Innovations in Self-Organizing Maritime Logistics

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Abstract Maritime logistics, where competition is fierce, is in dire need of efficient modes of transport. Automated systems are inevitable, ultimately developing themselves into self-organizing logistic systems. This chapter highlights some promising recent innovations in that area. As innovative automated systems, we discuss: (i) autonomous yard tractors, (ii) unmanned cargo aircraft, (iii) truck platooning, (iv) autonomous vessels, and (v) extended gates. To control these systems, we discuss innovative forms of intelligent decision-making, namely: (i) distributed planning, (ii) matching platforms, (iii) cooperation between barges and terminals, (iv) shared services and fair optimization, and (v) gamification in container supply chains. Moreover, we design a unifying framework that classifies automated systems within maritime logistics according to their potential to grow out to self-organizing systems.

1 Introduction

This chapter focuses on promising recent innovations in maritime logistics. We discuss innovations based upon two pillars: automated systems and intelligent decision-making. We show how these pillars intertwine and sketch a road toward self-organization.

To exploit to the fullest the many features of modern transport, we need a system to support us. Decision-support systems like automated braking and adaptive cruise control are already helpful. But why not delegate the entire control to some kind of autonomous system? In the field of maritime logistics, where various modes of transport come together, practitioners need to be efficient in order to outperform the fierce competition. Availability of human labor may be scarce, especially 24-7. Here, automated systems come to our rescue. But they may be conceived as a first step.

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Ultimately, a far more advanced idea would be a self-organizing logistic system. Such a system consists of autonomous units, each with its own goal. By mutual cooperation, they are able to achieve a common goal. We argue that an increasing degree of automation has the potential (or urge) to become more autonomous and simultaneously pushes toward self-organization.

Our aim is to highlight some interesting novel applications of automated systems within maritime logistics that have the potential to grow from automated—via autonomous—to self-organizing. Our discussion splits up into two parts. In Sec. 2, we consider innovations related to hardware (autonomous systems), such as autonomous vessels. In Sec. 3, we consider innovations related to processes (intelligent decision-making), such as Multi-Agent systems for barge handing. Subsequently, in Sec. 4, we elaborate on the concept of self-organization. More specifically, we combine autonomous hardware with intelligent decision-making and present a positioning framework. Sec. 5 gives our conclusions.

2 Innovations in Autonomous Systems

This section highlights some promising innovations regarding autonomous transport and automated systems in maritime logistics. Next to the key elements of maritime logistics, such as container terminals and vessels, we also address innovations in related areas, such as hinterland transport and first- and last-mile transport. Section 2.1 introduces autonomous yard tractors, which can be used for the horizontal transport of containers in container terminals or port areas. Section 2.2 focuses on hinterland connections using unmanned cargo aircraft. As for conventional hinterland transport by means of trucks, Sec. 2.3 introduces an optimization approach using truck platooning. In Sec. 2.4 we discuss the usefulness of autonomous vessels and in Sec. 2.5 we consider the use of extended gates, such as pre-gate parking areas and floating terminals.

2.1 Autonomous Yard Tractors

Container terminals worldwide have adopted increasing levels of automated or unmanned systems to increase productivity. In the early 1990s, the first Automated Guided Vehicles (AGVs) were introduced, and many related automated systems, such as automated ship-to-shore cranes and automated straddle carriers, have found their way to market, as an incentive to increase operational productivity (Montoya-Torres et al., 2015) and reduce the dependency on the availability of human labor.

Deploying AGVs in container terminals comes with certain infrastructural and safety requirements (e.g., transponders in the ground and separation of manual and automated transport). Therefore, AGVs and other highly automated solutions are typically only deployed in green field terminals as the required infrastructural and

Fig. 1 Illustration of automated yard tractors. Adapted from Gerrits et al. (2020)

safety-related changes are too costly. To exemplify, AGVs are exclusively deployed in so-called perpendicular oriented terminals, given the orientation of the stacks compared to the shore. Opposed to parallel-oriented terminals, where the stacks are parallel oriented to the shore. In perpendicular oriented terminals, the stacks create a physical barrier between the automated systems (i.e., horizontal transport between the shore and the stacks) and the manual operations (e.g., pick-up and drop-off by road trucks), resulting in a safe and controllable environment. These types of terminals are common in Europe, exemplified by the ECT Delta Terminal and the APM Maasvlakte II Terminal in Rotterdam, the Netherlands. However, the vast majority of terminals worldwide are parallel oriented and therefore lack a physical barrier. Mainly due to this layout, the adoption of automated vehicles in brownfield terminals is minimal. Instead, manual-operated yard tractors are used in many of these terminals for the loading and unloading of containers at both the ship-to-shore cranes and the stack cranes.

Recent advances and innovations have created opportunities for brownfield terminals to adopt automated vehicles in the form of Automated Yard Tractors (AYTs). Examples include the Volvo Vera and the Terberg AutoTUG, as illustrated in Fig. 1.

These AYTs are able to drive unmanned and autonomously. Theoretically, AYTs can be deployed in any parallel-oriented terminal, but they also pose additional challenges. In these terminals, (non-automated) road trucks and yard tractors share the same infrastructure. Therefore, introducing AYTs results in a so-called Mixed-Traffic Terminal (MTT). In an MTT the road infrastructure is shared between AYTs and road trucks. Gerrits et al. (2019) show how this merging process should be managed in order to create a safe, understandable, and efficient system. When new (parallel-oriented) terminals are planned and designed, it is crucial to take into account the impact of AYTs. Moreover, the business case of AYTs compared to manually operated yard tractors should be made explicit in order to positively influence the uptake of AYTs in practice. Besides the reduced dependency on human labor, which can be a serious issue when this specific skill set is little available, particularly in remote areas, it is also important to consider the impact on operational efficiency (e.g., ship-to-shore crane utilization).

A first step to explore the latter is presented in Gerrits et al. (2020). The authors develop a simulation model to address the impact of AYTs in parallel oriented terminals with mixed-traffic. They show that high utilization rates can be achieved with a modest number of vehicles. On the other hand, they show that when mixing in manual traffic (e.g., road trucks to pick-up and drop-off containers), such systems are prone to traffic congestion and thus a drop in performance can be expected. To counteract the latter, the authors propose to introduce a pre-gate control to manage the inbound flow of road trucks.

Moreover, AYTs can be used in combination with extended gates (see Sec. 2.5) to decouple pick-up and drop-off operations with long-haul transport. Also, inter-terminal or inter-company transport (e.g., from and to empty container depots) are application areas of AYTs. In these latter cases, the AYTs move away from an MTT to the open road, which poses additional challenges in terms of safety, legislation, and societal acceptance.

2.2 Unmanned Cargo Aircraft

Crucial for any seaport is a smooth connection to the hinterland (Merk & Notteboom, 2015). Cargo should be transported to the destination in an efficient way. Rail, road, and inland water are traditional modes to accomplish this. An interesting innovation—that is still in its childhood—is the use of unmanned cargo aircraft (UCA). There are basically two types of UCA: small drones like those developed by Amazon for delivering small packages over short distances, and large UCA that can fly loads of a few hundred pounds over large distances. The latter are particularly interesting for hinterland connectivity, so let us dwell on those in this section.

Depending on the type, a UCA has a cargo capacity between 2 and 20 tons, a range varying from 1000 to 10,000 km, and a cruising speed of around 450 km/h. A UCA is highly autonomous. It only needs a remote human controller giving general instructions on course, altitude, etc. This person can monitor multiple UCA simultaneously (Heerkens, 2017).

According to the Dutch platform for unmanned cargo aircraft (PUCA), UCA can be more productive and cheaper to operate than manned cargo aircraft. An obvious advantage of a UCA is the savings in crew costs. In addition, there is no need to take into account the duty lengths of the on-board crew. Therefore, UCA can fly with low cruising speeds so as to reduce fuel consumption. This leads to larger ranges compared to manned aircraft. Lower speeds can do with shorter runways, simplifying the infrastructure needed. Another advantage of a UCA is that no pressurized cabin is needed, since no living creatures will be inside the aircraft. Thus, a complicated and maintenance-intensive air-conditioning system can be eliminated (Heerkens, 2017).

A further advantage also has to do with the construction of the UCA. The ideal shape of an aircraft from a fuel efficiency point of view is a “flying wing,” a tailless fixed-wing aircraft that has no definite fuselage. Accommodating passengers or crew inside the main wing structure—next to cargo, fuel, and equipment—would require

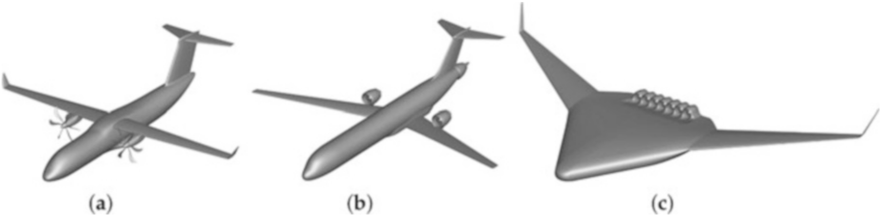


Fig. 2 Illustration of different types of unmanned cargo aircraft. (**a**) Tube and wing, (**b**) tube and wing, (**c**) blended wing body

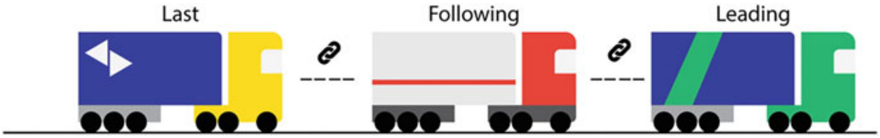


Fig. 3 Illustration of a truck platoon. Adapted from Gerrits et al. (2020)

a deep and heavy structure. On the other hand, since most cargo can be transported in relatively small containers, a flying wing with just a small thick section in the middle can in theory be an excellent UCA. Such a "blended wing body" (Liebeck, 2004) ideally uses up to a quarter less fuel than a conventional "tube and wing" aircraft, see Fig. 2 (Heerkens, 2017).

Because of the ability to start and land from short runways—roughly at least 150 m—and the high range of a UCA, it can reach destinations almost everywhere in the world without needing much infrastructure. Where other transport modes fail, they can easily reach regions affected by disaster.

A major barrier to the introduction of UCA is the problem of how to integrate them into controlled airspace. Until standardized "sense & avoid" equipment is certified worldwide and procedures like protocols for communicating with air traffic controllers are developed, UCA will be confined to dedicated airspace. Nevertheless, the American Federal Aviation Administration predicts that in 40 years, 40% of air cargo will be transported by UCA.

2.3 Truck Platooning

The concept of truck platooning has been around for several years and is an intermediate solution in the transition from manual to fully autonomous driving. Similar to army platoons, a truck platoon is a convoy of digitally connected trucks, as illustrated in Fig. 3. In at least one of the trucks, there is a human driver to coordinate the platoon in order to comply with (future) legislation regarding autonomous driving. Through digital connectivity and advanced sensor systems like lidars, the trucks are able to maintain a short, but safe following distance on for example highways. One may view truck platooning as an advanced version of adaptive cruise control found in consumer cars, and we denote this as Cooperative Adaptive Cruise Control (CACC). Given the short following distances as a result of CACC, one can expect a decrease in fuel consumption and related emissions due to a decrease in aerodynamic drag (Alam et al., 2015; Robinson et al., 2010). Moreover, it increases road capacity (Li & Ioannou, 2004), without sacrificing safety (Taleb et al., 2010).

Taking into account the operational side of truck platooning (e.g., finding a truck to platoon with) is also an important step to facilitate the integration of truck platooning in the supply chains of logistics service providers. This particular aspect of truck platooning is denoted by *platoon matching* and is further discussed in Sec. 3.2.

Besides the benefits mentioned above, platoons reduce the dependency on the availability of truck drivers. Ignoring (current) regulatory issues, it is possible that only one driver is needed in the leading truck and the other truck(s) follow automatically, without the need for a person in the driver seat. Moreover, truck drivers may be replaced by a control room, where platoons are remotely monitored. This is particularly useful when few truck drivers are available in a certain region, for example in remote areas. Long-haul transport can be carried out using platoons with only one driver, or using teleoperators. Besides the obvious cost reduction, this also allows the shift from daytime to nighttime operations. Particularly in highly congested areas, moving away from peak hours has multiple benefits, both for the traffic system as a whole, as well as for logistics service providers. To exemplify, trucks typically operate a large part of their operations during the day, due to the dependency on human labor and opening hours of businesses. When deploying platoons, fewer drivers are required to transport the same amount of goods and thus an opportunity arises to execute this during the night time or in less congested time periods. The platoons can be parked and split on strategic (secured) locations when platoons arrive outside the opening hours of the destination (e.g., a container terminal). When the terminal opens the next day, the (inbound) goods are immediately available for further processing. Similarly, at the end of the day, transports can be prepared for (nighttime) transport using platoons. Obviously, when a platoon arrives at a destination, the very last mile is operated manually. However, this can be done by the driver of the leading truck, operating every truck in the platoon one at a time. Moreover, at the destinations (e.g., container terminals) personnel is typically readily available to execute these final operations (e.g., entering the terminal, taking care of paperwork or rear-ward docking). Similar to unmanned cargo aircraft, truck platooning is also beneficial for connecting container terminals and businesses in (far away) remote areas with more densely populated business areas.

2.4 Autonomous Vessels

The shipping industry is vital for our global economy. Maritime transport is the only option for transporting large volumes of cargo among continents (Gu et al., 2021). In coping with growth and complexity, traditional solutions such as building larger ships have reached their limits. Major innovations, such as autonomous vessels, are believed to be necessary (Kretschmann et al., 2017). The interest within academic literature on automated marine vessels is rapidly increasing. In (Gu et al., 2021) a comparison is made between the existing literature on autonomous vessels and autonomous vehicles. It is observed that, in both cases, significant work has been done on navigation control and safety. Due to the high maturity of self-driving vehicle technology, the attention from the logistics research community shifted from fundamental topics (control and safety) to application topics (transportation and logistics).

For autonomous vessels, the development of real-world applications is slower. Therefore, the research priority still remains on the basic issues today (control and safety) and has not yet switched to transportation and logistics issues. The situation is gradually changing. In December 2018, Rolls-Royce and the Finnish state-owned ferry operator Finferries demonstrated the operational feasibility of the world's first fully autonomous ferry (Rolls-Royce, 2018). In the trial voyage, both navigation and docking are handled by the ferry with zero human intervention. Furthermore, the world's first fully electric and autonomous container ship, Yara Birkeland, will start fully autonomous operation by 2022 (Kongsberg, 2018).

The focus of autonomous vessel literature on control and safety is understandable. Collision avoidance is critical when no human is on-board monitoring the surroundings and controlling the vessel. In Gu et al. (2021), studies are reviewed about individual and group navigation control problems for unmanned vessels. The most discussed issue in the literature regarding the control of one single autonomous vessel is the planning of its path or trajectory. Methods are manifold. They vary from Dijkstra's algorithm to fast marching methods and multi-objective particle swarm optimization. To complete certain tasks, multiple autonomous vessels are needed. Therefore, the group control of these vehicles in such scenarios becomes critical. One of the most popular formations used in group control of autonomous vessels is the leader-follower structure. In leader-follower strategies, one or more vessels can be considered as leaders, and others regarded as followers. The followers track the locations and velocities of the leaders to achieve a desired formation pattern. Similarity with truck platooning (see Sec. 2.3) is obvious, albeit that the latter requires a more rigid formation.

As the technology of autonomous vessels matures, we expect—as for autonomous vehicles—an attention shift from control and safety to transportation and logistics, which will motivate researchers to start working on realistic applications of autonomous maritime transport.

2.5 Extended Gates

The notion of extended gates in maritime logistics comprises operations by different firms (e.g., terminal operators) beyond their own gates. In this section, we discuss two specific uses of the extended gate concept: pre-gate parkings and floating terminals.

Pre-gate parkings are useful to decouple long-haul and last-/first mile transport. By establishing a parking area close to a port, firms can use this area as a temporary buffer or as a physical decoupling point. When using a pre-gate parking as a buffer, inbound transport no longer drives directly to a terminal, but to the pre-gate parking instead. The terminals close to the parking area decide when to call the truck. This allows terminals to streamline their processes, as the predictability of arrival times can be increased and trucks arrive neither too late nor too early. This also reduces congestion in the port area itself as there are fewer queues. Moreover, trucks can park safely at a pre-gate parking. In addition to a buffer function, a pre-gate parking can also function as a decoupling point. In this case, inbound trucks decouple their cargo after which the last-mile transport is carried out by a yard tractor. Similarly, outbound cargo is transported by a yard tractor from the terminal to the pre-gate parking, after which a truck takes over for the long haul. Ideally, inbound trucks decouple their cargo and immediately pick up an outbound trailer on the pre-gate parking, thereby minimizing waiting time. Moreover, the first-and-last mile transport can be carried out by a fleet of autonomous yard tractors, as discussed in Sec. 2.1. Such advanced usage of a pre-gate parking, where connected and automated transport are combined is also referred to as a *smart yard*, see for example Brunetti et al. (2020).

Also on the seaside, it is possible to use the concept of extended gates, namely by deploying floating, off-shore terminals (Souravlies et al., 2020). To overcome the scarcity of land, it is promising to extend terminals toward the sea by using floating terminals. The core operations of a terminal, such as the loading and unloading of sea vessels can be carried out on such a floating terminal, eliminating the necessity of large sea vessels to enter the port. The transport from and to the floating terminal can be carried out by smaller vessels, potentially autonomous.

3 Innovations in Intelligent Decision-Making

This section highlights innovations regarding intelligent decision-making for autonomous systems. We argue that to exploit the full potential of the autonomous systems discussed in the previous section, such systems need to be combined with intelligent decision-making systems. In this way, the use of these (expensive) autonomous assets can be optimized. In this section, we highlight some intelligent decision-making solutions. Section 3.1 introduces the notion of distributed planning and Sec. 3.2 discusses matching platforms. In Sec. 3.3, we discuss a cooperative system to align barge and terminal operations. Section 3.4 focuses on the fair optimization of shared resources and Sec. 3.5 highlights the usefulness of serious gaming to support (strategic) decision-making.

3.1 Distributed Planning

Due to the increasing scale and complexity of logistics systems (e.g., fleets of hundreds of autonomous vehicles), the use of global optimization methods to plan and control these assets becomes less useful. Such centralized control approaches are less suitable for large, dynamic, and complex environments as they typically (i) require a lot of information in advance, which may not be available, (ii) are sensitive to information updates, which occur frequently, (iii) are not able to respond in a timely manner, and (iv) are not flexible enough to changing environments with multiple autonomous actors (Mes et al., 2007). In line with the delegation of autonomy regarding the execution of tasks currently performed by a human (e.g., driving, flying, sailing), also the delegation of planning and control to autonomous actors and assets is a promising area. When delegating control, we shift from central control structures to decentral control structures. In such a control structure, automated decision-making is delegated to lower levels in the control hierarchy, for example to the autonomous systems described in Sec. 2. By distributing decision-making capabilities, the system is less prone to single points of failure and reduces the complexity of decision-making. The latter is important in environments where fast decision-making is key for operational success. In Sec. 4 we will argue that such distributed decision-making systems can lead to self-organizing logistics. A notion closely related to distributed planning is that of agent-based systems, which are widely applied in maritime logistics literature. For example, within papers focusing on port management (Wibowo et al., 2015), inter-terminal cooperation (Nabais et al., 2013), collision avoidance (Marinica et al., 2012), yard crane scheduling (Fotuhi et al., 2013), dispatching of straddle carriers (Garro et al., 2015), terminal planning (Mes & Douma, 2016), and bay planning (Parthibaraj et al., 2017). Other studies focus on the comparison between centralized and decentralized approaches, such as yard crane coordination (Sharif & Huynh, 2012) and port regulation modes (Zheng & Negenborn, 2014).

Either denoted by distributed planning or agent-based systems, the notions are useful in real-world problems where centralized control might not be suitable (e.g., in dynamic and complex environments, as discussed above) or preferable (e.g., a central unit might not reflect the interests and preferences of the individual actors and assets adequately). The interested reader is referred to Mes and Gerrits (2019) for more details.

3.2 Matching Platforms

Online platforms are a popular approach to coordinate supply and demand, exemplified by platforms like Uber, Yandex, etc. Such matchmaking platforms are becoming increasingly popular in the logistics sector. In this section, we highlight a specific example of such a platform: truck platoon matching. As discussed in Sec.

2.3, a truck platoon consists of two or more digitally connected trucks that drive with a short following distance. In order to form a platoon, an agreement needs to be made on when and where to form the platoon, in which order the trucks drive, and how to divide the savings and costs among its members. We denote this process by truck platoon matching. In this section, we address three types of matching: scheduled, real-time and opportunistic. Although illustrated using truck platooning, the different variants can also be applied to other online platforms, e.g., pick-up and delivery services.

Scheduled platooning is an offline variant of matchmaking where all matches are generated before the trucks depart. Here, in order to find suitable matches, the matchmaking system needs to have access to information on the location, destination, and route of the trucks involved. When this information is not shared appropriately, or when it is only available for a subset of the available trucks, the performance of the matchmaking system decreases. Nevertheless, in some cases, this centralized approach may be relevant. For example, on frequently used routes with similar departure times (e.g., inter-terminal transport) or for logistics service providers that manage their own fleet. In the latter case, potential matches can be found easily, especially when there are many recurring trips (e.g., departures in the morning and arrivals in the evening). This is relevant for small countries, such as the Netherlands, where domestic deliveries are done within the time span of 1 day, with trucks departing from the depot in the morning and returning to the same depot in the evening (Gerrits et al., 2020). In larger countries, or in remote areas, this offline variant is useful when large distances need to be driven in combination with a relatively low density of trucks.

Real-time platooning is an online variant of matching, where the matches are made just before departure based on the latest information available. In practice, this may occur during breaks at truck stops or when refueling. These periods can be seen as small windows of opportunity for a truck to find a match based on nearby trucks with an overlap in routes. This type of matching is thus more dynamic in nature and focuses on local decision-making. It does not require any information in advance. Information is only required on the opportunities at the very moment. This type of matching is especially useful in unpredictable environments and for trucks of different logistics service providers, since gains can be shared without cumbersome coordination beforehand, as is the case with scheduled platooning (Gerrits et al., 2020). For large countries with low truck density, this matching variant is less relevant.

Opportunistic platooning is another online variant. Here, matches are made while driving. That is, trucks continuously seek for potential platoon partners while driving on the highway. This type of matching has a limited scope, since looking for matches far away leads to practical objections (e.g., speed changes may be required to get the trucks together). The matchmaking process focuses on trucks that are in the process of driving in the same direction as the truck, at most a few kilometers away. While this scope may be limited, matches are made easily as there is hardly any waiting time to form a platoon, since trucks are already driving and close to each other. The costs of forming a platoon are thus negligible; hence, the earnings of the platoon quickly become interesting. This type of matching is relevant in areas with high truck density and with enough opportunities to physically form the platoon (Gerrits et al., 2020).

3.3 Cooperation Between Barges and Terminals

The barge handling problem is the problem of how to optimize the alignment of barge and terminal operations in a port. Barge operators (companies that contract barges) have to decide on the sequence in which their barges visit the terminals in the port, aligned with the decisions of terminal operators (companies that operate a terminal) on the way they schedule the visiting barges at their terminal(s). Typical for the problem is that barge operators compete with each other (and so do terminal operators). Earlier research revealed that these companies are not willing to accept a central trusted party, since they want to stay in control of their own operations and are reluctant to share information as they fear undermining their competitive position by doing so. A few studies, therefore, propose a distributed planning approach by means of a Multi-Agent system (Melis et al., 2003; Schut et al., 2004). Barge and terminal operators made clear in discussions that they regard a Multi-Agent system as a promising concept, since it meets two important requirements as mentioned above that cannot be satisfied with central planning.

Douma et al. (2011) propose a Multi-Agent system using a specific interaction protocol (based on “service-time profiles”) that enables barge and terminal operators to align their operations efficiently. The practical aspects the authors take into consideration are: (i) restricted opening times of terminals, (ii) sea vessels, (iii) closing times of containers, and (iv) unbalanced networks.

Let us briefly describe the basic notions of the Multi-Agent system proposed in Douma et al. (2011). The basic idea behind the Multi-Agent system is that every barge operator and every terminal operator is equipped with an agent. Each agent is empowered to make decisions on behalf and in the best interest of its principal, i.e., the company it represents (either a barge or a terminal operator). Barge operator agents have to decide on the sequence and the time a barge visits its terminals. Terminal operators have to decide which possibilities they offer to barges to be handled and how these barges are scheduled at the quays. Agents are assumed to behave opportunistically, similar to their principals. Key in a Multi-Agent system is the interaction protocol, describing the way agents communicate, the content of the communication, and the aimed outcome of the communication. Figure 4 visualizes the communication in the Multi-Agent system. As shown, barge operators and terminal operators communicate directly with each other. There is no mutual communication between barge operators nor between terminal operators.

The communication between barge and terminal operators consists of two phases and is initiated by a barge operator. In the first phase, the barge operator agent sends a request for service-time profiles to the terminal operators that have to be visited by the barge for which a rotation is being planned. We assume that these requests are

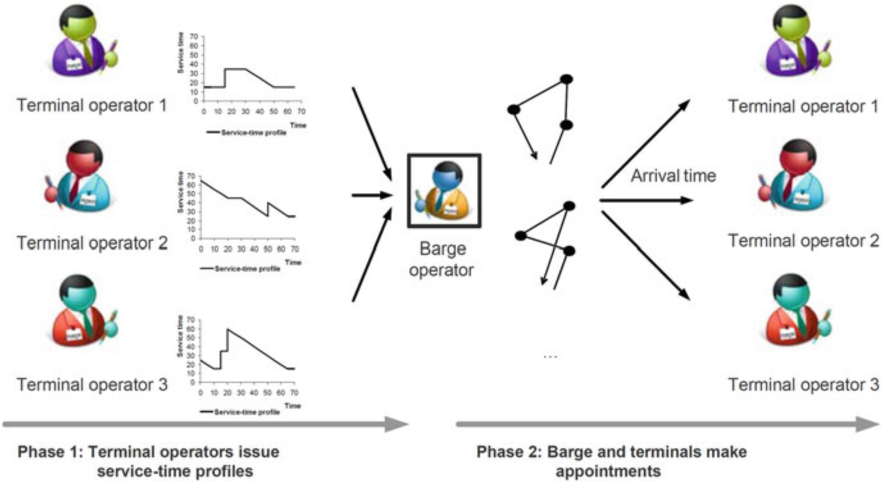


Fig. 4 Visual representation of the communication in the Multi-Agent system. Adapted from Douma et al. (2011)

sent prior to the first terminal visit of a barge, e.g., when a barge is approaching the port. Terminal operator agents reply instantaneously to the request of the barge operator agent with a barge-specific service-time profile. In the second phase, the barge operator agent determines the "best" rotation for its barge and makes appointments with the terminals concerned. A barge operator agent calculates the "best" rotation using the information expressed in the service-time profiles, i.e., the guaranteed maximum service time. Next to that, it uses information about sailing times between terminals. When a barge operator agent has determined the "best" rotation, then it makes an appointment by announcing the arrival times to the concerning terminal operators. The arrival time a barge announces to a terminal is also the latest arrival time of the barge at the terminal. Terminals confirm the appointment request by sending a confirmation of the guaranteed maximum service time.

Douma et al. (2011) show through an extensive simulation study for the Port of Rotterdam that distributed planning can perform well compared to central coordination and is a promising approach for solving the barge handling problem.

3.4 *Shared Services and Fair Optimization*

Autonomous solutions as discussed in Sect. 2 and related advanced planning and control systems require a large capital investment. Compared to manually operated systems, the hardware is relatively expensive, although operational benefits and cost reductions should allow viable long-term investment. Nevertheless, the hurdle to investing in autonomous solutions can be too big for single stakeholders, resulting in a slow uptake of these innovations. Therefore, it makes sense to invest and work together with other stakeholders. For example, a group of companies located in and around a container terminal can jointly invest in a fleet of autonomous yard tractors (see Sect. 2.1), to facilitate on-terminal and inter-terminal transport. In such a joint system, companies need to share the pool of vehicles with other users, but benefit from a risk-pooling effect. Moreover, such a collaboration can eliminate empty backhauls, raise vehicle utilization and increase the profit of each party involved (Dai & Chen, 2012). Furthermore, without a joint initiative, the investment may not have been feasible for all or multiple stakeholders. Such a joint initiative, therefore, facilitates a speedier uptake of innovations discussed throughout this chapter.

To coordinate the shared service, one may resort to a fourth-party logistics provider (4PL). Such a party coordinates the planning of the shared fleet, without owning the vehicles themselves. 4PLs have as their core business to make supply chains more efficient (Saglietto, 2013). When multiple parties agree to collaborate on a shared service, the 4PL manages the data (e.g., available capacity and jobs to be executed) and coordinates the planning. In such a control structure, information is typically only shared between the 4PL and the parties, but not between the parties themselves, as this is often confidential information. Such a structure enables cooperation between companies, without sharing confidential information with competitors. Opposed to the cooperation mechanism described in Sect. 3.3, this approach has the requirement of a "trustee," a trusted central party, namely the 4PL. Depending on the parties involved, this may not be a favorable approach and thus other coordination mechanisms (e.g., agent-based systems) can be more useful. In Alacam & Sencer (2021) the trustee concept is operationalized digitally, in a decentralized fashion, on a public blockchain network. The proposed design intends to ensure the neutrality of the digital trustee in its decisions, as well as preventing the single point of failure problem intrinsic to centralized trustee models.

Regardless of the coordination mechanism used, the involved parties need to be treated in a proper way. That is, in some sense the "shared" service needs to be shared fairly among the parties involved. For example, suppose one would use typical global optimization methods to allocate capacity to each stakeholder. From a system perspective, this can yield an optimal solution, but from an individual perspective, this may not be true. Or at least maybe wrongly understood from a single stakeholder's perspective. This is particularly of interest when a small group of large parties work together with a large group of small parties. To find such a balance between global optimization and "local satisfaction," we briefly introduce the notion of fair optimization, which combines fairness with optimization methods.

Fairness plays a role in allocation problems in which the number of resources to be allocated is limited or constrained. In many network allocation methods, the main assumption is that the *social* optimum is achieved by optimizing the sum of utilities of individual agents (e.g., parties sharing the service). With such an allocation method, a party can receive a disproportionate amount of resources as long as that player wants to and is able to pay for it (Sinha & Anastasopoulos 2017). To counter this imbalance in allocations, fairness can be factored in by using different allocation methods.

A resource allocation problem can be modeled as a cooperative game that can be captured by a set of users, the claim of a user, and the total amount of available resources. In the classical approach of measuring a user's satisfaction for a given allocation, satisfaction is maximal when the user gets exactly what it asks. Obviously, when resources are limited, maximum satisfaction may be out of reach. According to (Fossati et al. 2018) an allocation should fulfill three properties. First, all users should receive at least zero. Secondly, a user should not receive more than its demand. Lastly, the sum of all individual allocations should equal the total available resources.

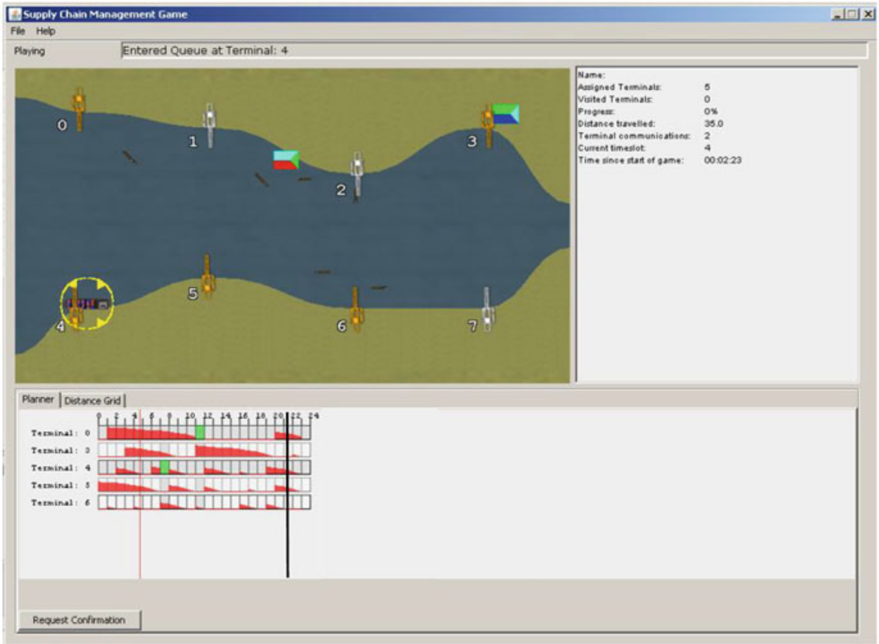
In dealing with resource allocation problems, the most widely used methods are (i) the weighted proportional rule, (ii) max-min fair allocation, and (iii) α-fairness. The first is based on a logarithmic utility function and the idea that it captures the individual worth of a resource. The second gives the lowest claimer its total demand and evenly distributes the unused resources over the others. Lastly, the α-fairness algorithm is a family of assignment rules with the outcomes depending on a smoothing parameter α (Fossati et al. 2018).

3.5 Gamification in Container Supply Chains

When you design an innovative solution for a problem from practice, then the inevitable question is: will the future users accept it? Whether future system users are willing to accept a new technology is, in particular, depending on their *perception* and *expectations* of the system (Venkatesh et al., 2003). According to the Technology Assessment Model (Davis et al., 1989; Venkatesh & Bala, 2008), the two main factors for users to decide on the acceptance of new technology are (i) perceived usefulness and (ii) perceived ease of use. Perceived usefulness is defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" and perceived ease of use as "the degree to which a person believes that using a particular system would be free from effort" (Davis et al., 1989). In our experience, in order to let the intended user explore "perceived usefulness" and "perceived ease of use" of an innovative design, a "serious game" may be helpful.

To illustrate the added value of gamification, let us revisit the barge handling problem discussed in Sect. 3.3. There, in the process of designing a Multi-Agent solution for the barge handling problem, Douma et al. (2009, 2011) had a keen eye for design choices that could influence the acceptance of the users. In the early stage of their research, when they discussed their proposed solution to practitioners, they discovered that it was hard for these people to get a picture of how the system would work in practice. Practitioners experienced the approach as rather abstract and saw little benefit in supporting it. The researchers, therefore, decided to develop a *simulation game* to better communicate their ideas, thus providing future system users with a transparent picture of what the solution is about (Douma et al., 2012).

Their simulation game aims to realize the following four objectives:



Entered Queue at Terminal: 4

Name:
Assigned Terminals: 5
Visited Terminals: 0
Progress: 0%
Distance travelled: 35.0
Terminal communications: 2
Current timeslot: 4
Time since start of game: 00:02:23

Fig. 5 Screenshot of the user interface. Adapted from Douma et al. (2012)

1. To *communicate the Multi-Agent solution to practitioners*. By playing the game, practitioners are able to compare the present situation—as it is modeled—to the proposed situation thus getting a clear understanding of the added value of the solution suggested. This may support the acceptance of the solution. Moreover, it may generate a discussion on design choices and assumptions. Furthermore, it may evoke a discussion about the conditions for implementation.
2. To use the game as a *practical validation of the proposed Multi-Agent system*. The game will show in what way people interpret and use the information provided, in particular how they use this information to base their decisions upon.
3. To use the game as a *prototype solution for the user interface*. The game will indicate to what extent the information presented is useful. It will also show to what extent the interface is intuitive and clear.
4. To *evaluate the way players perceive different interaction protocols*. It is interesting to observe how the perception of an interaction protocol will influence a player's performance.

The user interface consists of three parts (see Fig. 5). The upper left part is a graphical representation of the game state. It depicts the location of all the barges and terminals. The performance of the barge under consideration is presented in the upper right part of the screen. The lower part is reserved for planning a rotation. There, a time bar—divided into time slots—is given for every terminal the player has to visit. The player can select a time slot by clicking on it. The selected time slots can be communicated with the terminals by clicking the button on the left bottom corner of the screen.

Findings are that a simulation game has many advantages for communicating a Multi-Agent system to practitioners. It helps people to quickly get an understanding of the system and to decide whether they are willing to give support for implementation. The game is also useful as a prototyping technique for the user interface and to evaluate the way players perceive the different interaction protocols. To practically validate the performance of the Multi-Agent system, the game is less useful, unless players are trained in playing the game and play the game in multiple rounds to get statistically significant results. This was beyond the scope of the research. All in all, the experiences are that a simulation game is an effective means to contribute to the "perceived usefulness" and "perceived ease of use" of the proposed system by future system users.

4 Self-Organizing Logistics

Combining autonomous systems with intelligent decision-making is a promising area of research in (maritime) logistics. We argue that this combination can lead to self-organizing systems, where minimal or no human supervisory control is required. The notion of self-organization in logistics is thus one focused on automated systems (of systems) with certain decision latitudes in order to meet its design objectives. Due to the complexity of logistic systems, a self-organizing system should be fragmented into smaller autonomous units. This is similar to how we divide a company into smaller departments (i.e., sales, inventory management, production), each which their own responsibility, but working together to achieve a common shared goal (e.g., company profit). A self-organizing logistic system is thus a system of small(er) autonomous units (also commonly referred to as agents) each with their own goal, and by communication and cooperation striving toward a common goal.

Having discussed various options for autonomous hardware and related intelligent decision-making solutions in the previous sections, we now unify them in the framework presented in Fig. 6. The framework is presented alongside two axes: object autonomy and decision-making autonomy. The first refers to the ability of the system to perform its core tasks in an autonomous fashion. For example, an unmanned cargo aircraft should be able to take off, fly and land autonomously under various (weather) conditions. Such an aircraft thus has a high object autonomy, whereas a manually operated truck has a low object autonomy as the core tasks are executed by the driver. The latter axis refers to the system's decision-making autonomy. That is, the degree to which the system is able to make intelligent decisions on its own. These decisions are not related to the core tasks (e.g., driving, flying, sailing), but rather related to operational decisions, like scheduling and routing. These decisions include for example the work that a human planner typically does.

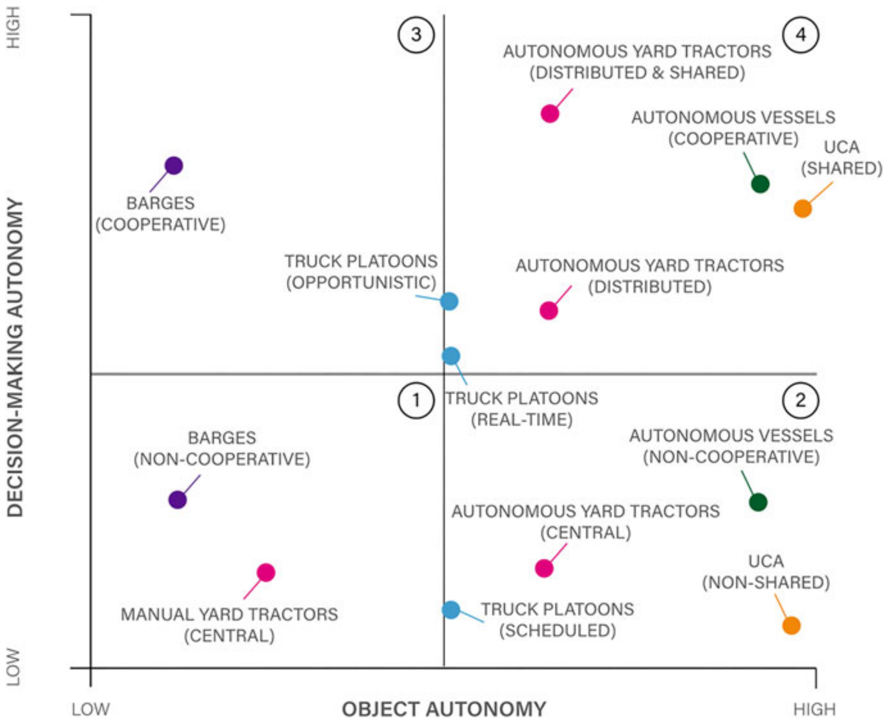


Fig. 6 Unifying framework for intelligent and autonomous systems

The examples provided throughout this chapter are plotted in the framework shown in Fig. 6. Moreover, the framework allows four different quadrants: (1) manual operated systems with manual decision-making, (2) autonomously operated systems with manual decision-making, (3) manual operated systems with automated decision-making, and (4) autonomously operated systems with automated decision-making. Obviously, the latter quadrant contains the most promising examples regarding self-organization, as both decision-making and execution are performed autonomously. Nevertheless, also quadrants two and three contain interesting examples where either the decision-making or the task execution is performed autonomously, stressing the fact that not *both* dimensions need to be carried out autonomously in order to make progress (toward self-organization).

To exemplify the transition from manually operated systems to more autonomous, and intelligent systems (e.g., toward self-organization), we highlight the following two examples: autonomous yard tractors in Sect. 4.1 (color-coded pink in Fig. 6) and autonomous vessels in Sect. 4.2 (color-coded green).

4.1 From Manual to Autonomous to Intelligent Yard Tractors

Regarding yard tractors, let us focus on their usage at container terminals and as a last-mile solution in combination with extended gates. In current practice, manually operated yard tractors are used for the horizontal transport of containers from and to the quay. Typically, a central control system determines which transport jobs need to be processed and in which order. Operators of the yard tractors receive information on the current job list and can select one particular job to be processed. The decision-making autonomy is thus low, as factually all decisions are made on a central level and the operator of the yard tractor has limited decision-making autonomy. The same goes for object autonomy, as the vehicle is operated manually by a human driver. The only autonomy of the vehicle itself maybe an emergency brake which is automatically applied in some safety-critical situations. Clearly, this system belongs in quadrant one, see ‘manual yard tractors (central)’ in Fig. 6. When making the transition to autonomous yard tractors (AYTs), one moves to quadrant two, where the driving tasks are performed autonomously and a human driver is no longer required. Typically, there are still operators involved, which monitor the tractors from a distance and can take over control (e.g., tele-guided) when required. The object autonomy thus increases, but not to the extent of, for example, unmanned cargo aircraft. Moreover, when the same centralized planning and control system is deployed, the decision-making autonomy does not change. When deploying a distributed planning approach, where decision-making is delegated to the vehicles themselves, as illustrated in Sect. 3.1, the system moves from quadrant three to four. In such a system, a human planner is no longer required to make decisions regarding dispatching, scheduling, and routing. Instead, the fleet of AYTs themselves controls these processes. Clearly, this moves in the direction of a ‘self-organizing’ system, where minimal or no human involvement is required. As a last step, one can also share the fleet of AYTs with other firms or stakeholders, for example when deploying a shared first- and last-mile transport system in combination with an extended gate (see Sects. 2.5 and 3.4). In such a system, the AYTs are not servicing a single stakeholder (e.g., solely for the horizontal transport on its own terminal), but are shared with other firms in the port. In addition to a distributed planning approach, which is useful in such a situation (see Sect. 3.1 on the advantages), the fleet of AYTs also needs to decide how to share its AYTs among (rival) users in a fair and efficient manner. This is a complex optimization problem and thus requires an advanced degree of decision-making autonomy by the autonomous system. This is denoted by “distributed and shared” in Fig. 6. The same options hold for unmanned cargo aircraft (UCA), namely shared service, operated by multiple stakeholders, or non-shared service, operated by a single stakeholder. This transition is also depicted in Fig. 6, color-coded yellow.

4.2 Manual, Autonomous, and Cooperative Vessels

Consider a barge that is currently manually operated with manual decision-making. By cooperating with other barges and terminals (cf. Sect. 3.3), the barge may rise to a high level of automated decision-making. This transition is depicted in Fig. 6, color-coded purple. As another example, consider an autonomous vessel. Such a vessel can sail with an economic speed and coordinate its navigation plan—fully automated—with its due time in the port. Nevertheless, its decision-making potential may be rather low. By cooperating with other autonomous vessels, e.g., in a leader-follower structure, the vessel may acquire a higher level of automated decision-making, e.g., benefitting from the joint knowledge of sailing obstructions further ahead. This transition is depicted in Fig. 6, color-coded dark green.

5 Conclusions and Outlook

This chapter highlights some promising recent innovations in maritime logistics. As innovative automated systems, we discuss: (i) autonomous yard tractors, (ii) unmanned cargo aircraft, (iii) truck platooning, (iv) autonomous vessels, and (v) extended gates. To control these systems, we discuss innovative forms of intelligent decision-making, namely: (i) distributed planning, (ii) matching platforms, (iii) cooperation between barges and terminals, (iv) shared services and fair optimization, and (v) gamification in container supply chains. Next, we design a unifying framework that classifies automated systems within maritime logistics according to their potential to grow out to self-organizing.

One may wonder about the viability of the innovations discussed. Many of them, like unmanned cargo aircraft, are still emerging technology. Technical, regulatory, control, and safety issues have to be dealt with. As technology matures, and humans start to interact with it, unforeseen adaptations may be necessary. Nevertheless, the potential of autonomous systems for maritime logistics is huge. To stay competitive no seaport in the world can afford to ignore autonomous transport.

How to bring the innovations discussed to the market? We recommend the following general steps:

1. Evaluate the viability of the innovation by interviewing practitioners.
2. Develop a serious game (gamification, see Sect. 3.5).
3. Invite future users to play the game.
4. Evaluate their perception of usefulness and ease of use.
5. If this perception is satisfactory then proceed, else repeat steps 1, 2, 3, 4.
6. Introduce the innovation into pilot markets.
7. If successful, then proceed, else repeat steps 1, 2, 3, 4, 5, 6.
8. Extend to other markets.

Despite the immense potential of the innovations discussed, one may never forget the human factor. In our view, step 4 in the above list helps us to safeguard that.

References

Alacam, S., & Sencer, A. (2021). Using blockchain technology to foster collaboration among shippers and carriers in the trucking industry: A design science research approach. *Logistics, 5*, 37. https://doi-org.ezproxy2.utwente.nl/10.3390/logistics5020037

Alam, A., Besselink, B., Turri, V., Martensson, J., & Johansson, K. (2015). Heavy-duty vehicle platooning for sustainable freight transportation: A cooperative method to enhance safety and efficiency. *IEEE Control Systems, 35*(6), 34–56.

Brunetti, M., Mes, M., & van Heuveln, J. (2020). A general framework for smart yards. In K.-H. Bae, B. Feng, S. Kim, S. Lazarova-Molnar, Z. Zheng, T. Roeder, & R. Thiesing (Eds.), *Proceedings of the 2020 Winter Simulation Conference* (pp. 2743–2754). Institute of Electrical and Electronics Engineers, Inc.

Dai, B., & Chen, H. (2012). Profit allocation mechanisms for carrier collaboration in pickup and delivery service. *Computers & Industrial Engineering, 62*, 633–643.

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science, 35*, 982–1003.

Douma, A. M., Schutten, J. M. J., & Schuur, P. C. (2009). Waiting profiles: An efficient protocol for enabling distributed planning of container barge rotations along terminals in the Port of Rotterdam. *Transportation Research Part C, 17*, 133–148.

Douma, A. M., Schuur, P. C., & Schutten, J. M. J. (2011). Aligning barge and terminal operations using service-time profiles. *Flexible Services and Manufacturing Journal, 23*, 385–421.

Douma, A. M., Van Hillegersberg, J., & Schuur, P. C. (2012). Design and evaluation of a simulation game to introduce a multi-agent system for barge handling in a seaport. *Decision Support Systems, 53*(3), 465–472.

Fossati, F., Hoteit, S., Moretti, S., & Secci, S. (2018). Fair resource allocation in systems with complete information sharing. *IEEE/ACM Transactions on Networking, 26*(6), 2801–2814.

Fotuhi, F., Huynh, N., Vidal, J. M., & Xie, Y. (2013). Modeling yard crane operators as reinforcement learning agents. *Research in Transportation Economics, 42*(1), 3–12.

Garro, A., Monaco, M. F., Russo, W., Sammarra, M., & Sorrentino, G. (2015). Agent-based simulation for the evaluation of a new dispatching model for the straddle carrier pooling problem. *Simulation, 91*(2), 181–202.

Gerrits, B., Mes, M., & Schuur, P. (2020). Mixing it up: Simulation of mixed traffic container terminals. In K.-H. Bae, B. Feng, S. Kim, S. Lazarova-Molnar, Z. Zheng, T. Roeder, & R. Thiesing (Eds.), *Proceedings of the 2020 Winter Simulation Conference* (pp. 1384–1395). Institute of Electrical and Electronics Engineers, Inc.

Gerrits, B., Schuur, P., Ilin, I., & Kalyazina, S. (2019). Mixing automated with non-automated yard traffic in container terminals: A digital transition. In *Proceedings of the International Conference on Digital Technologies in Logistics and Infrastructure (ICDTLI 2019)* (pp. 397–401). Atlantis Press.

Gu, Y., Góez, J. C., Guajardo, M., & Wallace, S. W. (2021). Autonomous vessels: State of the art and potential opportunities in logistics. *International Transactions in Operational Research, 28*(1), 1706–1739.

Heerkens, H. (2017). Unmanned cargo aircraft: From anywhere to everywhere. *Engineering & Technology Reference*. https://doi-org.ezproxy2.utwente.nl/10.1049/etr.2017.0009

Kongsberg. (2018). *Autonomous ship project, key facts about YARA Birkeland*. https://www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/4B8113B707A50A4FC125811D00407045?OpenDocument.

Kretschmann, L., Burmeister, H. C., & Jahn, C. (2017). Analyzing the economic benefit of unmanned autonomous ships: An exploratory cost-comparison between an autonomous and a conventional bulk carrier. *Research in Transportation Business & Management, 25*, 76–86.

Li, K., & Ioannou, P. (2004). Modeling of traffic flow of automated vehicles. *IEEE Transactions on Intelligent Transportation Systems, 5*(2), 99–113.

Liebeck, R. H. (2004). Design of the blended wing body subsonic transport. *Journal of Aircraft, 41*(1), 1–24.

Marinica, N. E., Capiluppi, M., Rogge, J. A., Segala, R., & Boel, R. (2012, June 6–8). Distributed collision avoidance for autonomous vehicles: World automata representation. In *IFAC Proceedings Volumes (IFAC-PapersOnline)* (pp. 216–221). IFAC.

Melis, M., Miller, I., Kentrop, M., Van Eck, B., Leenaarts, M., Schut, M., & Treur, J. (2003). Distributed rotation planning for container barges in the Port of Rotterdam. In T. Verduijn, & B. Loo (Eds.), *Intelligent logistics concepts* (pp 101–116). Eburon Publishers.

Merk, O., & Notteboom, T. (2015). *Port Hinterland connectivity*. International Transport Forum Discussion Paper No. 2015-13.

Mes, M., & Douma, A. (2016). Agent-based support for container terminals to make appointments with barges. In A. Paias, M. Ruthmair, & S. Voß (Eds.), *Computational logistics* (pp. 80–95). Springer International Publishing.

Mes, M., & Gerrits, B. (2019). Multi-agent systems. In *Lecture notes in logistics*. Springer International Publishing. https://doi-org.ezproxy2.utwente.nl/10.1007/978-3-319-92447-2_27.

Mes, M., van der Heijden, M., & van Harten, A. (2007). Comparison of agent-based scheduling to look-ahead heuristics for real-time transportation problems. *European Journal of Operational Research, 181*(1), 59–75. https://doi-org.ezproxy2.utwente.nl/10.1016/j.ejor.2006.02.051

Montoya-Torres, J. R., Franco, J. L., Isaza, S. N., Jimnez, H. F., & Herazo-Padilla, N. (2015). A literature review on the vehicle routing problem with multiple depots. *Computers & Industrial Engineering, 79*, 115–129.

Nabais, J. L., Negenborn, R. R., Carmona Benitez, R. B., & Botto, M. A. (2013, October 6–9). Setting cooperative relations among terminals at seaports using a multi-agent system. In *IEEE Conference on Intelligent Transportation Systems Proceedings* (pp. 1731–1736). ITSC.

Parthibaraj, C. S., Palaniappan, P., Gunasekaran, A., & Subramanian, N. (2017). Multi-agent system with iterative auction mechanism for master bay plan problem in marine logistics. *Maritime Policy & Management, 44*(6), 705–726.

Robinson, T., Chan, E., & Coelingh, E. (2010). *Operating platoons on public motorways: An introduction to the SARTRE platooning programme*. In *Proceedings of the 17th ITS world congress*.

Rolls-Royce. (2018). *Rolls-Royce and Finferries demonstrate world's first fully autonomous ferry*. https://www.rollsroyce.com/media/press-releases/2018/03-12-2018-rr-and-finferries-demonstrate-worlds-first-fully-autonomousferry.aspx

Saglietto, L. (2013). Towards a classification of fourth party logistics (4PL). *Universal Journal of Industrial and Business Management, 1*(3), 104–116.

Schut, M., Kentrop, M., Leenaarts, M., Melis, M., & Miller, I. (2004). Approach: Decentralised rotation planning for container barges. In *Proceedings of the 16th European conference on artificial intelligence*.

Sharif, O., & Huynh, N. (2012). Yard crane scheduling at container terminals: A comparative study of centralized and decentralized approaches. *Maritime Economics & Logistics, 14*(2), 139–161.

Sinha, A., & Anastasopoulos, A. (2017). Incentive mechanisms for fairness among strategic agents. *IEEE Journal on Selected Areas in Communications, 35*(2), 288–301.

Souravlies, D., Dafnomilis, I., Ley, J., Assbrock, G., Negenborn, R. R., & Scott, D. L. (2020). Design framework for a modular floating container terminal. *Frontiers in Marine Science, 7*, 1–17.

Taleb, T., Benslimane, A., & Letaief, K. (2010). Toward an effective risk-conscious and collaborative vehicular collision avoidance system. *IEEE Transactions on Vehicular Technology, 59*(3), 1474–1486.

Venkatesh, V., & Bala, H. (2008). Technology acceptance model 3 and a research agenda on interventions. *Decision Sciences, 39*, 273–315.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quartely, 27*, 425–478.

Wibowo, R. A., Hidayatno, A., Komarudin, K., & Moeis, A. O. (2015). Simulating port expansion plans using agent based modelling. *International Journal of Technology, 6*(5), 864–871.

Zheng, S., & Negenborn, R. R. (2014). Centralization or decentralization: A comparative analysis of port regulation modes. *Transportation Research Part E: Logistics and Transportation Review, 69*, 21–40.