Serious Games for Improving Situational Awareness in Container Terminals

Alexander Verbraeck, Shalini Kurapati and Heide Lukosch

Abstract Container terminals decouple the long-distance, high volume deep-sea transport from the short-distance, highly fragmented hinterland transport. As around 65 % of general cargo is shipped in containers, these terminals play a very important role in global trade. Planning and aligning the activities in and around container terminals is quite difficult, even more because of frequent disturbances in the seaside and the landside operations within the transportation network. The theory of Situational Awareness (SA) might help to improve the alignment between planning activities and to increase resilience. SA asks, however, for a different way of working and communicating. Awareness and practice sessions are needed to train managers and planners to use the SA concepts. The Dinalog project SALOMO has developed tools and serious games to serve as a training, learning, and "try-out" tool for students and practitioners to gain experience in Situational Awareness, alignment of planning activities, and in dealing with disturbances in and around container terminals. This chapter discusses the Situational Awareness framework, on which the tools and games have been built, as well as first experiences in using these tools and games.

1 Container Transportation

Global container trade by deep-sea vessels is responsible for 65 % of the general cargo that is transported internationally (UNCTAD 2014), and for some routes even for 100 % (Steenken et al. 2004). Over 160 million TEU (Twenty foot Equivalent

A. Verbraeck (✉) · S. Kurapati · H. Lukosch
TU Delft, PO Box 5015, 2600 GA Delft, The Netherlands
e-mail: a.verbraeck@tudelft.nl

S. Kurapati
e-mail: s.kurapati@tudelft.nl

H. Lukosch
e-mail: h.k.lukosch@tudelft.nl

H. Zijm et al. (eds.), *Logistics and Supply Chain Innovation*,
Lecture Notes in Logistics, DOI 10.1007/978-3-319-22288-2_25

Units, the size of a 20 ft container) were transported in 2013 (UNCTAD 2014). The value of the transported containerized goods is more than 50 % of all global seaborne trade (WTO 2013, Table 3), and amounts to more than US$4 trillion annually (World Shipping Council 2014). Container terminals play a key role in the transhipment of containers between deep-sea vessels and hinterland transportation modes. More than 200 countries have container terminals to handle container ships (World Shipping Council 2014). Several functions are carried out by the container terminal: loading and unloading of deep-sea vessels, transportation of containers between the quay and the stack, storage and retrieval of containers from the stack, loading and unloading of hinterland transportation modes, and organizational activities and paperwork such as customs inspection (Steenken et al. 2004). The container terminal is organized into a number of areas (see Fig. 1): the deep-sea quay where deep sea vessels are loaded and unloaded, the horizontal transportation area to transport containers between the quay and the stack, the stack where containers are stored, loading areas for trucks and trains, and the gate where trucks are cleared for picking up or delivering a container (Brinkmann 2011). In case an inland waterway system is in use for the terminal, there is also a barge quay. Empty containers can be stored in a separate area, or in the general stack. A separate area on the container terminal or empty depot is sometimes in use for empty containers because they can be stacked higher than full containers. Containers carrying dangerous goods, and containers that are refrigerated (so-called reefers) are also stored

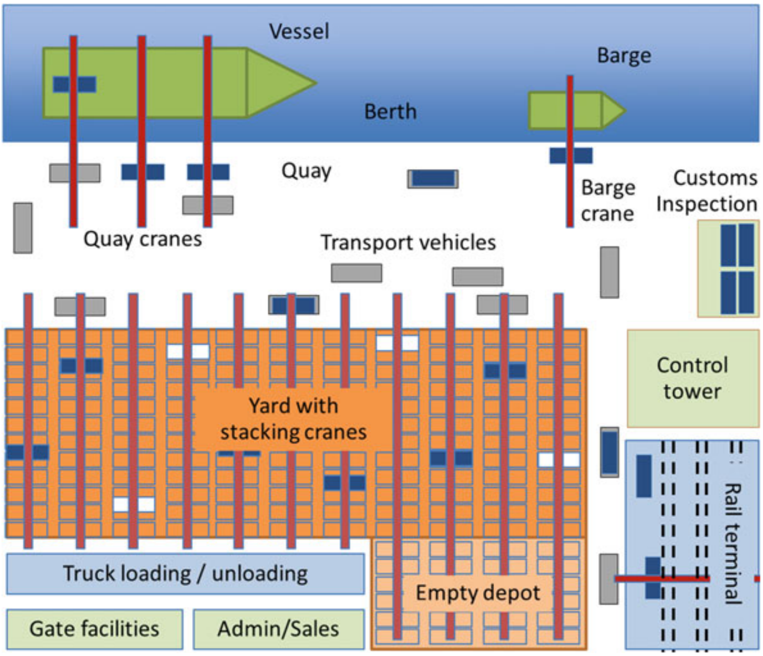

Fig. 1 General layout of a container terminal

in special areas of the terminals (Wiese et al. 2011). Reefers need to be hooked-up to a power source, which is typically a manual process.

Container ships have tremendously increased in size over the past decades, where the largest ships can now transport 18,000 TEU (Tran and Haasis 2015). This asks for a higher berth productivity in the container terminals than what is currently being offered (Port Technology International 2011), because the shipping lines want to have the ships handled as efficiently as possible in the terminals. Therefore, large vessels are served by multiple quay cranes that load and unload the containers (Brinkmann 2011). As a result, crane planning is an important planning task (Böse 2011). When unloading the ship, the quay crane places the container on the quay to be picked up by a vehicle, or containers can be directly placed on a vehicle. Vehicles can for instance be Automated Guided Vehicles (AGVs), Automatic Lifting Vehicles (ALVs), or manned straddle carriers (Kemme 2011). These vehicles transport the containers between the quay and the yard. In the yard, containers are stacked and retrieved by Rubber-Tyred Gantry cranes (RTGs) or Rail-Mounted Gantry cranes (RMGs) (Saanen 2004). There can be one or two cranes per stacking lane. In case of two cranes, one serves the sea-side containers, and the other the land-side containers. When no import or export containers have to be transferred to or from the stack, the cranes are used for so-called housekeeping moves to optimize the location of the containers in the stack. e.g., when a container that will have to be taken from the yard an hour from now is at the bottom of a stack of four containers, housekeeping moves will 'dig' for the container by first moving the containers that are on top of it (Legato et al. 2012).

One of the main functions of a container terminal is to decouple the deep-sea transport from local and hinterland transport (Steenken et al. 2004). Containers that arrive or depart by deep sea vessel can for instance be transported between the customer and the terminal by a combination of transport moves by truck, train, barge, or short-sea vessels (IDVV 2012; Notteboom 2008). Separate dedicated areas in the container terminal are available for (un)loading of trucks (Guan and Liu 2009), and (un)loading of trains (Newman and Yano 2000) (see also Fig. 1). In case of barge transportation, barges either share the quay with deep-sea vessels, or are served at a barge quay by separate cranes (Douma 2008; Melis et al. 2003).

2 Planning, Variability, and Disturbances

Planning and aligning all functions in the terminal is a difficult task (Brinkmann 2011). It involves, amongst others, planning of the berth location and timing of deep-sea vessels, feeders and barges, stowage planning of the ships (which determines the sequence of containers to be (un)loaded), planning of the number and location of quay cranes to use for each ship, planning of the horizontal transport vehicle operations, planning of the location of the container in the stack, allocation of stack resources for sea-side or land-side operations, and planning of priorities for (un)loading containers from the stack for different modalities (Böse 2011; Steenken et al. 2004). All these planning activities are interrelated, and changes in one plan have a big influence on other plans (Böse 2011). When a ship arrives late and has to use a different quay position, the location of the containers that have to be loaded onto the ship is often sub-optimal, leading to longer horizontal transportation times (Pani et al. 2014). When import containers are picked up by a different modality than planned, containers were, in hindsight, stored in the wrong part of the stack. When a horizontal transport vehicle that carries a container for a deep-sea vessel breaks down, other containers that were planned on top of that container in the ship cannot be loaded until the container of the broken vehicle has arrived to comply with the stowage plan. In addition, the broken vehicle can block other vehicles with containers, leading to a propagation of the disturbance. When a truck arrives at the terminal without a pre-notification to pick up a container, the container can be at the bottom of the stack and housekeeping moves are necessary to retrieve the container. This will take time causing waiting time for the truck, and it keeps the stacking crane busy which may cause delays for sea-side operations (Phan and Kim 2015). Again, a delay in retrieving one export container for a deep-sea vessel may cause delays for other containers because of the strict sequence of loading in the stowage plan. Usually different planners, sometimes even from different departments are responsible for maintaining the plans on the terminal. While terminals operate on a 24/7 basis, not all planners are available during the night. The so-called Terminal Operating System (TOS) helps to store and align several of the plans, but aligning all plans remains a difficult task (Lau and Zhao 2008), and human intervention is often needed to solve problems.

Many of the processes in a container terminal show variability (Han et al. 2010; Vis and de Koster 2003). An example is the number of moves per hour of quay cranes, which may differ considerably between container terminals, but also between crane operators. Weather (wind, fog) can also have a severe influence on the speed by which containers can be loaded and unloaded from vessels. Driving times in the horizontal transport system can be influenced by congestion. Stacking crane operations are impacted by the unpredictability of the arrival of trucks to pick up containers and/or bring containers. Train and barge arrivals can deviate from plan, due to delays at the previous (un)loading location or congestion. Because of the tight interrelations between plans, other processes are affected as well by the variability.

Supply Chain and Transportation executives are worried about the effect of external disruptions on their operations. On top of their list are natural disasters, conflicts and political unrest, sudden demand shocks, export or import restrictions, weather conditions, and terrorism.[1] Each of the larger disturbances or risks, described for instance in Behdani (2013), Harrington et al. (2011), Jüttner et al. (2003), Manuj and Mentzer (2008), can have a ripple effect in the terminal (Gurning

[1]World Economic Forum. New models for addressing supply chain and transport risk. http://www3.weforum.org/docs/WEF_SCT_RRN_NewModelsAddressingSupplyChainTransportRisk_IndustryAgenda%202012.

and Cahoon 2011). When a deep-sea vessel with 5000 containers arrives two days late due to bad weather conditions, the planned berth positions will probably not be available. Import containers will be too late to be loaded on the scheduled barges and trains. Truck drivers that want to pick up urgent containers arrive too early. Alerting thousands of truck drivers is impossible, because of the effort this would take, and because it is usually unknown to the terminal who are going to pick-up or bring a certain container.

Therefore, important challenges are: to better align plans and make them more robust against disturbances; to be able to detect deviations and disturbances quickly; to communicate them in an efficient manner to departments or parties who need the disturbance information to adapt their processes; to design ways to effectively deal with deviations and disturbances; and to train employees in detection, communication, and problem solving. These challenges are addressed in a project called SALOMO, which is funded by Dinalog, the Dutch Institute for Advanced Logistics. SALOMO stands for Situational Awareness for LOgistic Multimodal Operations, and focuses on improved detection and communication of disturbances based on a framework for (Shared) Situational Awareness (SSA) (Endsley 1995; Endsley and Jones 1997) and Distributed Situational Awareness (DSA) (Boy 2013), and on serious gaming methods to research and train problem solving capabilities in relation to SA (Lo and Meijer 2014; Lukosch et al. 2014; Perla et al. 2000). The next section will introduce the framework for Situational Awareness, and the subsequent sections will briefly introduce a number of the developed tools and games in the SALOMO project that help to train planners and managers to use the Situational Awareness concepts.

3 Situational Awareness Framework

In spite of the fact that container terminals become more and more automated (Saanen 2004) and information technologies such as a Terminal Operating System are in use at all large terminals, dealing with variance and disturbances remains difficult. Larger terminals and larger container ships make it difficult to assess the situation at hand, choose with whom to communicate and collaborate, and jointly decide on the best course of action. According to Endsley (1995), Situation(al) Awareness or SA is ‘the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future’. Endsley defines three phases for Situational Awareness (Endsley and Jones 1997), which look to be particularly applicable to handle variance and disturbances on the container terminal and in the entire transportation chain:

1. **Perception** of the elements in the environment. The first step in achieving SA is to perceive the status, attributes, and dynamics of relevant elements in the environment. In case of disturbances, this can already be hard. Finding out that

several of the thousands of trucks that arrive at a container terminal are severely delayed is outside the typical information gathering capabilities of a terminal. Assessing the effects of a crane breakdown on a terminal on the abilities to load or unload a barge is typically not possible for a barge operator. Of course it would be possible to 'push' the information to the other party rather that to try to 'pull' it, but it is hardly ever known on beforehand which stakeholders would need certain pieces of information.

2. **Comprehension** of the current situation. By combining elements from the first step into patterns, the decision maker forms a holistic picture of the environment, comprehending the significance of objects and events. In case of several trucks being late, the planner on the terminal can look for a common cause, such as road works, a strike, or an accident. If an AGV is malfunctioning and has to be repaired, the location and routes of other AGVs can be checked, as well as the status of the container on the AGV. This creates a full picture of the situation that can help to develop a course of action.
3. **Prediction** of future status. In order to prepare for action, the future status of the system has to be known. Will the situation deteriorate further? What other stakeholders will be impacted, and at what time? The future state of the system is modeled using the knowledge of the status of the elements in the system and their dynamics, and insight into the interaction patterns between different parts of the system. If a ship is estimated to arrive late, this is related to the estimated time of arrival of other ships, to the berth plan, and to the quay crane plan, to create a full picture of the future state of the berth and queue that can be used to assess whether the late arrival can be accommodated or whether replanning would be necessary.

Situational Awareness is a preparation for a design process of potential future actions, and a decision making process where the best course of action will be chosen, after which it can be implemented (Endsley and Jones 1997).

Where Endsley's model was developed for more individual settings, such as SA for fighter pilots in the Air Force, we are looking for SA in a setting that involves multiple decision makers. In such cases, different actors want to create a "common operational picture" (Allen et al. 2014; Nofi 2000) to help different decision makers to solve problems as a team, rather than individually. Instead of optimizing individual goals, which could be far from the optimal solution, a team jointly decides on the best course of action. When we want to accomplish Shared Situational Awareness (SSA), shared mental models, communication and cooperation are crucial (Nofi 2000). As Nofi (2000, p. 29) states: "*communications is the most critical issue in treating shared awareness.*" Shared awareness is often accomplished in a team setting, where actors can quickly exchange information about the evolving situation (shared mental model), and can align their planned courses of action with each other (cooperation). One can imagine that in case of a major delay of an ocean vessel, or a truckers' strike, several planners and decision makers can work together on designing the best course of action. These collaborative sessions typically take place within one organization, as there is a common frame of reference and a single authority that can decide in case of trade-offs.

When we move outside the organization into the transport network, the single authority and common frame of reference are lacking. Boy (2013) indicates that in such complex, socio-technical and distributed settings, four concepts play a major role to accomplish Distributed Situational Awareness (DSA): sharing, distribution, delegation, and trading. Let's illustrate this with the example of a deep-sea vessel arriving late. *Sharing* relates to the fact that the shipping line, which usually learns of the late arrival first, informs other stakeholders such as the terminal and freight forwarders about the disturbance that might occur. *Distribution* means that each actor can now assess the situation from their role in the system. The terminal can, for instance, make more cranes available to other ships in order to stimulate an early departure of one of the current ships to free space on the quay for the delayed ship. These changes in plan need to be shared, in turn, with other planners and outside stakeholders such as the shipping line of the currently berthed ships. Freight forwarders can inform trucking companies to reschedule deliveries and pick-ups of containers. *Delegation* is needed because not all actors have the power or ability to implement required actions. For instance, replanning of trains and barges might be needed for containers that will not arrive on time due to the late arrival of the ship. If these plans are made by external freight forwarders, the decision making and action implementation needs to be delegated to them. After delegation, sharing changes in the current situation with the parties to which decisions have been delegated becomes even more important. Finally, *trading* refers to negotiation among actors. In many cases, distribution and delegation are not sufficient. Trade-offs need to be discussed between actors. In the case of the ship arriving late, the late arriving ship could be allowed to berth when it arrives, forcing another ship to wait, or the delayed ship could wait longer for an empty spot in the plan, increasing its tardiness even further. Clearly, this is not something a single organization can decide. The effects of different options have to be discussed and potentially the decision between the options has to be escalated to higher positions in the organizations (delegation) to force a final decision.

These ideas have been implemented into a framework for Shared and Distributed Situational Awareness as depicted in Fig. 2 (Kurapati et al. 2012, 2013). For individual situational awareness, the three elements of Endsley (1995), perception, comprehension, and prediction are key. When we want to accomplish Shared Situational Awareness, shared mental models, communication and cooperation are the main concepts (Nofi 2000). On the organizational and inter-organizational level (the system's level), we have to address planning and disturbances in a distributed setting (Boy 2013). Here, sharing, distribution, delegation, and trading play a major role.

The SALOMO project uses Serious Games to study the Situational Awareness framework. The games simulate the scenarios in which situational awareness can be used to increase the resilience of planning operations and management decisions. Because the games form a controlled environment, they are ideal to observe and study the activities of the players, in their role as planners or decision makers

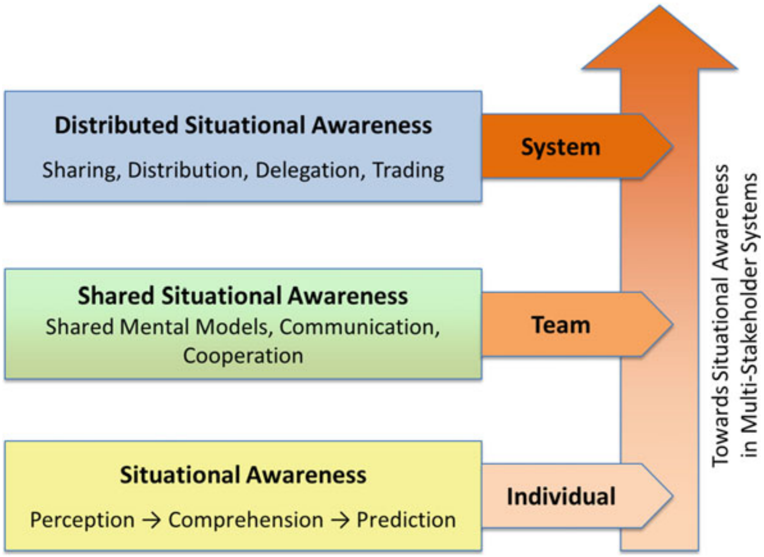

Fig. 2 Conceptual framework for shared & distributed situational awareness

(Mayer 2009). The same games can be used later as training games to replicate situations that the planners and decision makers have to be trained for (Crookall 2010). One of the main questions we had to answer was what elements to include in the game to be able to study and train the concepts of the three layers of the Situational Awareness framework. The next two sections cover two games, one game in which we studied SA and SSA for planning operations, and one in which we studied SSA and DSA for disruption mitigation. For both games we introduced a number of specific game elements that will be summarized in Sect. 6.

4 Container Terminal Planning Game: SA and SSA

To study game elements for Individual Situational Awareness and Shared Situational Awareness, an online, web-based training game was developed by SALOMO partner InThere.[2] The game is a so-called microgame (Kurapati et al. 2014) where learning takes place in short sessions, which can be repeated a few times to explore which kind of strategy works best (Lukosch et al. 2013). Microgames support situated learning, as they always start from a well-defined problem of a client, which is translated into a short simulation game (Lukosch and de Vries 2009; Overschie et al. 2013). In this particular game, the Yard Crane

[2]http://www.inthere.nl.

Scheduler game (YCS), players have to allocate resources to container terminal functions as described in Fig. 1. The main objective of the YCS game is to manage the yard and align various planning and resource allocation activities in the container terminal. The YCS game provides the top view of a container terminal with the quayside, and the yard storage areas. Deep-sea vessels that bring containers and pick-up containers arrive at the terminal. Their berth location will be determined by the scenario, but the locations where containers are stacked can be chosen by the player by making an unloading plan for the vessel. Multiple vessels have to be handled and their arrival and departure times are shown (see Fig. 3 at the right). Cranes have to be allocated to each vessel by dragging them to the right locations for unloading and loading the ship. Horizontal transportation between the quay and the stack takes place automatically. The player can move stacking cranes to the right positions to move containers between the stacking location and the horizontal transport vehicles. Several containers have to be unloaded from one ship, and loaded onto another ship that arrives later. Choosing the right stack location for those containers can be quite difficult. Other containers are picked up by trucks. Truck loading has to be handled as efficiently as possible. Several so-called missions can be played with an increasing level of difficulty. On the higher levels, equipment breaks down at random times, forcing players to adapt their plans to a continuously changing environment.

Players have to make sure that ships are unloaded and loaded in time, and equipment keeps busy. Ships that cannot be (un)loaded in time result in negative points, ships that have been fully handled and depart early in bonus points. Equipment that is idle also costs points. The player has to be aware of a number of different plans or decisions that have to be aligned to each other: the unloading schedule, the loading schedule, the quay crane allocation, and the stacking crane locations.

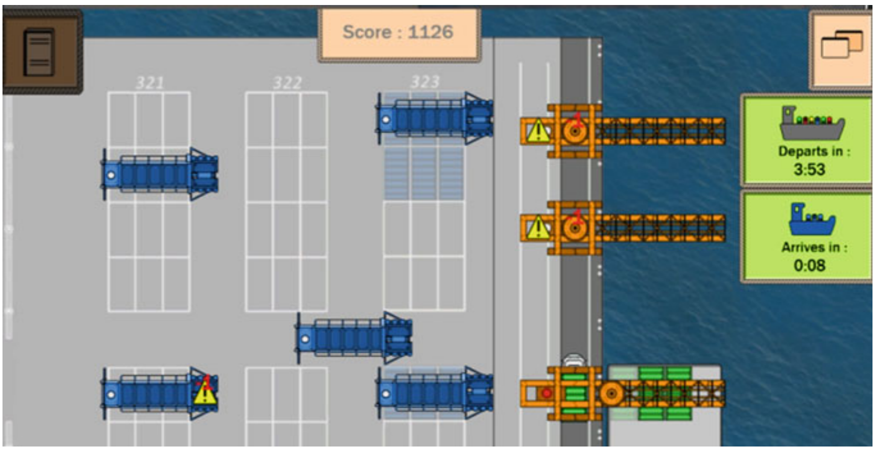

Fig. 3 Yard-crane-scheduler game (part of the screen)

4.1 SA Mode of the YCS-Game

The standard mode of playing the game is single-user. Players have to align several planning operations to efficiently unload and load a number of vessels during a so-called mission. This means that they will go through the SA phases perception, comprehension and prediction multiple times during a mission. By studying their scores in successive iterations of a mission, we can look whether learning takes place. To help *perception*, visualization plays an important role. Several indicators during the game help the player to perceive the state of the container terminal. Examples are pre-notification of the arrivals and departures of ships (arrival and departure information on the right in Fig. 3), and warnings for idle quay cranes and yard cranes (yellow triangles on the cranes in Fig. 3). In addition to visualization, sounds indicate loading and unloading operations and departure of ships, helping players to keep track of the status of the terminal when studying other parts of the terminal. To help *comprehension*, training missions are provided, in which players can practise patterns of activities for different operations such as making an unloading plan, a yard plan, and a loading plan, and planning quay crane and yard crane movements. These patterns come back during the more complex missions where all activities need to be combined and aligned. *Prediction* is realized by giving players detailed feed-back on several aspects of their performance and letting them play the same mission again to see whether other patterns of activities yield a better result.

Our hypothesis was that players would improve the quality of their plans in successive iterations of a mission, due to gaining more situational awareness. In order to test this, we set up an experiment in December 2014 with M.Sc. students of the R.H. Smith School of Business of the University of Maryland in the USA, who specialize in transportation and supply chain management. The students played a number of rounds of practice missions, after which they played two iterations of a more complex mission that we included in our analysis. In this way, the learning effect (getting to know container terminal operations and understanding the working of the game) should have mostly disappeared. In total, 50 students played the complex mission twice. Their average scores went up from 4160 to 5154 (with a minimum score of −772 and a maximum score of 13,658, see Fig. 4). Individual

	μ 1	μ 2	σ1	σ2	min	max	correlation	t-value	sig.	different?
Game scores	4160	5154	2913	3300	-772	13658	0.710	-2.938	0.005	yes
Playing time (s)	471	470	69	54	132	633	0.586	0.167	0.868	no
Waiting ship (s)	867	846	136	112	449	1166	0.516	1.150	0.256	no
Waiting stack (s)	434	411	192	166	0	976	0.476	0.892	0.377	no
Waiting yard (s)	323	302	195	207	6	1421	0.761	1.050	0.299	no
Waiting berth (s)	144	141	73	85	0	322	0.354	0.240	0.811	no
QC idle time (s)	142	138	70	76	9	409	0.439	0.420	0.676	no
YC idle time (s)	738	751	176	215	286	1301	0.597	-0.521	0.605	no

Fig. 4 Differences between scores for first and second iteration of mission play in YCS (n = 50)

scores between playing the mission the first time and the second time were highly correlated with a paired sample correlation of 0.71, which shows that low scoring students stayed low, and high scoring students stayed high, but both improved on average on their scores. In spite of the high standard deviation of the scores (2913 for the first iteration and 3300 for the second iteration), the difference between the first and second time score was highly significant; a paired samples t-test showed a t-value of −2.9 with a significance of 0.005 (Fig. 4). Because we challenged the students to improve their scores (the highest scorers received actual prize money), time on the second iteration of the mission was not significantly lower than on the first one (471 vs. 470 s). The hypothesis that the game time differed between the two iterations could be rejected. This also indicates that the students did not just become more "skillful" in playing the same mission, as that would certainly have led to a lower game play time. Interesting is that also here, playing time to complete the mission correlated highly between the first and second mission with a value of 0.586. Finally, we looked at a number of more detailed variables in the game to see whether students improved their scores by just getting more skilled in using the game and thereby decreasing waiting times at individual resources (see bottom 6 rows in Fig. 4). The fact that each of these *partial* indicators did not change significantly according to the paired t-tests, but the *overall* scores did, indicates that the players were better able to integrate the different patterns of activities in the second iteration of the mission, but their pure skills to handle individual aspects of tasks remained the same on average. This was confirmed by discussions with the students in the debriefing session after game play.

4.2 SSA Mode of the YCS-Game

A second version of the game was created, in which four different planning roles in the terminal are separated and played by four players in a team. The screen looks similar to the game screen of Fig. 3, but players can only influence the plans and operations they are responsible for, and cannot see all planning decisions of the other players. In order to fulfill their mission, individual SA is not enough. Players have to create a common operational picture (Nofi 2000) to efficiently unload and load the deep-sea vessels, which means that Shared Situational Awareness is needed. As indicated in Sect. 3, SSA is enabled by three concepts: shared mental models, communication, and cooperation. In the distributed YCS-game, we supported the formation of a *shared mental model* in several ways: one is the fact that all players see the same screen of the terminal. This provides the common operational picture (Allen et al. 2014; Nofi 2000) for the four planning roles. Secondly, the players carry out several missions with the single-user YCS-game to get used to the terminal and its operations. Thirdly, we have the players play all four roles in a single-user version of the multi-player game. In this version of the game, they have to explicitly switch to the right role before they can make a planning decision. This helps them to understand the information needs of the other players and the handovers between activities. *Communication* is supported by allowing the players to talk, by using a chat program (in case we want to capture their communication for research purposes), or by allowing the players to draw on a centrally placed picture of the terminal (in case we want to study the effect of exchanging location-dependent information). *Cooperation* is forced in the game because all four roles are needed to unload and load the vessels. Because not all information is shared on the screen that all players see, they will have to help each other to run the terminal in an efficient manner. Cooperation is further stimulated by giving the teams the goal to maximize their *team score*, with a team prize for the best performing team, which challenges them to align their activities even more.

In Spring 2015, we played the YCS-game in a distributed fashion for the first time. It became immediately clear that it is much more difficult to run the terminal than in the single-player version. Even in the single user version that asks for explicit role switching, scores already drop tremendously compared to individual play, and decision efficiency decreases. In the multi-player version where players were facing each other and could talk to each other, decision times increased, and players found it very hard to exchange the right information with each other, in order to help the other planners to do their work in the best possible way. As this was the whole purpose of developing the distributed version of the game, it forms an excellent starting point for further research on SSA.

4.3 Turning the YCS-Game into a Training Instrument

The game has been played by over 200 players in a large number of different sessions, involving both students and professionals from different backgrounds and countries. The sessions have been evaluated using questionnaires, focusing on the usefulness of the YCS game as a training instrument as well as the playability for potential users. The survey results show that players become very aware of the dependencies between different functions in the container terminal, and the need to align plans. The majority of the participants indicated that their understanding of the processes in container terminal operations and their interdependencies increased by playing the game. They also mentioned in the debriefing after the game that they understood the need for coordinating and aligning planning and resource allocation in container terminal operations. When playing the distributed version, it is clear that players become aware of the enormous amount of information that has to be exchanged between planners to run the terminal in an efficient manner. The microgame is able to illustrate the dynamics and interrelatedness of planning operations, and still provides a pleasant experience, as was stated by the majority of the test persons. In summary, we can conclude that the YCS game provides a well-balanced learning experience. Its conceptualization as web-based, short simulation game answers both the need for a dynamic representation of a complex problem and for flexible, situated learning approaches in complex working environments.

5 Disruption Mitigation Game: SSA and DSA

The Disruption Mitigation Game was developed by TU Delft as a table-top round-based board game that can be played by five people or five teams. In addition, SALOMO partner Open University developed a mobile version of the game that can be played using tablets or mobile phones. The game was conceived to achieve a set of key objectives (Kurapati et al. 2013):

- Understanding the impact of increased shared situational awareness on individual, group and system level performance;
- Setting a foundation to identify measures to increase SA;
- Offering a frame of reference to assess SA in the organization (SSA) and the network (DSA);
- To serve as a training tool for disruption management.

The key elements of the Situational Awareness framework have been translated into contextualized game play, using the principles of 'reality, meaning and play' of the triadic game design method (Harteveld 2011). The game focuses on how to handle disruptions in the transportation network around the container terminal, and whether and when to communicate information related to the disturbance to other players. Several roles are played in the game. The *vessel planner* has to decide on the time and location for unloading and loading the ship. One of the main goals for this player is to reduce vessel waiting times. The *yard planner* decides on the storage positions for the incoming and outbound containers in the yard. This player is responsible for ensuring sufficient stack capacity to maintain overall performance of the terminal. The *control tower* keeps track of all operations on the container terminal, and has to give permission for operations that violate existing plans. *Sales* is responsible for the booking of containers that the terminal handles and for financial transactions between the clients and the terminal. It has to arrange alternatives for clients during disruptions of the container flow in and out of the terminal. This player needs to keep the customer informed at all times, and is responsible for customer satisfaction. The *Resource planner* assigns equipment to each vessel planned for the terminal, such as quay cranes, automated guided vehicles, gantry cranes, and reach stackers. Goals for this planner are to ensure high performance and an even distribution of equipment use. Three types of disruptions can be played in the game: an equipment breakdown in the terminal with local consequences, an accident in the terminal that forces a complete shutdown while the investigation is running, and a truckers' strike with a blockage of the terminal gate that creates a major disturbance inside the terminal as well as in the hinterland network (Fig. 5).

5.1 SSA Mode of the Disruption Game

The disruption unfolds during the rounds of the game, and the players are given pieces of information (through game cards) about the disruption. The formation of

Fig. 5 Disruption mitigation game

shared mental models in the Disruption Game is supported by a shared central board with goals and decision steps of all the players that helps them to align their plans, and to consider the decisions of the other players. An important aspect of the game is that the players are evaluated on three aspects: safety in the terminal, customer satisfaction, and performance of the terminal. Evaluation is carried out both for their individual roles and as a team. Several decisions that players can make during the game affect the individual score in a negative way, but have a positive effect on the overall KPIs of the terminal, which creates a trade-off and might tempt players to not share all their ideas and plans with the other players. When playing in "SSA mode", the individual KPI scores and the team score can be viewed by all players. *Communication* is supported by a set of communication tokens that allow players to exchange information with one other player, or with all other players (a conference call). The two types of communication have different costs in terms of the number of tokens needed. Although there is a cost attached, the number of tokens is chosen in such a way that players are aware of the costs of communicating, but they don't see the costs as a burden. Mitigating each disruption needs a careful alignment of tasks between the five players. If certain steps are skipped, or intended steps are not shared with others, problems solving becomes less effective and the team score as well as the individual scores will decrease. Therefore, *cooperation* between all players is forced.

5.2 DSA Mode of the Disruption Game

According to Boy (2013), DSA is characterized by sharing, distribution, delegation, and trading. In the distributed version of the game, players cannot see the scores of others, and as a result there is more emphasis on the individual scores, which means that the players will behave more egoistic compared to the SSA version of the game. *Distribution* is implemented by giving different players different pieces of information (through game cards) about the disruption, which other players cannot see. SA is limited to awareness of individual responsibilities and goals. Players receive an individual board, with their respective KPI, goal, and decision steps based on their role description. There is a central board with the 3 overall KPIs visible to everyone, whereas individual boards are shielded from each other. Therefore, none of the players has a complete operational picture to effectively deal with the disruption. Therefore, *sharing* of information is needed to address the disruption. If certain steps are skipped, or important information is not shared with others, the problem will deteriorate and both individual and team scores will plummet. *Delegation* is implemented by allowing players to give a game card to another player at the end of a round. This enables the receiving player to start working on the issue that is mentioned on the game card. Other players do, however, not know what task was delegated. Finally, *trading* behavior in the form of trade-offs is implemented by making information exchange between players possible, but only on a one-to-one basis, and with high costs attached to communicating. They can send an email for 2 tokens (always received, but with a delay) or make a phone call for 1 token (we roll a dice to see whether the other party picks up). Players have only 10 tokens each, which makes communication much more of a burden. Trade-offs between communicating (spending tokens fast) and not communicating (hoping the information exchange was not really needed), and between individual scores (personal goal) and central scores (not really necessary to have a high score there, but on the other hand also an indicator of overall progress) can lead to interesting trading behavior, which is certainly much different from the more "open" information sharing in the SSA-mode of the game.

5.3 Turning the Disruption Game into a Training Instrument

The game has been tested with over 100 participants, both professionals and students at different universities. Players typically play on both levels, where they are able to see the effects of more or better communication and insight into each others' decisions on the individual and overall scores. Video recordings of the game play have been made, and players have answered questionnaires about playability and usability. First results indicate that players become aware of the interdependencies between different functions when addressing a disturbance in the transportation network around a container terminal, and learn about the usefulness of visibility of information and decisions of others, and the effects of (not) exchanging information. The observation of the gameplay as well as the feedback of the participants by survey show that the simulation game introduced creates a helpful learning experience in the field of disruption management and resilience of container terminal operations. The gameplay shows that players make use of communication and information sharing channels provided in the game.

6 Discussion, Conclusions and Further Research

The two games that have been described in detail in the paper address Situational Awareness in terms of the framework that was presented in Fig. 2. The YCS game looks at Individual Situational Awareness when playing in single-player mode, and at Shared Situational Awareness when playing in distributed mode. Important game elements in single player mode are visualization for perception, small training missions and detailed feedback for comprehension, and repetition for prediction. For the SSA setting of the YCS game, cooperation is forced by designing tight inter-dependencies between activities. Providing a partial shared view on the terminal for all players and supporting communication (chat, drawing or speech) helps in creating a shared mental model for the players. First results have shown, however, that it is very difficult for players to align their individual plans in the shared setting, even though they all look at the same situation of the terminal and can exchange information fully. This illustrates the importance of training for improving shared situational awareness.

The Disturbance Mitigation Game studies the differences between Shared Situational Awareness and Distributed Situational Awareness. When handling a disruption, distribution of information and not having a "common operational picture" makes it very difficult for the players to make the right decisions. Full sharing of the information and "conference calls" make it a lot easier for the players to align their decisions and increase the overall scores of the game. Players immediately understand the important role communication plays in the complex process of container terminal operation and hinterland transportation. Although the disruption game is a board game, the game elements that were used for SSA were very similar to those used in the computerized YCS game. For DSA, several new elements were introduced, such as hiding most information for other players, using game cards with information for delegation, and forcing trade-offs for the participants by having them focus on individual scores and creating a high cost and a time delay for communication.

With both games, we were able to address all three levels of the Situational Awareness framework. Our studies have provided first sets of game elements that can be used to study *and* train Individual, Shared, and Distributed Situational Awareness for planning operations and resilience in and around deep-sea container terminals. Further research will focus on studying the differences between the levels of the Situational Awareness Framework of Fig. 2 in more detail and enhancing the game elements that can help to research and train SA. Several more experiments with the different tools in the SALOMO project will be carried out to study the effectiveness of SA methods in transport networks.

The games and tools that have been developed in the SALOMO project will be made available to the wider logistics and transportation community, where they can be used for training, creating awareness, and further research on the necessary ingredients to make transportation networks more resilient.

Acknowledgments This research was funded by Dinalog, the Dutch Institute for Advanced Logistics. The SALOMO project (2011–2015) was carried out by TU Delft, APM Terminals Maasvlakte 2, InThere, Open Universiteit, Rotterdam World Gateway, TBA, TeamSupport, TRAIL Research School, and University of Maryland.

References

Allen DK, Karanasios S, Norman A (2014) Information sharing and interoperability: the case of major incident management. Eur J Inf Syst 23:418–432

Behdani B (2013) Handling disruptions in supply chains: an integrated framework and an agent-based model. PhD thesis, Delft University of Technology, Delft, The Netherlands

Böse JW (2011) General considerations on container terminal planning. In: Böse JW (ed) Handbook of terminal planning. Springer, New York, pp 3–24

Boy GA (2013) Orchestrating situation awareness and authority in complex socio-technical systems. In: Aiguier M, Caseau Y, Krob D, Rauzy A (eds) Proceedings of the third international conference on complex systems design and management CSD&M 2012, Springer, Berlin, pp 285–296

Brinkmann B (2011) Operations systems of container terminals: a compendious overview. In: Böse JW (ed) Handbook of terminal planning. Springer, New York, pp 25–39

Crookall D (2010) Serious games, debriefing, and simulation/gaming as a discipline. Simul Gaming 41(6):898–920

Douma A (2008) Aligning the operations of barges and terminals through distributed planning. PhD thesis, University of Twente, Enschede, The Netherlands

Endsley MR (1995) Toward a theory of situation awareness in dynamic systems. Hum Factors 37 (1):32–64

Endsley MR, Jones WM (1997) Situation awareness, information dominance, and information warfare. Technical report, United States Air Force Armstrong Laboratory, Belmont, MA. Report AL/CF-TR-1997-0156

Guan C, Liu R (2009) Container terminal gate appointment system optimization. Maritime Econ Logistics 11(4):378–398

Gurning S, Cahoon S (2011) Analysis of multi-mitigation scenarios on maritime disruptions. Maritime Policy Manage 38(3):251–268

Han X, Lu Z, Xi L (2010) A proactive approach for simultaneous berth and quay crane scheduling problem with stochastic arrival and handling time. Eur J Oper Res 207(3):1327–1340

Harrington LH, Boyson S, Corsi TM (2011) X-SCM—the new science of X-treme supply chain management. Routeledge, New York

Harteveld C (2011) Triadic game design: balancing reality, meaning and play. Springer, Heidelberg

IDVV (2012) Multimodal international container network (in Dutch). Deliverable 3.2. Technical report, Rijkswaterstaat, Delft, The Netherlands. Impuls Dynamisch Verkeersmanagement Vaarwegen, Spoor 3, Cluster 3

Port Technology International (2011) Berth productivity will have to keep up with shipping's super-sized revolution. Port Technol Int 50:18–20

Jüttner U, Peck H, Christopher M (2003) Supply chain risk management: outlining an agenda for future research. Int J Logistics Res Appl 6(4):197–210

Kemme N (2011) RMG crane scheduling and stacking—overview and implications on terminal planning. In: Böse JW (ed) Handbook of terminal planning. Springer, New York, pp 271–301

Kurapati S, Groen D, Lukosch HK, Verbraeck A (2014) Microgames in practice: a case study in container terminal operations. In: ISAGA 2014: 45th conference of the international simulation and gaming association. SAGSAGA, Dornbirn, Austria, pp 1–14

Kurapati S, Kolfschoten GL, Verbraeck A, Corsi TM, Brazier FMT (2013) Exploring shared situational awareness using serious games for supply chain disruptions. In: Proceedings of the 10th international ISCRAM conference, May 2013

Kurapati S, Kolfschoten GL, Verbraeck A, Drachsler H, Specht M, Brazier FMT (2012) A theoretical framework for shared situational awareness in sociotechnical systems. In: Proceedings of the 2nd workshop on awareness and reflection in technology-enhanced learning, Saarbrücken, Germany, pp 47–53

Lau HYK, Zhao Y (2008) Integrated scheduling of handling equipment at automated container terminals. Int J Prod Econ 112(2):665–682. (Special section on RFID: technology, applications, and impact on business operations)

Legato P, Mazza RM, Trunfio R (2012) Simulation for performance evaluation of the house-keeping process. In: Laroque C, Himmelspach J, Pasupathy R, Rose O, Uhrmacher AM (eds) Proceedings of the 2012 winter simulation conference (WSC). IEEE, p 1422

Lo JC, Meijer SA (2014) Gaming simulation design for individual and team situation awareness. In: Meijer SA, Smeds R (eds) Frontiers in gaming simulation—44th international simulation and gaming association conference, ISAGA 2013. Springer, Switzerland, pp 121–128

Lukosch HK, de Vries P (2009) Supporting informal learning at the workplace. Int J Adv Corp Learn (iJAC) 2(3):39–44

Lukosch HK, Littlejohn A, Margaryan A (2013) Simulation games for workplace learning. In: Littlejohn A, Margaryan A (eds) Technology-enhanced professional learning: processes, practices, and tools. Routledge, New York/London, pp 158–167

Lukosch HK, van Nuland B, van Ruijven T, van Veen L, Verbraeck A (2014) Building a virtual world for team work improvement. In: Meijer SA, Smeds R (eds) Frontiers in gaming simulation—44th international simulation and gaming association conference, ISAGA 2013. Springer, Switzerland, pp 60–68

Manuj I, Mentzer JT (2008) Global supply chain risk management. J Bus Logistics 29(1):133–155

Mayer IS (2009) The gaming of policy and the politics of gaming: a review. Simul Gaming 40 (6):825–862

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: Verduijn T, van de Loo B (eds) Intelligent logistics concepts. Eburon Publishers, Delft, pp 101–116

Newman AM, Yano CA (2000) Scheduling direct and indirect trains and containers in an intermodal setting. Transport Sci 34(3):256–270

Nofi AA (2000) Defining and measuring shared situational awareness. Technical report, Center for Naval Analyses, Alexandria, VA. Report CRM D0002895.A1/Final

Notteboom T (2008) The relationship between seaports and the inter-modal hinterland in light of global supply chains. Technical report, OECD Publishing. Report No. 2008/10

Overschie M, Lukosch HK, Mulder K, de Vries P (2013) Micro-training to support sustainable innovations in organizations. In: Appelman JH, Osseyran A, Warnier M (eds) Green ICT and energy: from smart to wise strategies. CRC Press, Boca Raton, pp 97–106

Pani C, Fadda P, Fancello G, Frigau L, Mola F (2014) A data mining approach to forecast late arrivals in a transhipment container terminal. Transport 29(2):175–184

Perla PP, Markowitz M, Nofi A, Weuve C, Loughran J, Stahl M (2000) Gaming and shared situation awareness. Technical report, Center for Naval Analyses, Alexandria, VA. Report CRM D0002722.A2/Final

Phan M-H, Kim KH (2015) Negotiating truck arrival times among trucking companies and a container terminal. Transp Res Part E Logistics Transp Rev 75:132–144

Saanen YA (2004) An approach for designing robotized marine container terminals. PhD thesis, Delft University of Technology, Delft, The Netherlands

Steenken D, Voß S, Stahlbock R (2004) Container terminal operation and operations research—a classification and literature review. OR Spectrum 26(1):3–49

Tran NK, Haasis H-D (2015) An empirical study of fleet expansion and growth of ship size in container liner shipping. Int J Prod Econ 159:241–253

UNCTAD (2014) Review of maritime transport 2014. Technical report, UNCTAD, Geneva, Switzerland. Report UNCTAD/RMT/2014

Vis IFA, de Koster R (2003) Transshipment of containers at a container terminal: an overview. Eur J Oper Res 147(1):1–16

Wiese J, Suhl L, Kliewer N (2011) Planning container terminal layouts considering equipment types and storage block design. In: Böse JW (ed) Handbook of terminal planning. Springer, New York, pp 219–245

World Shipping Council (2014) Website on global trade 2014. http://www.worldshipping.org/about-the-industry/global-trade. Accessed 2 Oct 2014

WTO (2013) WTO press release 688, 10 April 2013, World trade 2012, prospects for 2013. http://www.wto.org/english/newse/pres13%20e/pr688%20e.htm. Accessed 2 Oct 2014