Smart Yard. Export of freight at the airport is performed by freight forwarders that consolidate goods and send it to cargo handlers. Then, these cargo handlers load freight on assigned planes within tight time windows. The import freight follows the same pattern but in the opposite direction. We consider the possibility of having one rest area just outside the airport and either one or two DPs: one for inbound road modalities and an extra one between cargo handlers and the landing strips, effectively automating the handling between freight forwarders and cargo handlers. The main problem at the yard is traffic congestion, in and outside the airport area, and flow disruption due to certain trucks with precedence arriving from outside the airport area without prior notice. Due to the high strategic value of its land, the airport authority wants to analyze the calling system, as for the scenarios of the Moerdijk case. Then, by using AGVs, improved data sharing, and the chosen number of DPs, the airport authority aims to reduce disruptions (no external trucks with precedence), reduce congestions, e.g., using real-time analysis of traffic and route selection for AGVs, and have a peak-shaving effect on the daily workload by performing handling of orders with wider time windows at night.

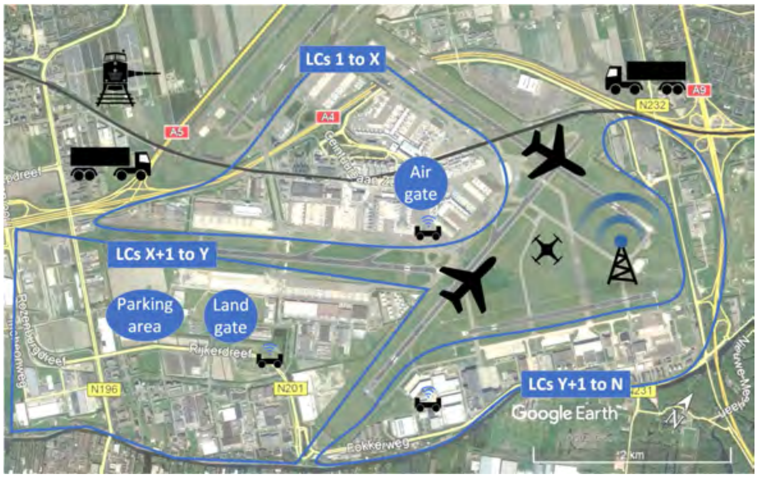

Figure 3: Smart Yard application at Amsterdam Airport Schiphol (AAS).

Having described the concept of Smart Yard and illustrated it using three potential real life applications, we now present a general framework for the simulation of Smart Yards.

3 SIMULATION FRAMEWORK FOR SMART YARDS

Following the description of conceptual models from Robinson (2008), we present a simulation framework for Smart Yards that comprises the necessary inputs, assumptions, KPIs, high-level process flows and logic agents for the simulation. The simulation framework should be able to guide the transition from yards to Smart Yards. Therefore, we want it to be general and adaptable to many different yards and future scenarios. The framework should allow to represent different layouts, equipment at LCs, equipment for internal handling, transport modalities, routing and planning methodologies, and changes to the available information and demand from the supply chain. Furthermore, it should enable the analysis of various challenges at yards, e.g., disruptions in traffic flows and safety concerns. The focus of the framework is on the logistics flows between the LCs and DP. Hence, the internal operations at LCs as well as the long-haul processes are not explicitly considered in the framework, but treated as black boxes.

In our simulation, a Smart Yard is characterized by a set of LCs, a set of different transport modalities, a set of internal handling vehicles, and a set of DPs (usually one). Each LC is characterized by an *(x,y)* position of its entry and exit point, a number of (un)loading locations for modalities, and a number of value adding services (VAS). Each transport modality j has a maximum load capacity $C^e(j)$ per type, while each internal handling vehicle k has a maximum load capacity $C^i(k)$, usually equal to that of a truck. Moreover, each DP has a set of parking spaces, each characterized by an *(x,y)* position, and a set of additional services for drivers and their trucks, each characterized by an *(x,y)* position and a capacity C^s. Lastly, new orders are generated following a time distribution or by the unannounced arrival of empty road modalities, and have a time window $[t_0, t_*]$ for on time fulfillment. An order o has a size $S(o)$ that uses up the capacity of assigned modalities, requires a processing time $T^p(o)$ depending on its size, and might require VAS with time $T^v(o)$. In Table 1, we summarize the necessary inputs for a simulation study on Smart Yards and their traffic flow capabilities. We consider five types of data for each main element of the model. While some parameters are given and presumably fixed on the short term (e.g., base yard layout, dimensions and capacity of modalities) others are up to us to define (e.g., logic behind the DP, capacity of the DP, drivers' services, number of AGVs, data availability). By data availability, we refer to the time at which we have information on the expected arrival, or delay, of a modality, be it deterministic or stochastic. By knowing or not knowing expected arrivals and delays beforehand, we can test the robustness of the scheduling algorithms for (un)loading time slots.

Table 1: Input data for simulation of Smart Yards.

Elements	*Geographical*	*Resources*	*Technical*	*Stochastic*	*Logic*
LCs	Location of entry/exit gates	Capacity of processes and VAS, docking bays	Dimensions	(Un)loading time, time for VAS, arrival of orders	Slot assignment, order time windows
DP + rest area	Location of gate and drivers' services	Parking slots, capacity of drivers' services	Dimensions of parking slots and drivers' services	Processing times at gate and drivers' services	Slot assignment, traffic rules
Transport modalities	(Un)loading locations	Load capacity	-	Arrivals, availability of data	Constraints on docking, departures
Internal handling vehicles	Standby area	Type and number of vehicles	Dimensions, speed, braking, turning angle, battery	Time to (de)couple, availability	Traffic rules, jobs assignment

Moving forward, we have a list of assumptions for our Smart Yards. Since we are interested in the traffic flow to evaluate the effects of AGVs and the DP, most of the assumptions are on internal processes at LCs and behaviors of sea, rail, and air modalities. These are clear points that can be modelled in more detail, if necessary, to increase the accuracy or credibility of the model.

- We assume operations inside LCs to be optimized and out of scope, except for the (un)loading of modalities and VAS.
- We assume that orders arriving at LCs are for one container or Full Truckload (FTL), i.e., the order size $S(o)$ equals the maximum capacity of road modalities C^{road}.
- We assume VAS to be either simple or complex. Complex VAS can only be performed at warehouses, while simple ones can also be performed at terminals.
- We assume the arrival process of transport modalities to be given, when approaching and leaving the Smart Yard. Therefore, we do not explicitly model congestion effects outside the yards.
- We assume transport modalities approaching the Smart Yards to have fitting dimensions for their respective terminals and docking bays.
- We assume containers and trailers to have negligible size differences when attached to trucks or waiting at parking locations.
- We assume traditional trucks inside the Smart Yard to follow the shortest path route to their destination.
- We assume resources, positions of gates, and dimensions of LCs to be fixed.
- We assume stocks to always be available for new orders and shipments. With this, we focus on the on time fulfillment of orders instead of the management of inventory levels.

Table 2: Key Performance Indicators.

Type	*Monetary*	*Process*	*Safety*	*Traffic flow*
LCs	-	Utilization of resources	-	Average vehicle queue
DP+ rest area	Investment for land area, invest. for service facilities	Util. of parking slot and services	AC, ISD	Congestion level Average vehicle queue
Transport modalities	-	Waiting time at LCs or DP	AC, ISD	-
Internal handling vehicles	Invest. on vehicles, cost of standby area, infrastructure	Util. of vehicles, idle and waiting times	AC, ISD	Number of trips, total driven distance
Smart Yard	Total investments	On time orders, avg. order throughput time	Total AC, total ISD	Internal congestion level

We propose a set of KPIs that are relevant for most studies on Smart Yards. These KPIs are related to costs, traffic flows, safety, and processes at LCs and the DP. In Table 2, we display various KPIs for each of the four model elements from Table 1 and on the overall level. Note that our list of KPIs is not exhaustive and various KPIs can easily be represented in multiple ways, e.g., the amount of on time shipments can be seen as a service level percentage or as a monetary loss for the late shipments. Although transport modalities are not the chosen mean of transport for internal handling, road modalities are occasionally allowed to enter the Smart Yard and directly go to a warehouse, due to planning exceptions. That is the reason we included collision avoidance, as the number of avoided collisions (AC) and infringement of safety distance (ISD) in the Transport Modality row.

As our focus is on improved planning of operations, decoupling, and AGVs, we create flowcharts for the movements of freight inside the yard. The flowcharts are stylized representations of operations in any yard, where we try to capture general choices and possible routes for the internal handling of goods, which can then be better specified for any given simulation study. We have two separate flowcharts for inbound and outbound cargo at Smart Yards, although a simulation model could represent only the inbound part, the outbound part, or both parts simultaneously. To obtain the corresponding flowcharts for traditional yards, it is sufficient to remove the physical processes with a trapezoid shape and to disaggregate the information processes, by performing the logical operations written in italics at the corresponding physical process instead of performing them in advance. For example, at traditional yards we discover if cargo requires a long or short stay after unloading it, not while the modality is travelling to the yard. Also, internal handling processes with a thick line are performed by AGVs at Smart Yards and by normal vehicles at traditional yards. Note that in our flowcharts we refer to terminals and warehouses instead of LCs.

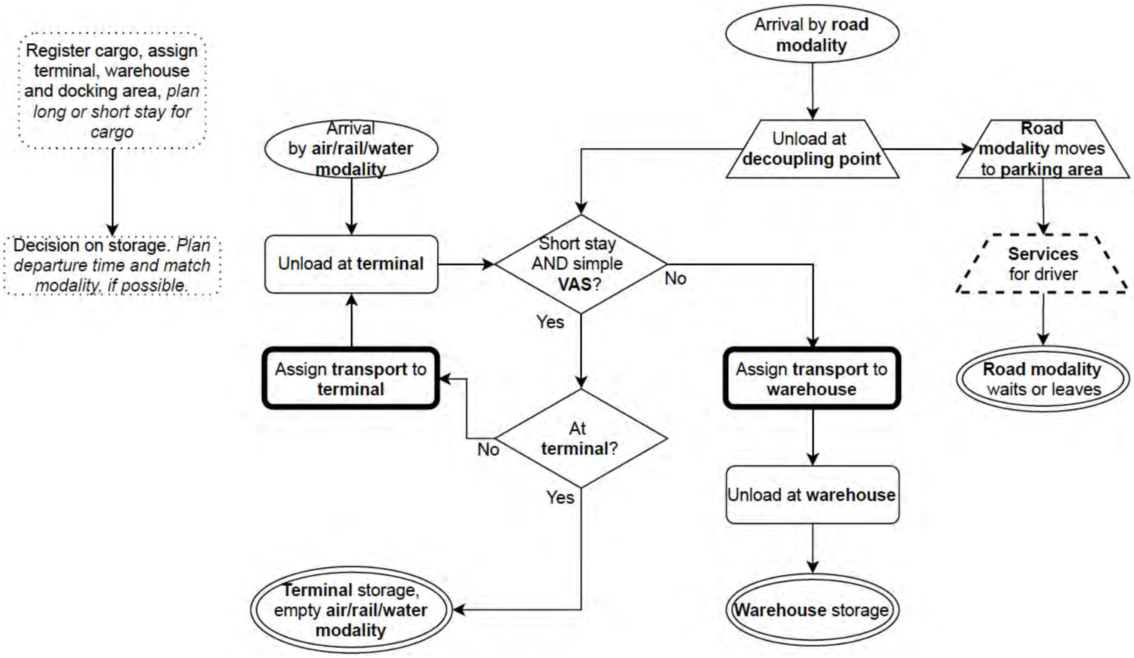

Figure 4: Inbound processes at a Smart Yard.

In Figure 4, we represent the inbound operations, where we distinguish between triggering events (ellipse), end events (double ellipse), optional processes (dashed line), information processes (dotted line), decoupling processes (trapezoid shape), and internal handling processes (thick line). Bolded words are inputs to the simulation model. The underlying logic of the inbound flowchart is that modalities arrive and their cargo, or freight, has to be unloaded at corresponding logistics center, e.g., sea terminal or rail terminal. The cargo unloaded at terminals can either be stored locally or moved to warehouses and stored there, depending on the expected length of stay and VAS required. For inbound road modalities, we see they always unload at DPs, potentially use driver's services and then decide whether to wait for freight to be picked-up or leave. The unloaded cargo is moved to a LC defined by the available information. Again, if freight is expected to leave soon and does not require complex additional services, it is unloaded at a terminal, otherwise it is unloaded at a warehouse. Additionally, a departure time and transport modality are immediately planned for the cargo, trying to satisfy the time windows of orders. If no information is available, a warehouse is selected as storage point and no plan is made. Finally, we represent the quicker digital administrative process by aggregating decisions and planning tasks at the first steps in the flowchart.

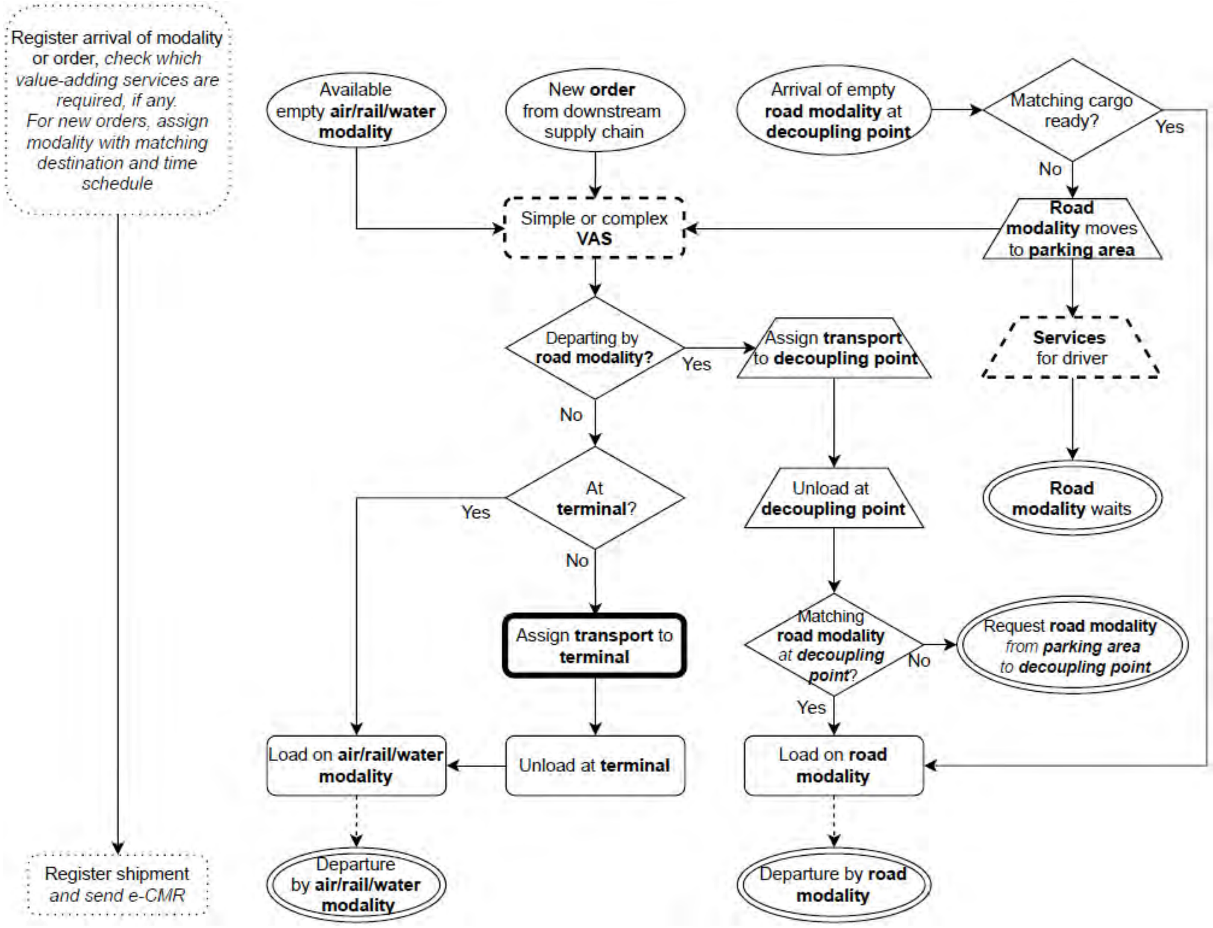

Figure 5: Outbound processes at a Smart Yard.

In Figure 5, we represent the outbound operations at Smart Yards. The outbound operations are triggered by an empty modality becoming available or the arrival of a new order. An empty modality could be a vessel, train, or plane that just finished unloading at the yard or a road modality that arrived empty or was waiting at the DP. Necessary VAS are performed based on the order and the LC, then the cargo is loaded on the assigned modality. In case the cargo is at a warehouse and needs to be loaded onto a vessel or train, it is transported to the specific terminal by internal handling vehicles. We see that the matching of transport modalities is only necessary for new orders, as the cargo stored in the inbound phase (Figure 4) was already planned and assigned to a modality if the order was already known. Also, freight and modality matching happens as soon as new orders are notified or a modality becomes available, completing administrative tasks early (before the physical loading) and digitally sending an electronic consignment note (e-CMR) when the modality leaves. The last important feature to highlight is the intertwined behavior of freight and road modalities at the DP. When an order is prepared and freight is brought to the DP, it might happen that a matching truck is not present. In this case, the freight waits. Vice versa, an empty road modality could arrive, or become active, at the DP, then wait until its matching cargo is ready. Using digital platforms, these situations can be managed with better and flexible matching. As shown by the locations being in italics, for traditional yard this matching is not performed at the DP but at LCs.

Lastly, we deem of high importance to represent the independent stakeholders with possibly conflicting interests, as well as individual AGVs, as realistically as possible in the simulation. Therefore, we use a combination of Discrete Event Simulation (DES) and Agent-Based Simulation (ABS), which are both substantiated to be effective and amply used in simulation studies of LCs, port areas, and AGVs. For a comprehensive literature review on port simulation see Dragović et al. (2017); for examples of ABS at container terminals and airports see Mes and Douma (2016) and Wibowo et al. (2015) respectively; for examples on ABS for AGVs see Marinica et al. (2012), Garro et al. (2015). More specifically, we use DES for all processes at the Smart Yard, and use ABS for conflict handling by AGVs and the assignment of AGVs to transportation demand of LCs. For the control of AGVs, we use the Multi-Agent System from Gerrits, Mes, and Schuur (2018). In their simulation study on automated container terminals, they propose a three-level system: a high-level control layer for terminal operations planning, a mid-level layer to efficiently manage the terminal equipment based on the planning coming from the higher level, and a low-level layer to model sensors and movements (e.g., turning, breaking) of each AGV. The middle level, called Traffic Manager, is composed of agents responsible for assigning tasks, routing vehicles, solving precedence conflicts, and managing the batteries of AGVs. In our case, the list of agents and their description is adapted from the Traffic Manager but still general, which means they can be further specified and even divided into sub-agents in future simulation studies. We extend this Multi-Agent System to cope with the multi-stakeholder environment. More specifically, we split the so-called Dispatching Agent into two agents, to address (i) the complexity of conflicting interests on the use of shared resources by a multitude of stakeholders, (ii) the necessity not to share sensitive information on internal operations at LCs, and (iii) the effect of system-wide optimization policies on the assignment of AGVs. Moreover, since the Smart Yard area can be very large and exhibit complex traffic situations, we propose conflict handling to be performed at a local level by allowing the AGV agents involved in the conflict to communicate with each other. These challenges advocate the use of ABS in our simulation framework for Smart Yards.

We propose eight agents to model AGVs' behavior in the simulation: the first four agents are system-wide and take decisions at the central level, the other four agents are instantiated for each LC or AGV, and represent the individual interests or status of the corresponding entity.

- Routing Agent. Triggered by the LC Dispatching Agents when requesting transport jobs. Determines the route for an AGV using the input of the Location Manager and (expected) congestion levels at the Smart Yard.
- Battery Manager. Triggered by the statuses of AGVs. Checks their battery levels and generates charging schedules considering assigned transport jobs.
- Location Manager. Triggered by the Routing Agent for geographical inputs. Returns origin and destination for each transport job and parking locations for AGVs and road modalities when idle.
- Central Dispatching Agent. Triggered by the LC Dispatching Agents for AGVs assignments and by newly available AGVs. Auctions AGVs to transport jobs based on the expected value of the route (the bid). The bidding value is corrected by fair allocation mechanisms, e.g., favoring companies that have not been serviced for longer, and optimization policies defined at a Smart Yard level, e.g., prioritization of terminals.
- LC Agent. Triggered by information on the arrival of a transport modality or a new order. (Re)schedules (un)loading slots based on capacity and available information, then requests a matching AGV to the LC Dispatching Agent.
- LC Dispatching Agent. Triggered by the corresponding LC Agent sending new transport jobs. Requests the matching of transport jobs and AGVs to the Central Dispatching Agent, based on the expected value of the route as calculated by the Routing Agent.

- AGV Agent. Triggered by changes in AGV status and requests from other agents. Brings awareness to the AGV regarding its status (e.g., speed, position), processes incoming information, and answers requests from other agents.
- Conflict Handling AGV Agent. Triggered by conflicts between own AGV and others, i.e., vehicles blocking each other's path. Solves or avoids conflicts by engaging other involved Conflict Handling Agents and deciding on precedencies.

4 SMART YARD SIMULATION FOR AMSTERDAM AIRPORT SCHIPHOL

To illustrate the applicability of the framework for the simulation of Smart Yards, we consider one of the business cases described in Section 2, namely the Amsterdam Airport Schiphol (AAS) case. For this case, we use the framework to implement a simulation model in the licensed DES software Tecnomatix Plant Simulation from Siemens, which features object-oriented programming and 2D/3D graphics. We created a 3D visualization of the south-west AAS area, as shown in Figure 6, where we used markers to define routes between the locations, so that vehicles follow the actual road infrastructure. We only modeled the export process and three LCs located near a landing strip, to focus on a first analysis of the calling system as described in Section 2, i.e., whether to have a DP or not.

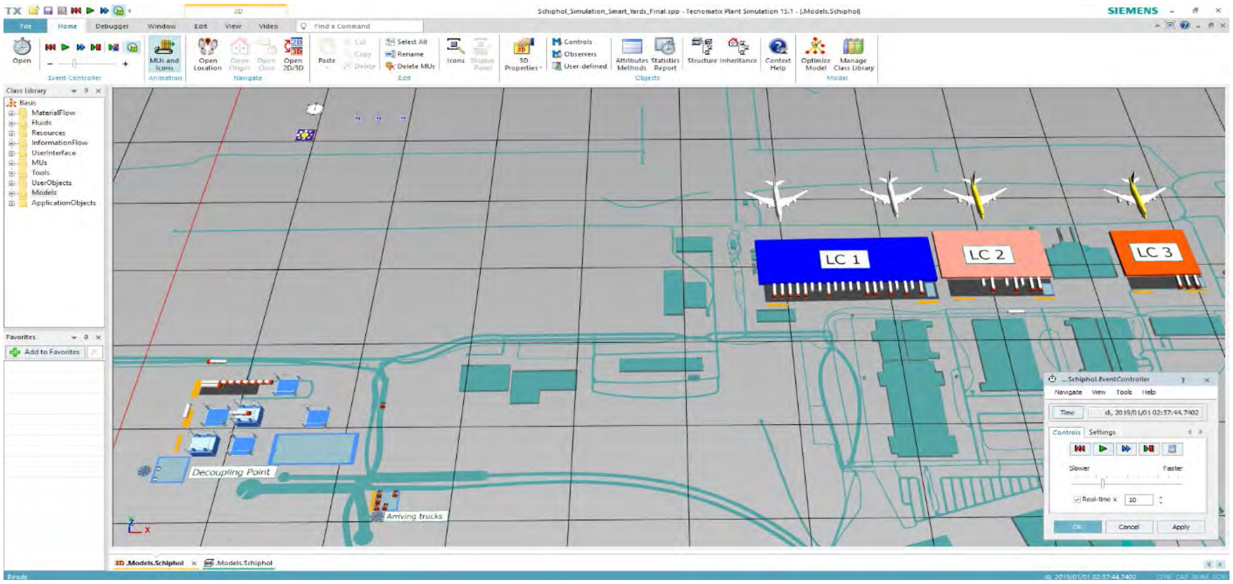

Figure 6: Screenshot AAS Smart Yard Simulation.

In the simulation, we modeled the current situation as a benchmark, where trucks move directly to LCs, to compare this to (i) a scenario where trucks wait at a Truck Parking (TP) area inside the DP until called by a LC, (ii) a scenario where the cargo is (de)coupled and traditional trucks are used for internal handling between the DP and LCs, and (iii) a scenario where cargo is (de)coupled and AGVs are used for internal handling. These scenarios can also be used in combination, except for scenario iii and iv together, as either traditional trucks or AGVs are used. Therefore, we can experiment with the percentage of inbound trucks directly unloading at an LC, stopping at the TP, or stopping and (de)coupling.

We created a flexible simulation model where various inputs can easily be extended or changed. We modeled the following inputs: locations of LCs, number of docks and unloading times at LCs, arrivals of road modalities with calm or busy periods (i.e., low or high freight traffic), DP location, TP capacity, (de)coupling time and capacity, number of internal handling vehicles (AGVs or trucks), and vehicle characteristics. Specifically, we set a capacity of 40 parking spots at the TP, 5 AGVs or trucks for internal handling, and a calm arrival of trucks except for Tuesdays and Fridays, which are busy days with respectively twice and thrice the usual traffic. Regarding the vehicles, we set a maximum speed of 60 km/h for traditional trucks and 35 km/h for AGVs. Moreover, we accounted for congestion by reducing the speed of all vehicles based on the number of trucks waiting at the LCs, thus vehicles waiting at the DP are excluded. For low, mid, and high congestion levels the reduction in speed is respectively, 10%, 30%, and 80%. This exponential decrease in speed is to assess the usefulness of a DP in extreme conditions.

The outputs assessed with the simulation model are the following: average throughput time (TT); waiting times at the LCs, TP, and for the (de)coupling process; and utilization of buffers at the LCs, TP and (de)coupling process. We run the following experiments: (1) the current situation where trucks move directly to the LCs; (2) the situation where 50% of the inbound trucks stop at the TP and 50% move directly to the LCs; (3) the situation where 33% of the trucks stop at the TP, 33% stop and (de)couple the trailer (or container) to a traditional truck for internal handling, and 33% move directly to the LCs; and (4) a situation with percentages identical to experiment 3 but using AGVs for internal handling.

For every experiment, we use a warm-up period of a week, five replications, and a run time of 3 weeks, to achieve a relative error lower than 5%. Table 3 shows the experimental results from the AAS case simulation model. From the results, we see that the average throughput time increases slightly due to the (de)coupling process. Furthermore, we see that the average travel time shortens with the TP option or (de)coupling with trucks, but rises again with AGVs due to their lower speed, and that the average waiting times shifted from the LCs to the TP and DP. Therefore, having a TP or DP should reduce congestion at the LCs and on the road, as the average travel time decreases. In turn, we suggest that this would improve road safety. We see that utilization of the TP or DP is low, thus waiting time at the TP or DP is caused by the queues at the LCs. This also means that the suggested capacity for the TP or DP could satisfy an increase in freight arrivals. With the current model, we see no significant benefits from the use of AGVs nor a positive pooling effect of shared resources (AGVs, TP or DP), as the modelled area is relatively small and with just three LCs. However, for small logistics systems, we can see the benefits of a TP with a calling system for inbound trucks.

Table 3: Simulation results AAS.

Experiment	Avg. TT (hh:mm:ss)	Avg. travel time (mm:ss)	Avg. waiting time (mm:ss)			Utilization (%)		
			LC	TP	(de) coupling	Avg. LCs Buffer (congestion)	TP	(de) coupling
1	00:59:08	03:53	25:14	-	-	33,1	-	-
2	01:05:23	02:47	00:54	31:42	-	17,6	14,3	-
3	01:05:18	03:13	02:08	26:28	02:07	23,0	13,3	3,4
4	01:06:25	03:43	01:23	23:51	06:07	22,8	13,2	7,4

5 CONCLUSIONS

We illustrated the concept of Smart Yard and presented a general simulation framework to guide traditional yards in their transition to a Smart Yard. We defined a Smart Yard as any logistics hub implementing a Decoupling Point (DP) to separate internal and external transport flows, AGVs for the internal handling of goods, and data-sharing to improve the (on-line) planning of operations. We applied the Smart Yard concept to three business cases. Next, we presented a hybrid Discrete Event and Agent-Based simulation framework, where agents represent the independent stakeholders and control the AGVs. Finally, we applied our framework to a simulation study at Amsterdam Airport Schiphol (AAS) and analyzed traffic flows, waiting times, and utilization of Smart Yard facilities.

Possible directions for further research are (i) to (more extensively) model all the business cases, to assess generality and flexibility of the framework, (ii) to expand the framework to form (driverless) truck platoons at the DP, (iii) to model Less Than Truckload (LTL) orders and the order consolidation at LCs, and (iv) to evaluate routing algorithms for AGVs using scenarios of demand and advance information.

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