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## A simulation gaming study in intermodal transport operations

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# Situation Awareness for Socio Technical Systems: A simulation gaming study in intermodal transport operations

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# Situation Awareness for Socio Technical Systems: A simulation gaming study in intermodal transport operations

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*Amor Vincit Omnia*
*To my family*
*Per la mia famiglia*

# Contents

# Summary

Operating socio technical systems such as energy distribution networks, power plants, container terminals, and healthcare systems is a grand challenge. Decision making in these systems is complex due to their size, diversity, dynamism, social component, distributed nature, uncertainty, and vulnerability to disruptions. Human actors in these systems have to channel their pre-decision time to assess and classify current situation based on their individual or organizational goals rather than analyse possible alternatives for an optimal outcome. In this effect, Situation Awareness, a human factor required to perceive, comprehend and project the future of a current situation is considered to be an essential prerequisite for decision making in socio technical systems. Although the importance of Situation Awareness is well established it has not been studied extensively in socio technical systems. Therefore the key objective of this dissertation was to study the role of Situation Awareness on decision making and performance of individuals and teams in socio technical systems within the context of intermodal transport operations in container terminals. This led us to our first research question:

**RQ1**: How can Situational Awareness (SA) influence the decision making and performance of actors involved in intermodal transport operations?
The sub-questions that complement the **RQ1** are:
i. What is the role of SA in actors' decision making and performance, while handling dynamic intermodal transport operations?
ii. What are the factors that affect the relationship between SA and decision making in intermodal transport operations?

After analysing the available theories on individual and group SA, we proposed a theoretical framework to represent SA in socio technical systems. We divided the socio technical systems into three organizational levels— Individual, Team and System. We proposed that SA at the individual level followed the three level model of Endsley, SA at the team level was shared and at the system level was distributed. We also proposed individual, team and environmental factors that affect SA at the different organizational levels. In order to answer the above research questions and test the SA theoretical framework, we used simulation gaming as our key research method. Although simulation gaming is not a well-established research method in the field transportation, we chose the same due to its ability to engage human participants in a safe and controlled setting. This led us to our second research question:

**RQ2**: How can simulation games be designed and used to study SA in individuals and teams in socio technical systems?

In order to answer our research questions and test our SA framework, we developed a research approach to design and use simulation games that consisted of a design cycle and an empirical cycle. The design cycle began with the definition of a research objective, followed by a prototype design that was well balanced among the elements of reality meaning and play, and that was sufficiently tested and validated. The design cycle was iterated until a satisfactory research instrument was developed. The design cycle produced three games— Yard Crane Scheduler 1 (YCS1), Yard Crane Scheduler 3 (YCS3), and the disruption management board game. Each of the three games fed into the empirical cycle that consisted of simulation gaming sessions that generated qualitative and quantitative data that helped us to answer the research questions and test the SA theoretical frame work.

The YCS1 game was a single player Microgame, a short digital game that focussed on a single research objective. The main objective of the YCS1 game was to manage the yard and align various planning and resource allocation activities in the container terminal. The game focussed on two main challenges— dynamic planning and distribution of containers in the yard, and allocation of resources to ensure maximum utilization of resources and reduce ship turnaround times. The YCS3 micro game was a multi-player extension of YCS1. YCS3 was designed to explore SA in teams where 4 players take on the roles of berth planner, vessel planner, controller and yard planner. The game objective of YCS3 was similar to that of YCS1. The players needed to identify the interdependencies between their tasks in the game and had to align their plans accordingly through communication, coordination and information sharing in a short period of time. The disruption management game was the third and final game developed for this thesis. It was a five player table-top board game. The five roles in the game were berth planner, vessel planner, yard planner, controller and sales manager. The players needed to mitigate disruptions un-

folded in the game to avoid long waiting times for ships and monetary losses to the terminals while maintaining a safe operating environment in the terminal. They had to achieve this by sharing information, coordinating their plans and by making tradeoffs between their individual and organizations KPIs .

We used the games discussed above to study SA in individuals and teams within three studies carried out with the help of student participants majoring in supply chain, logistics and transportation in the Netherlands and United States. We received the approval of the Institutional Review Board of the University of Maryland and Human Research Ethics Committee of the Delft University of Technology to use students for our research.

In the first study, we used YCS1 as a part of a larger experimental set-up to explore the influence of four factors— multi-tasking ability, personality type, gender and culture— that are related to the characteristics of socio technical systems on SA and task performance in intermodal transport operations. We also used Multi Attribute Test Battery (MATB-II), a software designed by NASA to measure multi-tasking ability, Ten-Item Personality Inventory (TIPI) to assess personality type and a pre-game questionnaire to collect the demographics of the participants. One hundred and forty five student participants across 15 nationalities formed the sample population for this study. We analysed the data collected from the gaming sessions using correlations, hierarchical regression, pair-wise and group-wise comparisons. Our results indicated that multi-tasking ability had a significant positive correlation to planner task performance represented by the YCS1 score. This finding was consistent with the crucial role of multi-tasking ability on performance in other complex systems where automation reduces physical workload, but increases cognitive workload. Among the personality traits, emotional stability had a direct and statistically significant positive correlation with planner task performance. Another personality trait, Openness to experience had a negative moderating effect on the relationship between multi-tasking ability and planner task performance. Although openness to experience had been credited with superior performance in other studies, the negative relation in our case could be attributed to the fact that planning tasks are bound by rules and deadlines providing little room for creativity. Female participants performed significantly better than their male counterparts. This could be explained by different cognitive approaches chosen by men and women towards planning tasks. However the difference could also be attributed to social and individual differences rather than on gender alone. Dutch participants significantly outperformed their Chinese and American colleagues. One possible explanation of the result could be the high tolerance for uncertainty by the Dutch. The YCS1 game needed a flexible planning strategy, where the player had to constantly reallocate containers and resources based on changing circumstances in the game. We conducted this first study with a focus on individual actors and our second study focussed on SA in teams.

In the second study, we used the YCS3 game in a quasi-experimental set-up to understand the role of Shared SA and Distribute SA, and several team factors in performance and decision making in teams. Twenty six participants, predominantly Dutch (23) participated in this study in a Dutch technical university. We used a pre-game survey to capture the demographics of the participants, TIPI questionnaire for personality type and TeamSTEPPS questionnaire to measure the team factors that affect performance. Given the small sample size we used qualitative methods (video analysis and observation) to support the quantitative analysis (correlations and pair- wise and group- wise comparison) of the study. Our results showed that team member performance was better at the Distributed SA level compared to the Shared SA level of the game play. This showed that teams in complex systems developed and maintained better SA when information is distributed (information pull) rather than when it is shared (information push) especially under time pressure. Similar to the YCS1 study, emotional stability had a significant positive influence on team task performance. Other personality traits did not exhibit direct influence, and the sample size was relatively small to examine indirect effects. At least in the short term, homogeneous teams (gender balanced, same nationality) performed better than their heterogeneous counterparts, and the added value of diversity in teams could have been noticed in long term. With respect to team factors, situation monitoring had a significant positive effect on team task performance, and mutual support between team members has a negative effect . The temporal pressure of the game made mutual support among team members detrimental to task performance in a fast paced environment, although it improves social cohesion. Shared mental models and closed loop communication were found to be important for the team task performance but the development of shared mental models through shared displays and the effectiveness of closed loop communication were hindered by the fast paced tasks in complex planning operations.

Our third and final study on SA in teams was based on the disruption management board game. We studied the role of Shared and Distributed SA in improving resilience in intermodal transport operations using the disruption management board game in an exploratory set-up. Eighty participants across

13 nationalities in the United States and the Netherlands participated in this study. We used qualitative observational methods and participant perception based on a post-game survey to derive results from this study. We observed clear differences in the behavioural patterns of players at different SA levels of the game. In an individual SA level of the game play, all players had limited awareness and understanding of the disruption scenario, the potential effects of their mitigation actions, and their role and objective in the game. Information was being requested from/sent to the wrong providers/recipients. In the Distributed SA level, players had relatively a higher awareness of the situation. They made good use of the available communication channels, as they understood who needed their information and who possessed the information they needed. The flow of redundant information reduced compared to individual SA level. Players tried to attune their plans, considering the decisions of others. In Shared SA level, players had more discussions and negotiations. Players came up with innovative ways of teaming up to jointly mitigate the situation. Sometimes, players compromised their individual KPIs to boost the overall KPIs. Well-informed and rational decisions were best made in the Shared SA level although it was time consuming to reach such decisions. Finally, we consolidated, compared and contrasted the results of the studies based on the design cycles of the three games and the empirical cycles of the related studies to gather answers for our research question and validation for our SA framework.

With respect to the first part of RQ1, we confirmed the crucial role of SA in the performance and decision making for individual actors and teams involved in container terminal planning. Our major finding was that Situation Awareness in operational phase of socio technical systems, similar to intermodal transport operations in container terminals had to be viewed through a renewed theoretical framework. In this framework we argued that the development and maintenance of SA need not be limited to SSA for teams or DSA for networks. We proposed that both SSA and DSA could be applied to a collective setting (team, group or network) depending on the combinations of their three distinctive characteristics— goal orientation, information sharing and geographical location. With regards to the second part of RQ1, multi-tasking ability, personality type , gender and cultural differences and team composition, significantly affected SA and task performance of individual actors and teams while handling dynamic intermodal transport operations. Our key recommendation to container terminal management was to consider these SA factors while designing tasks and training programs to enhance task performance in individuals and teams.

The second and final research question, RQ2, was related to simulation gaming as a research method. With the experience and lessons learnt in this research work, we asserted simulation gaming to be a suitable research method for studying SA in complex socio technical organizations. The key considerations for designing simulation games for research were: type of the game (digital, analogue, multi-player, single player), computational and technical requirements, reliability, scalability, portability, participant involvement and ability to foster social cohesion. With regards to using the developed games for research, recommendations were related to experiences on preparation and planning, reliable data gathering and analysis and participant selection for the study.

Although we designed and implemented our studies in a rigorous manner our results and conclusions have limitations. The level of complexity of all the three games is not as high as complexity in a real terminal. Our studies were limited to one example system and did not cover SA in geographically distributed teams and SA in a network of organizations. Future work is needed to extend these ideas to other socio technical organizations using high fidelity simulation models to match the complexity of real world operations of socio technical systems.

# Samenvatting

Het exploiteren van sociotechnische systemen zoals energiedistributienetwerken, elektriciteitscentrales, containerterminals en de gezondheidszorg vormt een enorme uitdaging. De besluitvorming in deze systemen is complex als gevolg van hun omvang, diversiteit, dynamiek, sociale component, verspreide karakter, onzekerheid en kwetsbaarheid voor verstoringen. Voordat menselijke actoren in deze systemen een besluit vormen, moeten ze de bestaande situatie op basis van hun individuele doelen of de doelen van de organisatie evalueren en classificeren en niet zozeer mogelijke alternatieven op een optimaal resultaat analyseren. In dit verband wordt situation awareness, een menselijke factor die nodig is om de huidige situatie waar te nemen, te begrijpen en naar de toekomst te projecteren, beschouwd als een essentiële voorwaarde voor besluitvorming in sociotechnische systemen. Hoewel het belang van situation awareness voldoende is aangetoond, is het nog niet uitgebreid onderzocht in sociotechnische systemen. Het hoofddoel van dit proefschrift was daarom de rol van situation awareness te bestuderen in de besluitvorming en de prestaties van personen en teams in sociotechnische systemen binnen de context van intermodaal vervoer in containerterminals. Dit leidde ons naar onze eerste onderzoeksvraag:

**RQ1**: Hoe kan situation awareness (SA) de besluitvorming en prestaties van actoren in het intermodaal vervoer beïnvloeden?
De deelvragen in aanvulling op RQ1 zijn:
i. Wat is de rol van SA in de besluitvorming en prestaties van actoren bij de afhandeling van dynamisch intermodaal vervoer?
ii. Wat zijn de factoren die de relatie tussen SA en besluitvorming in intermodaal vervoer beïnvloeden?
Na analyse van de beschikbare theorieën over individueel en team-SA stelden we een theoretisch kader op, waarin SA in sociotechnische systemen uiteen wordt gezet. We deelden de sociotechnische systemen in drie organisatorische niveaus in: individueel, team en systeem. We namen aan dat situation

awareness op het individuele niveau het model van Endsley volgde, dat SA op teamniveau gedeeld was (shared SA) en dat het systeemniveau verspreid was (distributed SA). We definieerden bovendien individuele, team- en omgevingsfactoren die SA op de verschillende organisatorische niveaus beïnvloeden.
Om de bovenstaande onderzoeksvragen te beantwoorden en het theoretisch kader voor SA te testen, gebruikten we simulatiegaming als belangrijkste onderzoeksmethode. Hoewel simulatiegaming geen gevestigde onderzoeksmethode is op het gebied van transport, kozen we toch hiervoor omdat het ons in staat stelde om menselijke deelnemers in te zetten in een veilige en gecontroleerde omgeving. Dit leidde ons naar onze tweede onderzoeksvraag:

**RQ2**: Hoe kunnen simulatiespellen worden ontworpen en gebruikt om SA in personen en teams in sociotechnische systemen te onderzoeken?

Om onze onderzoeksvragen te beantwoorden en ons SA kader te testen, ontwikkelden we een onderzoeksaanpak voor het ontwerpen en gebruiken van simulatiespellen. Deze bestond uit een ontwerpcyclus en een empirische cyclus. De ontwerpcyclus begon met de definitie van een onderzoeksdoel, gevolgd door een prototype-ontwerp dat een goede balans tussen elementen met werkelijke betekenis en spelelementen bood en voldoende getest en gevalideerd was. De ontwerpcyclus werd herhaald, totdat er een bevredigend onderzoeksinstrument was ontwikkeld. De ontwerpcyclus leverde drie spellen op: Yard Crane Scheduler 1 (YCS1), Yard Crane Scheduler 3 (YCS3) en het disruption management bordspel. Elk van de drie spellen voedde de empirische cyclus. Deze bestond uit simulatiegamingsessies die kwantitatieve en kwalitatieve data genereerden, die ons hielpen de onderzoeksvragen te beantwoorden en het theoretisch kader voor SA te testen.

Het YCS1 spel was een microgame voor één speler; een kort, digitaal spel dat op één onderzoeksdoel was gericht. Het hoofddoel van het YCS1 spel was het beheren van de werf en het afstemmen van verschillende activiteiten op het gebied van planning en toewijzing van middelen in de containerterminal. Het spel richtte zich op twee belangrijke uitdagingen: de dynamische planning en distributie van containers op de werf en de toewijzing van middelen met het doel de maximale benutting van middelen te waarborgen en de doorlooptijden van schepen te reduceren. De YCS3 microgame was een uitbreiding van YCS1 voor meerdere spelers. YCS3 was ontworpen om SA in teams te onderzoeken. 4 spelers kruipen in de rol van berth planner, vessel planner, controller en yard planner. Het speldoel van YCS3 was hetzelfde als dat van YCS1. De spelers moesten in een kort tijdsbestek de onderlinge afhankelijkheid tussen de taken in het spel identificeren en hun plannen dienovereenkomstig afstemmen door te communiceren, coördineren en informatie te delen. Het disruption management spel was het derde en laatste spel dat voor dit proefschrift werd ontwikkeld. Het was een bordspel voor vijf spelers. De vijf rollen in dit spel waren berth planner, vessel planner, yard planner, controller en sales manager. De spelers moesten de verstoringen die tijdens het spel optraden mitigeren om lange wachttijden voor schepen en geldelijk verlies voor de terminals te voorkomen en daarbij de veilige werkomgeving in de terminal handhaven. Ze moesten dit bereiken door informatie te delen, hun plannen te coördineren en afwegingen te maken tussen hun individuele KPI's en de KPI's van de organisatie. We gebruikten de hierboven besproken spellen om SA in personen en teams in drie onderzoeken te bestuderen. Deze onderzoeken werden uitgevoerd met deelnemers bestaande uit studenten die in Nederland en de Verenigde Staten een major in supply chain, logistiek en transport volgden. We kregen goedkeuring van het Institutional Review Board van de University of Maryland en het Human Research Ethics Committee van de Delft University of Technology om studenten voor ons onderzoek te gebruiken.

In het eerste onderzoek gebruikten we YCS1 als onderdeel van een grotere experimentele opzet. Hierin onderzochten we de invloed van vier factoren die samenhangen met de kenmerken van sociotechnische systemen op SA en taakuitvoering in intermodaal vervoer: het vermogen tot multitasken, persoonlijkheidstype, geslacht en cultuur. We maakten ook gebruik van Multi Attribute Test Battery (MATB-II), software die door NASA werd ontworpen om het vermogen tot multitasken te meten, van Ten-Item Personality Inventory (TIPI), waarmee we het persoonlijkheidstype beoordeelden en een vragenlijst voorafgaand aan het spel om de demografische gegevens van de deelnemers te verzamelen. De steekproefpopulatie voor dit onderzoek bestond uit honderdvijfenveertig studenten, verdeeld over vijftien nationaliteiten. We analyseerden de data die in de spelsessies werden verzameld aan de hand van correlaties, hiÃńrarchische regressie, paarsgewijze en groepsgewijze vergelijkingen. Onze resultaten lieten een significante positieve correlatie zien tussen het vermogen tot multitasken en de planningsprestatie zoals uitgedrukt door de YCS1 score. Deze bevinding was consistent met de cruciale rol die het vermogen tot multitasken heeft voor de prestaties in andere complexe systemen waar automatisering de fysieke werkbelasting reduceert, maar de cognitieve werkbelasting verhoogt. Wat betreft de persoonlijkheidskenmerken had emotionele stabiliteit een directe en statistisch significante positieve correlatie met de planningsprestatie. Een ander persoonlijkheidskenmerk, openstaan voor ervaringen, had een negatief matigend effect op de relatie tussen het vermogen tot multitasken en de planningsprestatie. Hoewel in andere onderzoeken werd geconcludeerd dat openstaan voor ervaringen tot betere prestaties leidt, kon de negatieve relatie in ons geval worden toegeschreven aan het feit dat planningtaken aan strikte regels en deadlines gebonden zijn en dus weinig ruimte voor creativiteit bieden. Vrouwelijke deelnemers presteerden significant beter dan hun mannelijke collega's. Dit zou verklaard kunnen worden doordat mannen en vrouwen voor een andere cognitieve aanpak van de planningtaken kozen. Het verschil zou echter ook aan sociale en individuele verschillen toegeschreven kunnen worden in plaats van uitsluitend aan het geslacht. Nederlandse deelnemers presteerden significant beter dan hun Chinese en Amerikaanse collega's. Een mogelijke verklaring van dit resultaat zou kunnen zijn dat Nederlanders een hoge tolerantie voor onzekerheid hebben. Het YCS1 spel vereiste een flexibele planningstrategie. De speler moest containers en middelen voortdurend opnieuw toewijzen op basis van de veranderende omstandigheden in het spel. Dit eerste onderzoek was op individuele actoren gericht, terwijl we ons met ons tweede onderzoek op SA in teams richtten.

In het tweede onderzoek gebruikten we het YCS3 spel in een quasi-experimentele opzet om de rol van shared SA en distributed SA en van een aantal teamfactoren in de prestaties en besluitvorming van teams rol te begrijpen. Er deden zesentwintig deelnemers, voornamelijk Nederlanders (23), mee aan dit onderzoek in een Nederlandse technische universiteit. We gebruikten een vragenlijst voorafgaand aan het spel om de demografische gegevens van de deelnemers vast te leggen, de TIPI-vragenlijst voor het persoonlijkheidstype en de TeamSTEPPS-vragenlijst om de teamfactoren te meten die de prestaties beïnvloeden. Gezien de geringe omvang van de steekproef maakten we gebruik van kwalitatieve methoden (videoanalyse en observatie) ter ondersteuning van de kwantitatieve analyse (correlaties en paarsgewijze en groepsgewijze vergelijking) van het onderzoek. Onze resultaten lieten zien dat de prestaties van teamleden op het distributed SA-niveau van het spel beter waren dan die op het shared SA-niveau. Hieruit bleek dat teams in complexe systemen vooral onder tijdsdruk een beter SA ontwikkelden en onderhielden als de informatie verspreid werd (information pull) dan wanneer deze gedeeld werd (information push). Net als in het YCS1 onderzoek had emotionele stabiliteit een significante positieve invloed op de taakuitvoering van het team. Andere persoonlijkheidskenmerken vertoonden geen directe invloed en de steekproef was te klein om indirecte effecten te onderzoeken. Homogene teams (evenwicht tussen de geslachten, zelfde nationaliteit) presteerden op de korte termijn beter dan heterogene teams. De toegevoegde waarde van diversiteit in teams zou op de lange termijn kunnen blijken. Wat betreft teamfactoren had situatiebewaking een significant positief effect op de taakuitvoering van het team, terwijl wederzijdse ondersteuning tussen teamleden een negatief effect had. De tijdsdruk van het spel zorgde ervoor dat wederzijdse ondersteuning tussen teamleden schadelijk was voor de taakuitvoering in een snel veranderde omgeving, hoewel het de sociale cohesie verbetert. Gedeelde mentale modellen en closed-loop communicatie bleken belangrijk te zijn voor de taakuitvoering van het team, maar de ontwikkeling van gedeelde mentale modellen via gedeelde schermen en de effectiviteit van closed-loop communicatie werden gehinderd door de snel uit te voeren taken in complexe planningwerkzaamheden.

Ons derde en laatste onderzoek betreffende SA in teams was op het disruption management bordspel gebaseerd. We bestudeerden de rol van gedeeld en distributed SA in het verbeteren van de veerkracht in intermodaal vervoer met behulp van het disruption management bordspel in een verkennende opzet. Aan dit onderzoek deden tachtig deelnemers, verdeeld over dertien nationaliteiten in de Verenigde Staten en Nederland mee. We leidden de resultaten van dit onderzoek af met behulp van kwalitatieve observatiemethoden en deelnemerperceptie op basis van een vragenlijst na afloop van het spel. We namen duidelijke verschillen in de gedragspatronen van spelers op verschillende SA-niveaus in het spel waar. Op een individuele SA-niveau van het spel hadden alle spelers een beperkt bewustzijn en begrip van het verstoringsscenario, de potentiële effecten van hun mitigatiemaatregelen en hun rol in en het doel van het spel. Informatie werd opgevraagd bij/verzonden naar de verkeerde verschaffers/ontvangers. Op het distributed SA-niveau hadden spelers een relatief hoger bewustzijn van de situatie. Ze maakten goed gebruik van de beschikbare communicatiekanalen, terwijl ze begrepen wie hun informatie nodig had en wie over de informatie beschikte die zij nodig hadden. De stroom van overbodige informatie nam af in vergelijking tot het individuele SA-niveau. Spelers probeerden hun plannen op elkaar af te stemmen, rekening houdend met de besluiten van anderen. Op het shared SA-niveau voerden spelers meer discussies en onderhandelingen. Spelers bedachten innovatieve manieren om samen te werken en de situatie gezamenlijk te mitigeren. Soms gave spelers voorrang aan de algemene KPI's ten koste van hun persoonlijke KPI's. Het nemen van goed geïnformeerde en rationele besluiten ging het beste op het shared SA-niveau, hoewel het tijdrovend was om tot dergelijke besluiten te komen.

Tot slot werden de resultaten van de onderzoeken op basis van de ontwerpcycli van de drie spellen en de empirische cycli van de betreffende onderzoeken samengevoegd, vergeleken en tegen elkaar afgezet om antwoorden voor onze onderzoeksvraag en validatie voor ons SA-kader te verkrijgen. Met betrekking tot het eerste deel van RQ1 bevestigden we de cruciale rol die SA heeft in de prestaties en besluitvorming van individuele actoren en teams die zich met de planning voor containerterminals bezighouden. Onze belangrijkste bevinding was dat situation awareness in de operationele fase van sociotechnische systemen, zoals het intermodaal vervoer in containerterminals, bezien moest worden in een vernieuwd theoretisch kader. In dit kader voerden we aan dat de ontwikkeling en het onderhoud van SA niet beperkt hoeft te zijn tot SSA voor teams en DSA voor netwerken. We stelden dat zowel SSA als DSA kan worden toegepast op een collectieve setting (team, groep of netwerk), afhankelijk van de combinaties van hun drie onderscheidende kenmerken: doelgerichtheid, het delen van informatie en de geografische locatie. Wat betreft het tweede deel van RQ1 bleken het vermogen tot multitasken, persoonlijkheidstype, geslacht, culturele verschillen en de samenstelling van het team een significante invloed op het SA en de taakuitvoering van individuele actoren en teams te hebben bij de afhandeling van dynamisch intermodaal vervoer. Onze belangrijkst aanbeveling voor containerterminalbeheer was om bij de ontwikkeling van taken en trainingsprogramma's rekening te houden met deze SA-factoren om de taakuitvoering van personen en teams te verbeteren.

De tweede en laatste onderzoeksvraag, RQ2, hing samen met simulatiespellen als onderzoeksmethode. Met de ervaring die we in dit onderzoek hebben opgedaan, stelden we vast dat simulatiespellen geschikt zijn als onderzoeksmethode om SA in complexe sociotechnische organisaties te bestuderen. De belangrijkste overwegingen bij het ontwerp van simulatiespellen voor onderzoek waren: het soort spel (digitaal, analoog, voor één of meer spelers), computer- en technische vereisten, betrouwbaarheid, schaalbaarheid, draagbaarheid, betrokkenheid van deelnemers en vermogen om de sociale cohesie te bevorderen. We gaven aanbevelingen voor het gebruik van de ontwikkelde spellen voor onderzoek op basis van onze ervaringen met de voorbereiding en planning, betrouwbare dataverzameling en -analyse en de selectie van deelnemers aan het onderzoek. Hoewel we onze onderzoeken nauwgezet ontwikkeld en uitgevoerd hebben, hebben onze resultaten en conclusies beperkingen. Het complexiteitsniveau van alle drie de spellen is niet zo hoog als de complexiteit in een echte terminal. Onze onderzoeken waren beperkt tot één voorbeeldsysteem en strekten zich niet uit tot SA in geografisch verspreide teams en SA in een netwerk van organisaties. Er is meer werk nodig om deze ideeën uit te breiden naar andere sociotechnische organisaties met behulp van betrouwbare simulatiemodellen die de complexiteit van activiteiten in sociotechnische systemen in de praktijk weerspiegelen.

Chapter 1

# Introduction

The 21st century society increasingly runs on a cluster of systems at the intersection of technology, science, regulation, user practices, markets, cultural meaning, infrastructure, production and supply networks (Geels and Kemp, 2007). These systems are called socio technical system, in other words, complex systems that involves physical-technical elements and networks of independent human actors (de Bruijn and Herder, 2009; Geels and Kemp, 2007). Examples include power generation and distribution networks, transportation networks, healthcare systems, crisis response teams, air traffic control, railroad operations and space expedition (de Bruijn and Herder, 2009; Carayon, 2006; Roth et al., 2006). In this thesis, the focal point of our research lies on one example of a socio technical system— a container terminal. Container terminals are specialized infrastructures that can handle containers and shift them between several modes of transportation with specialized operations (Meisel, 2009). Container terminals are an integral part of seaports that have been identified as critical infrastructures which are important for the economical and social well-being of any country in the 21st century (Mokhtari et al., 2012). This thesis will largely focus on studying and representing Situation Awareness with respect to decision making in socio technical systems within the context of container terminals. Situational Awareness (SA) is "being aware of what is happening around you and understanding what that information means to you now and in the future." (Endsley et al., 2003, p.13). SA can be defined in terms of the information required to accomplish or fulfil a particular job or goal in operational situations; examples include driving, air traffic control, and military missions (Endsley et al., 2003). In this chapter, we will provide the background and definitions of socio technical systems, explain the importance of SA in these systems, draw the major research gaps, select an example socio technical system for context, and provide a research approach containing the research questions, research philosophy and the research methods, of which simulation gaming is the most significant.

We will describe container terminal operations, and the reasoning behind categorizing container terminals as socio technical work organization in the course of this chapter. Before we provide that description, we first have to describe the characteristics of socio technical systems in general terms together with the related background and theory.

A socio technical system (Figure 1.1) is composed of human actors [1], within an organizational or network structure interacting with technology to achieve a specific purpose (Brandt and Cernetic, 1998).

In such systems, the interaction between actors and technology across organizational, geographical, cultural and temporal boundaries generates goods and services in the system, and maintains its functionality (Carayon, 2006).

## 1.1 Socio technical systems: History and background

The emergence of research interest in socio technical systems dates back to the post World War II reconstruction period in the late 1940's (Trist, 1981). The Tavistock research institute of London was involved in an action research project to analyse the efficiency issues in the British coal mining industry. A private engineering company that provided teams of workers for various coal seams hosted the study. The research project comprised 2 groups— one concerning the management, labour, personal and group relations in the organization and another team focussing on innovative work practices and technological interventions to increase productivity. The combined results of the two studies observed that the work organization of the best performing teams was a novel phenomenon, consisting of autonomous groups of inter-changing roles, and cooperation between task groups (Trist, 1981). The workers told the researchers that in order to make the best use of technology they had to focus on a new approach where they had to maintain group cohesion, coordination, and make decisions regarding their work arrangement in contrast to the one-man-

[1] The term agent (software or human) is sometimes used in the place of actor while describing socio technical systems. We specifically chose for human actors, since Situation Awareness, the crux of our study is a human factor (Endsley et al., 2003).

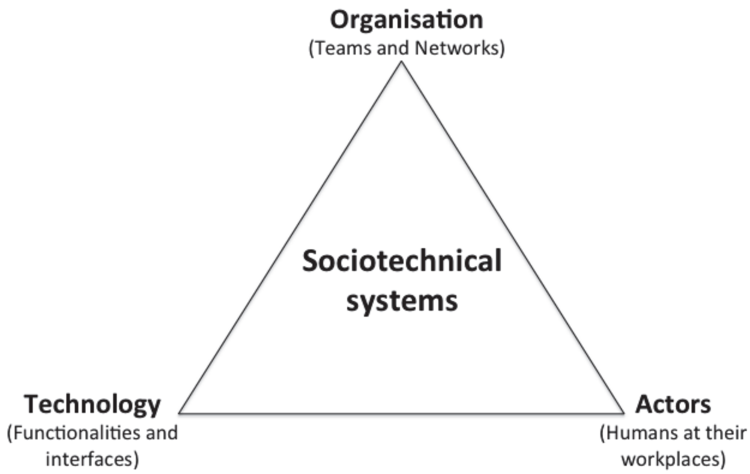



Figure 1.1: Components of sociotechnical systems. Adapted from Brandt and Cernetic (1998)

one-job approach they were used to (Trist, 1981). This phenomenon came to be known as the Haighmoor innovation, after the Haighmoor seam where the successful teams worked in a new work paradigm that required the best match would be sought between requirements of the social and technical systems (Trist, 1981). These observations starkly contrasted with pre-industrial revolution era where organizational performance was assessed separately without considering the relationship between human actors and their technical/ technological environment. This discovery triggered significant research interest in socio technical systems (Trist, 1981).

Subsequent works by Trist (1959), Emery (1964), Emery and Marek (1962), Trist and Weir (1976) contributed to the theoretical development of the concept, methods for analytical study of the interaction between social and technical aspects, criteria to obtain best match between the technological and social components, action research to improve it, comparative and longitudinal studies to measure and evaluate outcomes, and ways to diffuse socio technical improvements (Trist, 1981).

Table 1.1: Models and components of socio technical systems, (sources derived from Carayon (2006))

| Authors and models | Socio technical system components |
|---|---|
| Wilson (2000)'s model of interaction | People interact with other people (interaction through cooperation), remote agents (temporal and spatial interaction), structure, policy, task and roles (organizational interaction), hardware and software (through interface), supply chain (logistics interaction), society and politics (contextual interaction). |
| Carayon and Smith (2000)'s model of work system. | A socio technical work system comprises the individual, tasks, tools and technologies, physical environment and organizational conditions. |
| Kleiner (2004)'s model of subsystems | Personnel sub-system, technological subsystem, internal environment, external environment task and organizational design constitute a socio-technical system. |
| Rasmussen (2000)'s model of socio technical system | A socio technical system is composed of productive processes or the work done by operators and workers, personnel involved in planning the work, management that plans operations and provides resources, organization that interacts with various regulations, regulator, associations, interest groups, and government. |
| Vincent (2003)'s model of work factors | Institutional factors, type of work environment (workload, equipment, administrative support), team and individual factors (e.g. knowledge, skills, cooperation), and type of tasks make up a socio technical system. |

The three broad categories of socio technical systems proposed by Trist (1981) are:

1. **Primary work systems**. The systems that carry out a set of activities involved in a bounded and identifiable sub-set of a organization. Examples include service units, and line departments of an organization.

2. **Whole organization systems**. Factories, power plants, corporations or other equivalent self-standing workplaces fall into the spectrum of whole organization systems.

3. **Macro social systems**. These include industrial sectors, communities, networks of actors within a technical domain operating at the overall level of society.

There are several detailed models (see Table 1.1) to describe socio technical systems that are compatible with the three categories of Trist (1981) and the components described by Brandt and Cernetic (1998). Table 1.1 illustrates the various models and corresponding components of socio technical systems together with the respective authors.

In the following sub-section we will describe the characteristics of socio technical systems and the complexity associated with them.

### 1.1.1 The complex nature of socio technical systems

Socio technical systems are complex (Hollnagel, 2012; Klabbers, 2009). Complexity is a multidimensional concept (Vicente, 1999). Some of the important dimensions of complexity have been categorized by Hollnagel (2012) in the following manner: **mathematical complexity—** when it is not possible to describe a system or a phenomenon by analytical or logical methods because of the number of states a systems can take. Too many variables in a system can lead to **pragmatic complexity** (Hollnagel, 2012); **dynamic complexity** refers to situations where cause and effect, and the outcome of interventions are not obvious (Hollnagel, 2012). **ontological and epistemological complexity** refer to the challenges in describing and decomposing a system respectively to conduct scientific studies on it (Hollnagel, 2012).

In simple terms, socio technical systems are complex because we don't have the knowledge, and possibly will never have the knowledge to completely understand them (Hollnagel, 2012). We will first explain some possible reasons on why socio technical systems are so complex. Vicente (1999) provides the following list of characteristics of socio technical systems towards explaining the complexity, that is also supported by Geels and Kemp (2007), Carayon (2006), Appelbaum (1997) and Hollnagel (2012):

- **Large problem space**. Socio technical systems are composed of numerous elements and forces. As a result, the number of factors and variables that the actors need to consider while making a decision to solve a problem is very large (Vicente, 1999; Hollnagel, 2012).

- **The social component**. Teams of individual actors need to work together in a technological environment to ensure the functionality of the socio-technical system. It is challenging to ensure clear communication among teams to coordinate the actions of everyone involved (Vicente, 1999; Appelbaum, 1997).

- **Heterogeneous perspectives**. Actors in socio technical systems may come from different backgrounds and can have potentially conflicting values and principles. The actors need to resolve their differences to achieve a common goal usually through a lengthy and difficult negotiation process (Vicente, 1999; Carayon, 2006).

- **Distributed nature**. The issues with the social components are further complicated by the geographical distribution of actors. Communication and coordination are more difficult, and an addition factor of cultural differences can undermine the social cohesion of the actors (Geels and Kemp, 2007; Carayon, 2006; Vicente, 1999).

- **Dynamic nature**. Socio technical systems are characterized by constant change. The effects or consequences of decisions taken by the actors are not clear immediately. Therefore actors need to anticipate the future state of a situation to make suitable decisions (Vicente, 1999; Hollnagel, 2012; Geels and Kemp, 2007).

- **Coupling**. Socio technical systems are composed of interacting sub systems that are coupled. This makes it very hard to predict the effects of an action or trace the consequences of a disturbance due to several and potentially diverging paths. Some decisions maybe redundant due to lack of transparency and some might be undesirable. Reasoning in such a highly inter dependent environment places a big burden on the decision making of actors in socio technical systems (Vicente, 1999).

- **Automation**. Socio technical systems tend to be highly automated. During normal situations, computer algorithms control the work domain, and human actors monitor the state of work. When abnormal situations occur due to disruptions, automation may not always have the alternatives to solve it. Human actors have to intervene to resolve the situation, often under time pressure, stress and high stakes (Vicente, 1999).

- **Uncertainty**. Actors don't have complete information about a situation in socio technical systems. The actual state of the system with perfect certainty is never known. The high uncertainty leads to frequent trouble shooting and interference in socio technical systems (Hollnagel, 2012).

- **Mediated interaction**. Socio technical systems require a high level of human-computer interaction to function. This places additional design demands on the technological system to be user friendly, and cognitive demands on the actors to effectively use the interfaces (Vicente, 1999).

- **Disturbances**. Socio technical systems frequently encounter unanticipated events that disrupt their normal operation. During such events normal work procedures no longer apply, and actors need to make decisions based on their conceptual understanding of the new situation (Vicente, 1999; Hollnagel, 2012).

Given the above characteristics of socio technical systems, actors can be severely challenged in rapidly bringing all relevant information together in a form that is manageable for making accurate decisions in a timely manner (Endsley et al., 2003). Traditionally, the field of Human Factors and Ergonomics (HFE) seeks to propose interventions to assist people whose tasks exceed their physical, perceptual and mental capabilities (Endsley et al., 2003; Carayon, 2006). HFE is the "discipline that focuses on the nature of human-artefact interactions, viewed from the unified perspective of the science, engineering, design, technology and management of human-compatible systems" (Karwowski, 2005, p.436). The design, implementation and operation of socio technical systems can be greatly benefited by considering HFE guidelines and interventions. Carayon (2006) and Corlett (1988) argue that any HFE intervention "modifies the relationships of power between people and technology, or people and people" ; and that the effective and efficient use of HFE in different phases of socio technical system development can benefit from considering HE as an innovation and an intervention. Situational Awareness (SA), a key construct within the HSE field is considered to improve operational decision making and performance of the system (Endsley et al., 2003; Carayon, 2006).

(The formal definitions and theories related to SA will be discussed in detail in chapter 2)

In the following section we will discuss the importance of SA for decision making in socio technical systems.

## 1.2 Situation Awareness, decision making and performance

SA is considered as an essential prerequisite for good decision making in complex and dynamic systems (Endsley et al., 2003)— both characteristics attributed to socio technical systems (Vicente, 1999). Before we explore the importance of SA in socio technical systems, we need to understand the challenges of decision making faced by actors in socio-technical systems. This explanation will help us to clarify and highlight the importance of the relationship between SA, decision making and performance in complex systems.

In research and practice, decision making is traditionally associated with classical approaches such as decision analysis and Multi-Attribute Utility Analysis (MAUA), more commonly known as multi-criteria decision making (Zsambok and Klein, 1997).

Classic decision making models presume that human beings are rational decision makers who have a set of alternatives to choose the optimal decision for a specific problem situation (Endsley et al., 2003). Such models prescribe analytical and systematic methods to select the optimal course of action (Klein, 2008). These decision models are usually applicable to problems that are well-defined, and when time is a not a constraint to make decisions (Endsley and Jones, 1997). Even when problems are well-defined, Kahneman et al. (1982) demonstrated that human beings are not rational by nature and don't always choose a decision leading to an optimal outcome. They rely on heuristic as opposed to algorithmic strategies even when these strategies generated systematic deviations from optimal judgements derived from the laws of probability, the axioms of expected utility theory, and Bayesian statistics (Klein, 2008).

The strategies based on classical decision making models deteriorate when confronted with time pressure (Klein, 2008). Even if time pressure is not a constraint, they still require extensive work and lack flexibility to handle unexpected situations (Zsambok and Klein, 1997).

Classical decision models therefore are not suitable for socio technical systems where actors need to take tough and real-time decisions under difficult conditions such as limited time, uncertainty, high stakes, vague goals, multiple actors and unstable conditions (Klein, 2008).

To address this shortcoming, (Klein, 2008; Zsambok and Klein, 1997) proposed a naturalistic decision making approach for socio technical systems. Brehmer (1992) called it "dynamic decision making". (Klein, 2008) observed that when confronted with a complex situation, expert decision makers use pattern-matching mechanisms to draw upon long-term memory structures that allow them to quickly understand a given situation. They then adopt the appropriate strategy corresponding to the problem situation. They rarely spend much time analysing possible alternatives, but they spend most of their pre-decision time assessing and classifying the current situation (Endsley et al., 2003). Decision makers in these complex systems must understand the integrated meaning of situations with respect to their goals, which forms the basis for decision making (Klein, 2008). In this effect, (Zsambok and Klein, 1997; Endsley et al., 2003) concluded that Situation Awareness is a key pre-requisite for successful decision making in socio technical systems.


Figure 1.2: Situation Awareness drives decision making and performance in complex and dynamic systems (Endsley et al., 2003)

In complex systems (Endsley et al., 2003) describes SA to be an engine that drives decision making and performance because it presents a constantly evolving picture of the state of the environment to the decision maker (see Figure 1.2).

To study SA in socio technical system, we have to choose an application domain to give context to our study. We have already established that SA is most important in the operations phase of socio technical systems. We chose operations planning of container terminals as our application domain for this research because the complex, dynamic and interdependent nature of planning processes in container terminals is representative of an operational phase of a socio technical work organization. We will first briefly explain the operations in container terminals and will provide detailed reasoning behind choosing container terminals as our application domain in the following section.

## 1.3 Intermodal transport operations in container terminals

In this section, we will first provide a brief introduction to intermodal transportation and container terminals. We will then explain why we consider a container terminal to be a socio technical system based on the categorization of Trist (1959) and Vicente (1999).

### 1.3.1 Intermodal transportation

Intermodal freight transportation is defined as the system that carries freight from origin to destination using two or more modes of transportation (Muller, 1989). It is usually synonymous with container transportation. Intermodal freight transportation has revolutionized the world's economy by the easy, efficient and safe transport of goods through containers (Muller, 1989). Over 80% of the volume of the global trade is seaborne, among which 70% of the value of dry cargo is transported using containers (UNCTAD, 2015).

This huge trend in freight movement can be attributed to the trade liberalization policies of the 90's (Edwards, 1993). International manufacturing sources have been greatly sought out by firms in order to reduce costs, increase revenues and improve reliability (Meixell and Gargeya, 2005). Firms tend to take advantage of the tariff and trade concessions, low cost labour, capital subsidies and reduced logistics costs in foreign markets (Meixell and Gargeya, 2005). In the modern production processes, components of the goods are often produced as semi-manufactured goods, re-exported in containers to be assembled elsewhere (Meixell and Gargeya, 2005). These final products are further shipped in containers, as containerized goods are most suitable for transshipment (Vis and De Koster, 2003). The several advantages offered by containers such as safety, unit-load concept, fewer lost goods, less paperwork etc., have prompted a large wave of adaptation of containerized transport by many organizations worldwide (Muller, 1989). In accordance to the rise in global trade, the transport of containerized goods increased from over 45 million TEU (Twenty Foot Equivalent Unit, a standard measure for container size) in 1996 to 170 million TEU in 2015. The only slump in the growth trend was noticed in 2008 and 2009 due to the global economic crisis of 2008.

The huge volumes mean that the movement of the raw materials and processed goods has to be coordinated, and transported in a systematic manner across global destinations through a transportation network comprising several actors, institutions and organizations (Meisel, 2009; Henesey, 2006), shown in Figure 1.3.

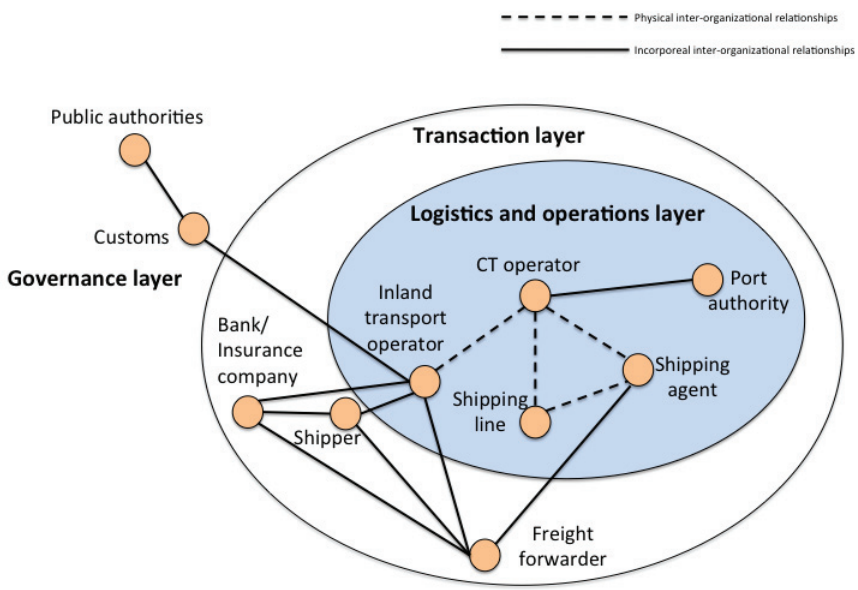



Figure 1.3: Key players in an intermodal transportation network. Adapted from Henesey (2006) and Popal (2008).

An intermodal transportation network, illustrated in Figure 1.3, is in itself a socio technical system with a governance layer composed of public authorities and custom officials, a transactional layer with shippers interacting with freight forwarders to plan the movement of goods through contracts and with banks and insurance companies overlooking the financial transactions (Henesey, 2006). The logistics and operations layer is responsible for the physical movement of goods and includes several players like the inland transport operator, shipping line, shipping agent, Container Terminal (CT) operator and the port authority (for definitions of these terms please refer to Popal (2008)). In this layer, container terminals, that form the subject of our research study, are crucial interfaces between landside and seaside transportation, and between various modes of transport (Kurapati et al., 2015). Management of container terminal operations is vital for an efficient and effective flow of containers through the entire transportation network Yun and Choi (1999). A concise explanation on the processes and operations of container terminals is provided in the following sub-section.

### 1.3.2 Introduction to intermodal transport operations in container terminals

Intermodal transport operations in container terminals can be divided into three parts— seaside operations, storage/yard operations and landside operations (Meisel, 2009). On the seaside or quayside of the terminal, containers are either unloaded from or loaded onto massive sea vessels. On the landside, containers are loaded onto or unloaded from trucks, trains and barges. The storage area of the terminal is called the yard, where containers are stored in stacks, thus facilitating the decoupling of seaside and landside operations (Steenken et al., 2004). There are special transport vehicles that move containers from the quayside to the yard and vice-versa. These can be e.g., trucks, straddle carriers, or in (semi) automated ports Automated Guided Vehicles (AGVs) (Steenken et al., 2004). Several types of cranes perform the loading, unloading and storage operations. Containers can belong to three categories - import, export or transshipment containers. Import containers are brought in by deep-sea vessels, stored in the terminal briefly, and need to be transported to the hinterland. Export containers follow the opposite path (Vis and De Koster, 2003). Transshipment containers need to be transferred from one deep-sea vessel to another without having to leave the terminal premises (Gambardella et al., 1998). The schematic processes of the container terminal can be summarized in Figure 1.4.

We will now explain our motivation to choose container terminals as our application domain to represent socio technical systems in the following section.

### 1.3.3 Container terminals: Socio technical work systems

Container terminal operations are influenced by the complex and dynamic interactions among multiple stakeholders, modes, industries, operating systems, liability regimes, legal and frameworks (Henesey, 2006), partially illustrated in Figure 1.3 . The volume of containers transported worldwide grew more than 600% in the last 20 years (UNCTAD, 2015). Compared to this growth, the size of container terminals have remained relatively inert (Mokhtari et al., 2012). The increasing volumes of containers exert pressure on container terminals to handle them without compromising on the efficiency of operations and turn-

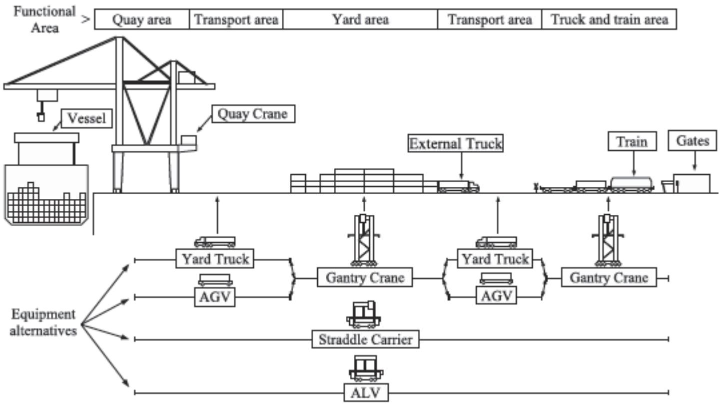



Figure 1.4: Schematic processes in a container terminal together with equipment (Meisel, 2009)

around times of ships (Kemme, 2012). The mismatch between ever-increasing volumes of containers arriving in container terminals and relatively inert infrastructure and size make the planning of operations in ports very complex (Bernhofen et al., 2016).

Furthermore, operations planning in container terminals happens under dynamic circumstances (Meisel, 2009). The frequent changes in the schedules of ships, changes in truck arrival times due to traffic, customs clearance, and other disruptions such as accidents and bad weather conditions create this dynamism (Meisel, 2009).

In addition to these stochastic factors, operations planning in container terminals is managed by disparate groups of individuals and departments whose decisions affect complex and time sensitive technical operations at the container terminals (Kurapati et al., 2015; Longo, 2012). This makes container terminals vulnerable to both external and internal disruptions (O'Reilly et al., 2004).

Adding to the complexity, the past two decades witnessed the automation of container terminal operations (Notteboom, 2012). Automation was expected to alleviate the physical work load of personnel in container terminal. Despite this advantage, automated handling systems and related rapidly progressing port technologies put a lot of pressure on terminal workforce due to increased information processing, aligning and coordination with both co-located and remote teams, and the need to execute multi-tasks that constantly evolve under dynamic situations (Notteboom, 2012; Meisel, 2009). However, the factors affecting task performance under automation haven't been well explored in the context of container terminals (Nam and Ha, 2001; Notteboom, 2012).

When we examine the above characteristics of container terminals, they can be categorized as socio technical work organizations within Trist (1959)'s classification of socio technical systems. Container terminals also fit very well within Vicente (1999)'s description of socio technical systems like large problem space (container volumes), dynamism in operations, vulnerability to risks and disruptions, a social component comprising heterogeneous work force, and automation. Therefore our choice of using container terminals to represent socio technical systems in our research is well founded.

So far, we have introduced socio technical systems, Situation Awareness (SA), the importance of SA in decision making and performance in socio technical systems, and container terminal operations as an example socio technical 'whole organization system'. Given this background, in the following section, we will now explain the main research gaps that motivated us to conduct the research presented in this book.

## 1.4 Research motivation and gap

Socio technical systems are characterised by continuous change (Carayon, 2006). We have mentioned earlier, within socio technical systems, important dimensions to deal with continuous change are long-run adaptability, individual and organizational learning, and sense-making (Weick et al., 2005). The design of operational processes of socio technical systems assumes that previous knowledge or experience of the actors is sufficient for effective decision making and performance in these systems (Carayon, 2006). However knowledge of actors in the system is not all encompassing, and actors require an additional ability to deal with dynamic circumstances that are not covered by their knowledge alone (Salvendy, 2012). It is very important that actors in socio technical systems are aware of the relevant information at the critical time, and are able to react to unexpected situations based on the available information (Salvendy, 2012). Effective performance of complex systems depends on knowledge and beliefs of the actors about the current situation, each other's goals, and their current and future activities and intentions (Roth et al., 2006). This ability is also known as Situation Awareness (Salvendy, 2012). The complex and interdependent nature of socio technical systems cause the poor visibility of their operation and functionality (de Bruijn and Herder, 2009). One of the main challenges is the impossibility of assessing and understanding the situation in its entirety for design, analysis of and decision making in socio technical systems (de Bruijn and Herder, 2009). Many researchers translate these challenges to the lack of 'awareness', an umbrella term in the Human Factors and Ergonomics (HFE) field used to signify constructs like situation awareness, workspace awareness, and common ground (Roth et al., 2006). According to Roth et al. (2006) the significance of situation awareness in socio technical systems is demonstrable by its very well-cited definition— the ability to perceive information regarding a situation, comprehend its current meaning, and project its future status (Endsley, 1995). The last decade witnessed an increasing research interest in Situation Awareness in socio technical systems (Abate et al., 2014; Chatzimichailidou et al., 2015b; Salmon et al., 2008b). Several studies (Endsley et al., 2003; Chatzimichailidou et al., 2015b; Smart et al., 2007; Fioratou et al., 2010; Naderpour et al., 2014) indicate that Situation Awareness is a crucial factor for decision making and performance in complex systems, socio technical or otherwise. The special characteristics of socio technical systems are not limited to dynamism, uncertainty, distribution, interconnectedness, human involvement, diversity and human-machine interaction (Vicente, 1999). Existing theoretical models of SA haven't sufficiently covered these characteristics of socio technical systems and don't accurately describe, represent and assess SA in socio technical systems (Abate et al., 2014; Chatzimichailidou et al., 2015b; Salmon et al., 2008b). Our research motivation arises from this insufficiency. Although SA is a driver of performance, it doesn't guarantee it (Endsley, 1995). The relationship between SA and performance is not always direct because SA can be affected by several individual, environmental and system factors. A thorough understanding of these factors can improve our confidence of attributing performance to SA (Endsley, 1995). Although (Endsley, 1995) defines some of these factors in her leading model on SA, the list is incomplete and the empirical evidence regarding these factors is not compelling (Adams et al., 1995). The SA construct is under constant criticism due to inadequate empirical evidence relating it to superior decision making and performance in socio technical systems (Dekker and Hollnagel, 2004). Sarter and Woods (1991) famously called termed SA as a critical but ill defined phenomenon. Although Parasuraman et al. (2008) argue that SA is an empirically backed concept, they refer to studies limited mainly to military applications that study SA as a cognitive engineering concept and do not address the issues raised by Dekker and Hollnagel (2004). Even in the broader Human Factors and Ergonomics field, much focus has been placed on the design and implementation of socio technical systems using HSE interventions, and little attention on the operational phase of socio technical systems (Carayon, 2006).

If we consider the example of operational planning in container terminals, the design phase is related to work space design, software design for planning, information systems design etc. The implementation phase revolves around issues of project management to plan and execute the designs based on feedback from user experience and participation. The operations phase is where actors and the technologies designed and implemented should come together to realize complex planning tasks. As we have mentioned before the impact or role of situation awareness in the operations phase of socio technical systems remains largely unexplored (Carayon, 2006) and holds true for operational planning in container terminals (Notteboom, 2012). This could be attributed to the fact that majority of SA research in an operational phase has been conducted in the military or aviation systems. Although these systems are complex, actors need to follow strict and rigid protocols and hierarchy (Salas and Dietz, 2011). Socio technical systems on the other hand may have protocols for technology use but social interaction is more democratic and participatory. Therefore, existing theoretical models of SA may prove impractical when applied to the description and assessment of SA in socio technical systems (Salmon et al., 2008b).

This key research gap largely motivates the author to study the role of SA and factors associated with SA in socio technical systems. The comprehensive analysis of this research gap is available in chapter 2. We chose operational planning in container terminals as our application domain.

Although container terminals can be classified as socio technical systems, in literature, transport is usually considered as a commodity, that needs to be optimized to minimize costs for the supply chain and has hardly been viewed from socio technical perspective (Doukidis et al., 2007). Studies related to human factors and SA are very limited in the field of intermodal transport operations if not absent (Nam and Ha, 2001; Notteboom, 2012). Therefore operations planning in container terminals accounts for a suitable and novel application domain for our SA research in socio technical systems.

Based on the above research gap, we have formulated the main research questions and related sub-questions that will be presented in the following section describing our research approach. Our approach that contains the research philosophy and research method required to answer the research questions. We have used simulation gaming as our key research method. The relative novelty of this approach required an addition research question that will also be discussed in the following section.

## 1.5 Research approach

In this section, we will propose the research questions that will be answered in the course of this thesis together with the research philosophy and methods employed to answer them.

### 1.5.1 Research questions

Our research motivation discussed so far is two fold— Firstly, SA has not been represented and studied sufficiently well within the context of socio technical systems, and secondly, intermodal transport operations in container terminals that are a good example complex operational processes of socio technical systems haven't been considered in SA or the wider human factors research. These research gaps initiate the following Research Questions (RQs) and related sub-questions,

**RQ1. How can Situational Awareness (SA) influence the decision making and performance of actors involved in intermodal transport operations?**

The sub-questions that complement the RQ1 are as follows

- What is the role of SA in actors' decision making and performance, while handling dynamic intermodal transport operations?
- What are the factors that affect the relationship between SA and decision making in intermodal transport operations?

### 1.5.2 Research philosophy and research method

Research philosophy and methods to study socio technical systems draw many parallels from those of information systems and information technology (March and Smith, 1995; Galliers, 1991; Sol, 1982; González, 2010).

Socio technical systems' research philosophy has a dual standing, encompassing both the analytical science and design science perspectives (March and Smith, 1995). Analytical science is concerned with explaining the nature of things, while design science aims at designing artefacts towards attaining specific goals (March and Smith, 1995).

Socio technical systems are human creations or artefacts to achieve a purpose (March and Smith, 1995). From the dual research perspective of socio technical systems, design science contributes towards creating these artefacts, giving rise to phenomena that can be used by analytical science to solve a research problem (March and Smith, 1995).

The research philosophy provides the ideological basis of a research method (Galliers, 1991). It's composed of ontology and epistemology, where ontology refers to the nature of being (Nandhakumar and Jones, 1997), and epistemology refers to how we acquire knowledge (Galliers, 1991). The three ontological positions identified in literature are: external realism— reality exists independently of individuals; internal realism— reality is an inter-subjective construction, shared between individuals; subjective idealism— sees reality is a personal construction of each individual (Nandhakumar and Jones, 1997). The two dominant epistemological stances in research are positivism and interpretivism (Creswell, 2013). According to positivism, the world consists of law-like generalizations based on empirical evidence (Nandhakumar and Jones, 1997). Positivist research is characterized by the presence of: hypotheses, propositions, models, quantitative variables and statistical inference of objective data (Nandhakumar and Jones, 1997; Popper, 2005). According to interpretivism, both the researcher and the subjects involved in the research subjectively interpret the situation (Nandhakumar and Jones, 1997). Instead of generalization like in positivism, it aims at in-depth understanding of the situation(Nandhakumar and Jones, 1997).

Positivist researchers generally adopt the ontological stance of external realism, while interpretive researchers choose internal realism and subjective idealism (Nandhakumar and Jones, 1997). Socio technical researchers often require the combination of positivist and interpretive methods for research due to its dual research stance (March and Smith, 1995; Galliers, 1991; González, 2010). Therefore our research method should be able to take this mixed stance. This means our research method should be able to provide us with quantitative data for fact based reasoning (positivism) and qualitative data for subjective analysis (interpretivism).

The research method is also influenced by the field of study, in our case, intermodal transport operations in container terminals. This is a sub-set of the wider field of supply chain, transportation, and logistics. In order to determine an apt research method to study SA in intermodal transportation, it is also imperative to explore the existing methods in the field.

The widely used research methods in the field of supply chain, transportation, and logistics are case-studies, questionnaires, action research, modelling & simulation, and a relatively new method known as simulation gaming (Meijer, 2009; Bryman and Bell, 2015; Voss et al., 2002). Case-studies, surveys and ac-

Table 1.2: Prominent research methods in the field of supply chain, logistics and transportation, adapted from Meijer (2009), Popper (2005), Sommer and Sommer (2002)

| | Case studies | Questionnaires or surveys | Action research | Computer simulations | Simulation gaming |
|---|---|---|---|---|---|
| Advantages | In-depth study into real world situations. Direct observations of real actions and communication of actors. | The ability to gather large number of responses while giving little or no disturbance to the actual behaviour of the respondents. etc. | The involvement of actors in all stages of research bridges the gap between research and application. | Unlimited number of experiments can be conducted with different scenarios. | Observation of actual actions and behaviour of participants if possible. The experiments can be repeated in a safe and controlled environment. |
| Disadvantages | Low repeatability and generalisability due to changing contexts and contextual bindings | Truthfulness of responses, and involvement of participants cannot be known. Questions maybe interpreted differently by different respondents. | Lack of standardization in research procedures and processes. Time-consuming. Loss of control on the research environment due to varying commitments of actors | Real data and observations are unavailable. Tacit knowledge of humans is hard to model. | A part of reality of the actual environment has to be compromised to enable playability of the related game. Complex, time consuming, and expensive. |

tion research can be categorized as analytical approaches (Bryman and Bell, 2015), while simulation gaming, modelling and simulation can be placed both in the design sciences and in the analytical sciences (Kriz and Hense, 2006). From the dual stance, analytical science uses computer simulations and simulation gaming as research methods to test theories in various fields, where as the design science emphasizes on the design of the artefact, and testing its usability (Klabbers, 2003; Kriz and Hense, 2006). The comparison of these methods is shown in Table 1.2.

From the comparison, simulation gaming and computer simulations emerge to be apt research methods to study socio technical systems. We choose simulation gaming as our main research method, due to its ability to engage human participants in a safe and controlled setting since SA is considered to be a human factor(Endsley et al., 2003). We have dedicated chapter 3 to motivate our choice in detail. To supplement our data collection with simulation gaming we will also use questionnaires, video recordings and observer notes in our research.

Our efforts put on using simulation gaming for SA research in socio technical systems warrants an additional research question for this thesis:

**RQ2.How can simulation games be designed and used to study SA in individuals and teams in inter modal transport operations?**

This research question will be answered in chapter 3.

Based on our research philosophy and research methods, we would like to conclude this sub-section by proving an overview of our research approach.

Simulation gaming represents an abstraction of reality (Duke, 1974). Our ontological stance is that of inter-subjective realism, where designers, researchers and experts share an idea of a distant reality of a socio technical system. Chapters 4 and 5 represent the abstraction and design part of this thesis. Our epistemological stance is a mix of positivism and interpretivism. This means we employ both quantitative and qualitative methods of data analysis, and our studies are designed to be of empirical nature. Our research method simulation gaming requires engagement with research subjects, and has been implemented in an iterative fashion. Our research design is dominated by quasi experimental studies using simulation gaming, surveys, and complemented by video recordings and observer notes. Each of these studies will be elucidated in Chapters 6, 7 and 8, that form the empirical part of this thesis. The outline of the overall thesis is presented below.

## 1.6 Outline of the thesis

Chapter 1 provides a summarized objective of the thesis by introducing the concepts of socio technical systems, Situation Awareness, and intermodal transport hubs as an example of a socio technical system. It briefly analyses the research gap in the field of Situation Awareness in socio technical systems, and introduces simulation gaming as a key research method. The chapter outlines the research philosophy, methods and strategy towards answering the research questions drawn from the research gap.

Chapter 2 discusses the need for SA in socio technical systems from the perspective of naturalistic decision making. It also describes the prominent individual and group SA models in literature, and discusses the shortcomings when applied to socio technical systems. Then, the researchers present their view of representing SA in socio technical systems with a framework that will be tested within the course of this thesis using simulation gaming.

Chapter 3 provides a detailed account on the usage of simulation gaming for research purposes. It begins with the background and history of simulation gaming. Subsequently, it introduces the terms and definitions used in simulation gaming research. After that, the researchers discuss the background and theoretical perspectives of simulation gaming as a research method. Following the discussion, they present a design process for developing simulation games that has been used in this research work.

Chapter 4 applies the design process derived in chapter 3 to describe and validate two games known as Yard Crane Scheduler 1 (YCS1) and Yard Crane Scheduler 3 (YCS3) to study SA in individuals and teams respectively in intermodal transport operations in container terminals.

Chapter 5 provides the design, evaluation and validation of a board game known as the container terminal disruption management board game that was developed to study the relationship between SA and decision making in dynamic situations in container terminals.

Chapter 6 uses YCS1, together with NASA's Multi-Attribute Test Battery, and a series of questionnaires to study the factors that affect the relationship between individual SA and decision making in container terminal operations. The researchers will explain the need to understand these factors, and then will present the research design, materials and methods related to the set-up of our study, followed by the results and discussion on the study.

Chapter 7 compares and contrasts some of the configurations of SA in socio technical systems, described in the SA framework in chapter 2. It also studies factors that affect team performance and decision making. The research design and execution includes YCS3, questionnaires, video taping and observation. The quantitative and qualitative results are later presented together with a discussion of the results.

Chapter 8 uses the container terminal disruption management board game to study SA in individual and teams during decision making under dynamic situations and under time pressure. The research design and execution is presented and the qualitative results on the factors affecting SA and the comparison of different SA configurations derived from chapter 2 both in individuals and teams are discussed in the conclusion.

Chapter 9 provides an overview of the research work conducted for the thesis, and answers the research questions posed in chapter 1. It also tests the SA framework presented in chapter 2 by consolidating the results presented in the various chapters. The chapter ends with discussion on the significance and limitations of the results.

Chapter 10 provides the concluding remarks for this thesis, along with future work that needs to be continued in the topic of SA and socio technical systems.

Chapter 2

# Situation Awareness framework for socio technical systems

Situation Awareness (SA) with its multitude of definitions might seem overwhelming for a first-time reader. To put in simple terms, SA is about knowing what goes around oneself (Endsley and Garland, 2000) or the level of awareness of a current situation that an actor has been placed in (Stanton et al., 2005). Situation Awareness has emerged as one of the leading constructs within the human factors research community over the last two decades (Stanton et al., 2005). The concept of SA rose to prominence in research, especially in the military and aviation domain mainly through the work of Endsley (1995). The significance of SA research can be attributed to the important role of SA on decision-making and performance in critical situations in complex systems (Salas and Dietz, 2011). Although SA cannot guarantee success or definitively predict failure, it represents itself as an important prerequisite for decision making towards operational efficiency, and performance especially in complex systems (Salas and Dietz, 2011; Endsley, 1995). The work environments of the 20th centuries began to develop and adopt new ways of manufacturing goods, diagnosing and curing illnesses, exploring space etc (Wellens, 1993). These endeavors require collaborative efforts of many machines and individuals, often geographically distributed (Wellens, 1993). Therefore Situation Awareness gained prominence as a crucial human factors component for these complex work environments (Wellens, 1993). The need for SA is more pronounced in socio technical systems, since technological advances designed for increasing the safety and efficiency of systems can increase system complexity and create challenges for human performance (Endsley and Garland, 2000; Salas and Dietz, 2011). In chapter 1, we briefly discussed the research gap regarding SA in socio technical systems. In this chapter, we will further expand that by looking into the definitions of SA, various theoretical perspectives, and analysing the research gap related to SA in socio technical systems. There are several theoretical models and perspectives on SA in individual and collaborative settings. We will discuss the most prominent theoretical models that describe both individual SA and collaborative SA. We will provide an overview of the SA models, analyse the research gap, and then introduce our theoretical framework to represent SA in socio technical systems.

## 2.1 Situation Awareness and decision making

The role of SA as a key factor to perform tasks and make decisions can be observed in all walks of life (Endsley and Garland, 2000). Prehistoric people needed to be aware of many cues in their environment in order to successfully hunt and to protect themselves from adversaries (Endsley and Garland, 2000). Until the beginning of the industrial revolution Situation Awareness was just a matter of experience— learning the important cues to watch for and what they meant (Endsley and Garland, 2000). In the case of research and practical application of the concept, Situation Awareness, most significantly individual Situation Awareness was conceived within the military and air force domain (Salas and Dietz, 2011). It is considered as a prerequisite for decision-making in dynamic situations (Salas and Dietz, 2011). The dissemination of the extensive research work of the likes of Endsley (1995), Bolstad and Endsley (1999) and Endsley and Jones (1997) on Situation Awareness in the military domain, created a great deal of interest among researchers to adapt this concept to civilian applications (Endsley et al., 2003). The advent of machine age, the subsequent computer age and the current information age have pushed humans to use very complex tools that involve physical tasks as well as elaborate perceptual and cognitive tasks (Endsley and Garland, 2000). They often need to work within a team coordinating and communication with other team members who could either be co-located or distributed on the other side of the world (Salmon et al., 2008b). Today's pilot, air traffic controller, power plant operator, anesthesiologist: all must deal with a large amount of data that often changes very rapidly (Endsley and Garland, 2000). This brings us to the topic of the challenges faced by actors in socio technical systems to make decisions in such a challenging environment. In the following sub-section we will discuss models that explain decision making in socio technical systems characterized by rapidly changing operational environment.

### 2.1.1 Decision making in socio technical systems

We have already discussed in chapter 1 that classical decision models cannot be applied to socio technical systems because decision problems of these systems cannot be easily solved analytically. The decision trees for such problems are impossibly large, even if computational power is not a concern, such decision trees still cannot fully support unexpected and real time situations (Brehmer, 1992). Brehmer (1992) and Zsambok and Klein (1997) proposed dynamic decision making and naturalistic decision making respectively as alternative approaches to decision making in socio technical systems. We will discuss both these approaches below.

#### Dynamic decision making

The concept of dynamic decision making was conceived to understand how actors make decisions to execute operational processes in socio technical systems (Brehmer, 1992). Based on observations in the fields of military, emergency management and intensive care operations, Brehmer (1992) states that decision making is goal oriented, i.e, the function of decision making is to achieve a desired state of affairs for a given situation. The characteristics of the process of dynamic decision making according to (Brehmer, 1992) are:

- It requires a series of decisions.
- Decisions are not independent. Their consequences affect not only the decision makers' future actions but others in their environment.
- The state of the problem changes as a consequence of internal and external factors as well as the nature of decisions that have made been made by the responsible actors. For instance, if we consider a fire fighting operation, the fire may spread or be contained due to changing weather conditions as well as the fire fighter's attempts to extinguish it.
- Decisions are made real time due to unexpected situations.

Under these circumstances, it is not only sufficient to make the right decisions in the right order, but also at the right time (Brehmer, 1992). Context and time are very crucial in dynamic decision making (Brehmer, 1992). The decision maker should be able to predict the consequences of their decision for a given situation (Brehmer, 1992). This ability to predict the consequence of a decision before making it forms the crux of the concept of Situation Awareness, making it a pre-requisite to decision making in socio technical systems (Endsley et al., 2003).

On the other hand, a similar approach known as naturalistic decision making has gained prominence to explain decision making in socio technical systems (Gore et al., 2015), and will be discussed in the following paragraph.

**Naturalistic decision making and SA**

Naturalistic decision making explains how "people working as individuals or groups in dynamic, uncertain, and often fast-paced environments identify and assess their situation, make decisions and take actions whose consequences are meaningful to them and to the larger organization in which they operate"(Zsambok and Klein, 1997).

Based on the summary of Klein (2008),the characteristics of naturalistic decision makers are:

- Decision makers use prior experience to rapidly categorize situations against generating and comparing various decision alternatives
- They relying on some kind of synthesis of their experience— a schema or a prototype or a category to make these decisions
- They actively try to shape events instead of passively waiting for the outcome of their actions.

We will explain the characteristics in detail. Naturalistic decision making model describes how people use their experience in the form of a repertoire of patterns. These patterns highlight the most relevant cues, provide expectancies, identify plausible goals, and suggest typical types of reactions in a particular type of situation to the decision maker (Klein, 2008). In this way the decision maker can quickly match the situation to the patterns they have learned to make a decision, enabling extremely rapid decision making (Zsambok and Klein, 1997). From observations in various complex field settings Klein (2008) found that decision makers evaluated the consequences of their decision by a mental simulation to imagine the future state of affairs given the current situation. If they were convinced of its success, they would proceed with their decision, if it has a small chance of failure they would adapt the decision, continuing until they found a decision that made them comfortable (Zsambok and Klein, 1997). This process can be compared to Simon (1957)'s notion of satisficing— looking for the first option that can work rather than trying to find the best possible or the optimal solution, in time pressed situations. Experienced decision arrive at 'satisfactory' solutions faster than novice decision makers in a given situation (Klein, 2008). The decision making process is a balanced combination of intuition (pattern matching) and analysis (mental simulation) (Klein, 2008). This balance is very important because a completely intuitive decision making strategy could results in serious flaws, whereas a comprehensive analytical strategy would be too slow (Klein, 2008). Referring to the fire fighting example, the fire would've spread rapidly before the fire fighters deliberated on the best strategy to put off the fire.

**Dynamic decision making vs. Naturalistic decision making**: Both these approaches have many similarities and can be viewed as complementary in terms of real time decision making under time pressure. Although dynamic decision making describes the characteristics of decision problems in socio technical systems, it lacks a well developed theory since it has not been researched and applied well enough in literature. However, naturalistic decision making has received more attention and has been studied in complex systems quite extensively in the last 25 years (Gore et al., 2015). It has been studied in complex field settings involving navy commanders, jurors, nuclear power plant operators, army small unit leaders, anaesthesiologists, airline pilots, nurses, and highway engineers (Klein, 2008).

A key merit of naturalistic decision making model is that it highlights the importance of SA in operational decision making in socio technical systems due to its focus on the decision maker's ability to understand and simulate a situation mentally and project its consequences before making a decision.

In the work of Zsambok and Klein (1997), the authors clearly state that a pre-decision stage of perception and recognition of situations, projection of decision consequences, also known as Situation Awareness (SA), is very crucial for the decision maker to arrive at 'satisfactory' solutions at the earliest. We will now introduce a few application domains that highlight the role of SA in decision making and operational performance in the following sub-section.

**Examples showcasing the role of SA in decision making**

SA has been well established as an essential pre-requisite to decision making in the military domain (Zsambok and Klein, 1997), however it has also found prominence in civilian applications shown below,

- *Anaesthesiology*, where SA is considered as an important characteristic as it is a the complex, dynamic, and risky field (Gaba et al., 1995). In anesthesiology, situations that the decision maker must remain aware comprise subtle cues, evolving situations, and special knowledge elements (Gaba et al., 1995).
- *Driving*. Individual SA is considered to impact driver performance, particularly for strategic and complicated navigation tasks during driving (Ma and Kaber, 2007).
- *Air-traffic control*. Individual SA is an important pre-requisite for information processing and subsequently decision making to execute complex and dynamic control tasks in air-traffic control (Kaber et al., 2006).
- *Energy distribution*. SA is a critical commodity for teams working in industrial systems such as energy distribution systems (Salmon et al., 2008a). Energy distribution constitutes a network of actors/agents (human and non-human) that benefit greatly by SA related information elements to achieve a coordinated behaviour within the system (Salmon et al., 2008a).
- *Process control* industries such as oil refining, paper manufacturing, chemical plants etc., have strict regulations and procedures and rely heavily on human supervisory control for their efficient and safe operations (Patrick and Morgan, 2010). Individual SA can improve both operator performance and safety and supervisory efficiency in such industries (Patrick and Morgan, 2010).
- *Emergency services*. SA is crucial in time-critical, constantly changing situations during emergency service operations, where decision making could make or break lives (Blandford and Wong, 2004).
- *Rail road operations*. SA is an useful construct in describing and understanding complex control tasks in railroad operations such as signalling (Golightly et al., 2010). Railroad repair operations require cooperative strategies between several distributed individuals comprising railroad workers, train crews and railroad dispatchers (Roth et al., 2006).

The above examples represent complex operational processes in socio technical systems. After introducing these examples, we can reiterate the important role of SA in operational decision making and performance in socio technical systems. Therefore, in our perspective, it is an essential pre-requisite to decision making in socio technical systems. In order to describe SA in such systems we have to evaluate various theoretical models of SA to assess their strengths and drawbacks when applied to socio technical systems. This will help us strengthen our research problem and motivation described in chapter 1.

## 2.2 SA: Theoretical perspectives

In this section we will first introduce and explain the various theoretical perspectives and models of individual and group SA. At the end of the explanation, we will analyse the suitability of each of these theories and models to explain and represent SA in socio technical systems. We will first begin with the definitions of SA.

A universally accepted definition of SA is unavailable in literature (Salas and Dietz, 2011). The lack of consensus is primarily due to the unresolved theoretical debate on whether SA is a product or a process (Salas and Dietz, 2011). However the most widely used definition of SA is that of Endsley (1995), presented in Table 2.1 together with other generic definitions of SA. The terms Situation Awareness and Situational Awareness are often used interchangeably, but in this thesis we will refer to Situation Awareness (SA) for consistency purposes.

SA has been studied in several areas of research leading to a wide variety of theoretical methodological approaches (Patrick and Morgan, 2010). In the following sub-sections we will explain the prominent theories of individual and collaborative SA.

### 2.2.1 Individual SA models

The three dominant theoretical models of SA are Endsley (1995)'s three level model, activity theory approach by Bedny and Meister (1999) and the perpetual cycle model of Smith and Hancock (1995), although Endsley (1995) emerges as the classic reference for SA (Parasuraman et al., 2008).

Table 2.1: Definitions of individual Situation Awareness

| Definition | Author(s) |
|---|---|
| The conscious dynamic reflection on the situation by an individual. SA provides dynamic orientation to the situation, the opportunity to reflect not only on the past, present and future, but the potential features of the situation. The dynamic reflection contains logical-conceptual, imaginative, conscious and unconscious components which enables individuals to develop mental models of external events | (Bedny and Meister, 1999). |
| The perception of elements within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. | Endsley (1995) |
| The invariant capacity to direct consciousness to generate competent performance given any particular situation that might unfold. | Smith and Hancock (1995) |

**Endsley's three level model of SA and decision making**

According to Endlsey's model of SA, the formal definition of SA is composed of 3 levels—"*perception* of elements in the environment, *comprehension* of the current situation and *projection* of future status" (Endsley, 1995). One of the key assumptions of the three-level model is the role of mental models in the development and maintenance of SA. According to Endsley (1995), mental models are developed in the individual's mind when they observe some instances in the environment, and the mental models facilitate the development of SA. For example, when a planner in a container terminal observes congestion at the gate (perception), he/she should be able to understand how the congestion could affect their immediate plans (comprehension) and should be able to foresee the consequences of the congestion for their future plans (projection). The first step in achieving SA is to perceive the status, attributes, and dynamics of relevant elements in the environment. Individuals perceive information through visual, auditory, tactile, taste, or olfactory senses, or a combination of these senses (Endsley et al., 2003). Some of the challenges faced by the individual in this level is the quantity, quality and reliability of information (Endsley et al., 2003).

The second step in achieving SA is comprehending the meaning of the information perceived in level 1, based on a comparison, prioritization and

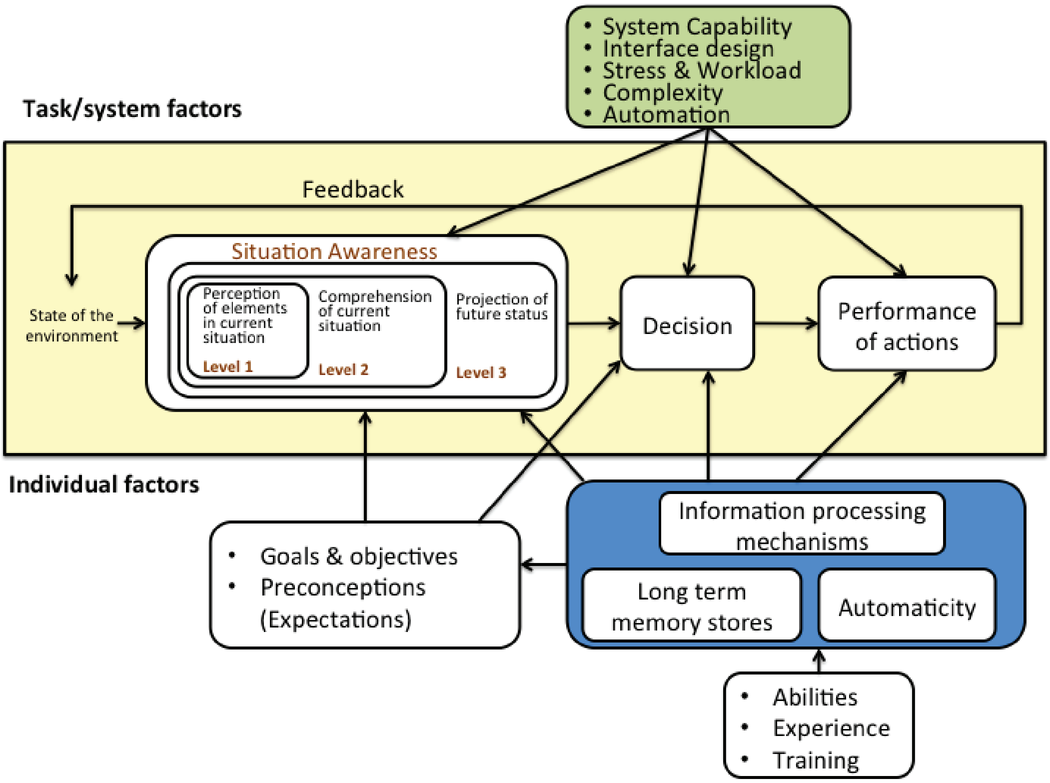



Figure 2.1: Model of Situation Awareness as a pre-requisite to decision making in complex systems(Endsley, 1995)

synthesis of various pieces of information gathered (Endsley et al., 2003). Level 2 of acquiring SA involves understanding the importance of the information at hand with respect to the goal that needs to be accomplished (Endsley et al., 2003).

The final level of SA is the ability to predict the status of elements in the environment based on the perception and understanding acquired about them in levels 1 and 2 (Endsley et al., 2003). Level 3 of SA is also compatible with the notion of 'mental simulation' of Klein (2008)'s naturalistic decision making theory discussed earlier in this chapter.

Endsley (1995)'s SA model, shown in Figure 2.1, explains the role of SA of an individual actor or a decision maker responsible for operational processes in socio technical systems (Endsley et al., 2003). SA is goal oriented (Endsley, 1995). The model depicts SA as a pre-requisite to decision making that leads to action selection, that consequently leads to a task performance with respect to the goal of an individual (Endsley, 1995).

Several factors influence an individuals's ability to acquire SA and take 'good' decisions (Endsley et al., 2003). The development of SA for a given situation is not uniform across individuals, even if they are provided with the same information (Endsley, 1995). This variation is hypothesized to be caused by the differences in individual information processing mechanisms, memory, and automaticity (Endsley, 1995). These differences are influenced by innate abilities, experience and training of individuals (Endsley, 1995). An individual's SA is also dependent on the way their operating environment is designed. Related aspects like stress, work-load, task complexity may affect SA (Endsley, 1995).

Given the various factors that affect the relationship between SA, decision making and performance, good or bad SA doesn't automatically predict good or bad performance (Endsley, 1995). However good SA greatly increases the probability of good performance, if we account for the internal and external factors that affect the development SA in individuals (Endsley, 1995).

(Endsley, 1995)'s SA model is arguably the most adopted SA models for individual SA in research and practice, and has been extensively used and tested over the past two decades (Parasuraman et al., 2008; Salmon et al., 2008b).

**Activity theory approach**

Activity Theory is formulated in terms of a logically ordered system of goal directed mental and behavioural actions (Bedny et al., 2000). Information processing is represented by function blocks, each serving a distinctive function like goal formulation, task assessment, and decision correction (Bedny et al., 2000). "Activity Theory (AT) is a psychological paradigm that was a foundation for the study of work behaviour in the former Soviet Union. Activity is inextricably linked with internal mental activity and consciousness of abstractions from a concrete situation that anticipates sequences of other situations, provides insight into one's own and others' mental processes guiding conscious, volitional behaviour" (Bedny et al., 2000).

Based on the Activity Theory, Situation Awareness includes logical, conceptual function blocks that provide a dynamic, conscious reflection of the situation to an individual (Bedny et al., 2000).

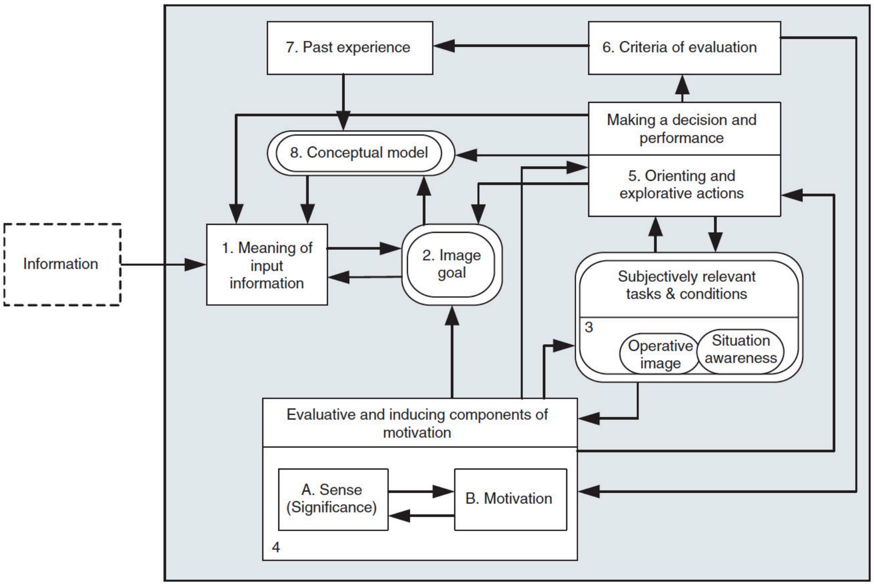



Figure 2.2: Interactive sub-systems approach to SA based on activity theory (Bedny and Meister, 1999), adapted from Salmon et al. (2008b)

Bedny and Meister (1999) proposed a model for individual SA based on the activity theory which purports that individuals possess goals that represent an ideal image or desired end state of activity, and the difference between the current state of the situation and the desired state motives them towards methods of activity that enables the achievement of these goals (Bedny and Meister, 1999).

Based on this Bedny and Meister (1999) proposed an SA model with several functional blocks as shown in Figure 2.2. Each of the functional blocks has a specific role in the development and maintenance of SA in individuals. The interpretation of incoming information (function block 1) is influenced by an individual actor's image of his/her goals (function block 2), conceptual model of the current situation (function block 8) and past experience (function block 7). This interpretation then assesses the difference between actor's goals and experience and conceptual model of the current situation (Salmon et al., 2008b). Relevant tasks and conditions (function block 3) are identified based on the actor image of the goal created by Situation Awareness which leads to the assessment of the significance of the situation, which motivates the actor to take action towards the image goal (function block 3). This leads the actor to make relevant decisions (function block 5). The outcome of the decisions are evaluated in function block 6 based on past experience (function block 7). The past experience subsequently contributes to the conceptual model of the actor regarding the situation. The main processes involved in this model are development of a conceptual model of a given situation based on the image goal of the individual, thereby defining the relevant tasks to achieve the said goal (Bedny et al., 2000).

**Perceptual cycle model**

The perceptual cycle model of SA by Smith and Hancock (1995) views SA to be: 1. Adaptive externally directed consciousness and 2. an invariant at the core of Neisser's cycle that generates both up-to-the-minute knowledge and action that anticipates signal in the task environment (Smith and Hancock, 1995). In other words, SA is "purposeful behaviour that is directed towards achieving a goal in a specific task environment" (Smith and Hancock, 1995).

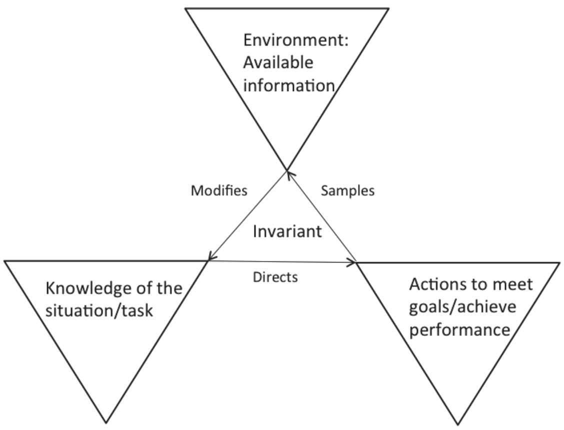



Figure 2.3: The perceptual cycle model of SA (Smith and Hancock, 1995)

A key characteristic of the perpetual cycle model of SA is that the focus of an individual actor's behaviour is in the environment rather than in their mind (Smith and Hancock, 1995). The notion of SA implies that the individual is naturally adherent to task goals and to criteria for performance (Smith and Hancock, 1995). To posses SA the individual should have a level of adaptive capability to match the specification of task goals and of criteria for assessing performance variables. Smith and Hancock (1995) represents SA in the form of a perpetual cycle, drawn from the work of Neisser (1976). This model illustrated in Figure 2.3 shows knowledge and action flow continuously in an actor's environment. Knowledge directs their activity, that activity samples, predicts or alters the environment which in turn feeds back information to the individual actor (Smith and Hancock, 1995). This dynamic, informed sampling of the environment forms the essence of the effectiveness of SA with respect to tasks and criteria of performance(Smith and Hancock, 1995). The invariant represented in Figure 2.3 is the structure of an individual actor's adaptation to the environment that forms the linkage among information, knowledge and action that produces competent behaviour towards performing the required tasks (Smith and Hancock, 1995). The invariant codifies the available information in the environment, the knowledge required by the individual actor to assess that information, and the knowledge that will direct him/her to meet his/her goals (Smith and Hancock, 1995).

**Other models of individual SA**

The most recent SA model is known as situation SA (Endsley, 2015b). The situated SA approach holds that "operators maintain their understanding of dynamic situations by relying on minimal internal representations and engaging in frequent interactions with a structured environment. Operators sample limited amounts of information from the environment in cycles, and extract its relevance by combining it with an easily accessible context, as per RT [relevance theory]" Chiappe et al. (2012b). Another approach towards SA is known as sense-making that is focussed on how operators make sense of the information and situations in which they find themselves, largely at the organizational level with respect to explaining accidents or unusual events (Weick et al., 2005). It is is largely retrospective in nature (Endsley, 2015b). We will analyse all the SA models that have been introduced and discussed so far to conclude on a suitable model to describe individual SA in socio technical systems.

**Overview of individual SA models**

Although there are several individual models that describe SA, the widely adopted model for individual SA is Endsley's SA model (Parasuraman et al., 2008). It is by far the most comprehensive model of individual SA(Parasuraman et al., 2008). It is arguably the only model that discusses the relationship between SA and decision making in complex systems, supporting the naturalistic decision making model for socio technical systems (Klein, 2008). The model also hypothesizes the various factors that affect the relationship between SA, decision making and performance (Endsley, 1995). There is contention on Endsley's SA model regarding the lack of empirical validity, as well as the poorly understood theoretical foundations (mental models) it is built upon (Patrick and Morgan, 2010; Salmon et al., 2008b), although (Endsley, 2015b) stands by the validity of her model attributing the contention to misunderstanding. The perceptual cycle of Smith and Hancock (1995) tries to provide proven theoretical underpinnings behind the model, but it has not been adopted because this model is quite abstract and makes SA measurement very difficult (Salmon et al., 2008b). The activity theory model of SA is not widely known and the theoretical concepts behind the model haven't been tested (Salmon et al., 2008b). With respect to situated SA, Endsley (2015b) argues that the model has a major flaw as it considers information in the environment unknown to the operator as situation awareness, which is actually the opposite of SA. Whereas sense-making is seen as counter intuitive to the very concept of SA as it is retrospective in nature (Endsley, 2015b). We consider naturalistic decision making model describe decision making in socio technical systems. In this model, decision makers have to actively react to changing situations rather than passively wait to observe the consequences of their actions. To achieve this they have to mentally simulate the consequences of their actions and project their status in future before making the decisions. Therefore situated SA and sense-making that have a retrospective approach are not suitable to describe SA in socio technical systems. Only Endsley's SA model addresses the pre-decision stage requirement of the naturalistic decision making process with clear levels of perception, comprehension and projection of a given situation.

After analysing the several SA models for individual SA, we choose to follow Endsley's three level model for individual SA needs in our research due to its strong focus on the relationship between SA and decision making in socio technical systems.

Although individual SA is very important for operational processes, the concept of socio technical systems is based on these work processes performed by groups of individuals within a technical environment that need to collaborate locally or distributed geographically (Appelbaum, 1997; Salas et al., 1995a) . Therefore it is very crucial to understand SA in group settings. In the following sub-section, we will discuss prominent models that cover SA in group settings.

### 2.2.2 Group SA models

In literature, most of the explanations of SA have focussed their attention on individual SA and very few models explain SA in group settings (Salas et al., 1995a). The prominent models by Salas et al. (1995a), Endsley (1995), Stanton et al. (2006) term SA in group settings as Team SA, Shared SA and Distributed SA respectively. We use the term group to indicate a collection of individuals with or without shared goals, whereas a team can be defined as a distinguishable set of two or more individuals who interact dynamically, interdependently, and adaptively towards a common goal, and each individual has been assigned a specific role or function to perform (Salas et al., 1995a). All the three models (Team, Shared, Distributed SA) study SA within teams (Salmon et al., 2008b).

#### Team Situation Awareness

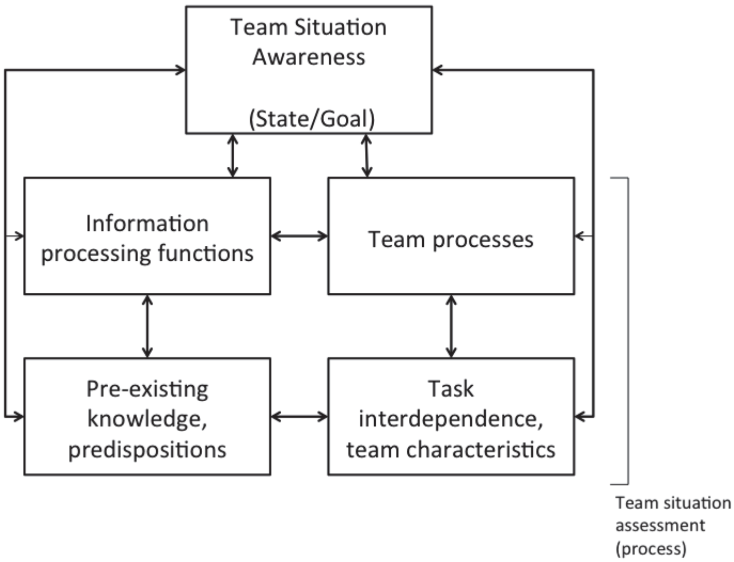



Figure 2.4: Team Situation Awareness model of Salas et al. (1995b)

The model of Team Situation Awareness was proposed by Salas et al. (1995a) based on the concepts of teamwork. This model, shown in Figure 2.4 illustrates both individual and team SA. Individual SA is influenced by previous knowledge and information processing, while team SA is affected by characteristics of team members, and team processes (Salas et al., 1995a). Towards building a strong Team SA, team members need to have information that will help each individual develop relevant expectation about the joint task (Salas et al., 1995a). Team SA largely depends on communication at several levels and on different aspects like objectives, own tasks, other relevant tasks, team capabilities and any other factor related to team performance (Salas et al., 1995a). Planning, assertiveness, and leadership are some of the team processes that can help build Team SA (Salas et al., 1995a). To sum it up, Team SA is the shared understanding of a situation among the team members at a certain time and communication among team members and team processes help maintain Team SA. In the next sub-section we will describe Shared Situation Awareness or SSA.

**Shared Situation Awareness**

Shared Situation Awareness (SSA) is the extension of the individual SA model of Endsley to teams (Endsley and Jones, 1997). Some of the definitions include: The degree to which team members possess the same SA on the shared SA requirements (Endsley and Jones, 1997); a common operational picture of a particular situation (Nofi, 2000); shared awareness of a situation (Nofi, 2000).

To develop SSA team members need to

- Build individual Situation Awareness
- Share their individual SA with other team members
- Develop and maintain their team's SSA (Nofi, 2000)

According to Endsley and Jones (1997), a team can function smoothly only when team members share a common understanding of what is happening on the SA elements and SA requirements that are common to the team. Accurate, shared SA is critical for effective team performance (Endsley et al., 2003).

Endsley et al. (2003) defines a Shared SA model, shown in Figure 2.5, that describes the factors that contribute to the development of SSA in teams. We will describe each of these factors briefly.

**Shared SA requirements**

The elements that need to be shared between team members are known as shared SA requirements (Endsley et al., 2003). These requirements specify the information on which common understanding is needed. The SA requirements for a particular team member include a consideration of what other

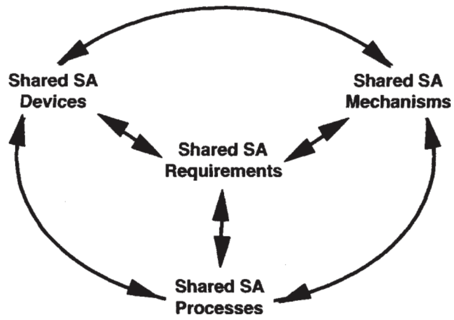



Figure 2.5: Shared SA model (Bolstad et al., 2005)

team members are doing (Endsley et al., 2003). Each individual has SA requirements related to the system he/she is operating, and also with the other team members he/she is interdependent with (Endsley et al., 2003). Shared SA in teams involves accurate and timely sharing of system and environmental information that affects all team members (Endsley and Jones, 1997). The requirements that needs to be shared are determined based on the cognitive task analyses of each team position, and the areas of overlap between each team pairing (Endsley et al., 2003). The degree to which team members reach shared SA on shared SA requirements are dependent on shared SA devices, shared SA mechanisms, and shared SA processes (Endsley et al., 2003).

**Shared SA devices**

Shared SA devices play a critical role in creating shared SA between team members (Endsley et al., 2003). The three shared SA devices identified by Endsley and Jones (1997) are communication (verbal and non-verbal), shared displays *(audio and visual) and a shared environment.

In addition to verbal communication, non-verbal communication (facial expressions, hand gestures etc.) plays a very important role in acquiring and maintaining shared SA (Endsley et al., 2003). Team members often get more information from non-verbal communication about the emotional state of another team member ( overloaded, concerned, asleep etc.) than with verbal communication (Endsley and Jones, 1997). Shared displays, both audio and visual, enable team members to directly view and/or hear the information that needs to be shared (Endsley and Jones, 1997). It is also important for the team to have a shared environment to gain shared SA since a shared environment automatically provides SA without requiring extra communications or displays

(Endsley et al., 2003).

**Shared SA mechanisms**

Shared mental models and schema are key Shared SA mechanisms that are believed to enhance SSA in teams without requiring extra communications (Endsley et al., 2003). Mental models and schema form the mechanisms upon which the comprehension and projection of individual team members are formulated in complex systems (Endsley et al., 2003). Bolstad and Endsley (1999) found that the teams with shared mental models perform better on a team task than those without. Shared mental models can be developed through joint training exercises involving all the team members (Bolstad and Endsley, 1999). Additionally team members who have been working together for a long period of time, develop shared mental models since they gather sufficient understanding of each other's role, function and personality (Endsley et al., 2003).

**Shared SA processes**

Shared SA processes are information sharing, shared understanding of functions and problems, contingency planning, communication of goals, helping each other, and freedom of expression (Endsley et al., 2003). These processes are considered to be crucial for developing and maintaining shared SA among team members (Endsley et al., 2003).

Team members require any of the four factors shown in the SSA model in Figure 2.5 or a combination of them to acquire, develop and maintain SSA.

We will now move on to discuss about Distributed Situation Awareness, that is the latest of the three prominent theoretical models on SA in group settings.

### Distributed Situation Awareness

The more recent theoretical concept related to group SA is that of distributed or systemic SA (Salmon, 2008). Distributed Situation Awareness is based on distributed cognition theory of Hollan et al. (2000) and cognitive engineering systems theory of Hollnagel and Woods (1999). Both these theories support a systems approach to understand cognition, and consider the system as an unit of analysis rather than an individual actor (Salmon, 2008). They consider agents (human and software) and artefacts forming a joint cognitive system, where cognition is distributed across this system, and SA is developed through coordination between agents and interaction among agents and artefacts (Salmon, 2008). In the DSA approach, the main assumption is that human and

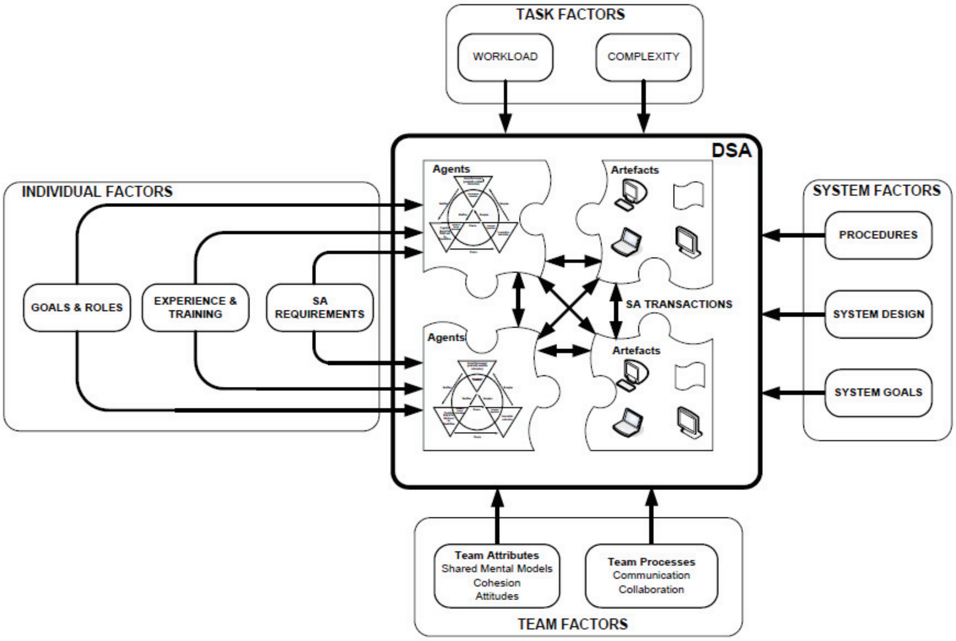



Figure 2.6: Distributed SA model (Salmon, 2008)

software agents share traits including emotive constructs (e.g. confidence, respect, commitment, and teamwork), cognitive constructs (e.g. understanding, ability, and expectancy), and behavioural constructs (e.g. reliability, performance, and communication)(Stanton et al., 2006). The key characteristics of DSA, according to (Stanton et al., 2006) are:

- SA is held by both human and non-human actors.
- Different actors (can) have different views on the same situation.
- The goals of individual actors can be different as long as they belong to the overarching common goal.
- Communication between actors can be verbal or non-verbal, including cultural practices.

- One actor could compensate for the poor SA of another actor. This means not all actors need to have the same awareness on a situation, and if a certain actor has limited awareness they can be supported by an actor with higher awareness through relevant information exchange.

DSA approaches view SA as an emergent property or a construct of the system itself and is viewed as the ’glue’ that holds the system together (Salmon et al., 2008b).

(Salmon, 2008) developed a model for DSA in complex systems, shown in Figure 2.6. The building blocks of this model are schema theory, perpetual cycle model, and the concept of compatible and transactive SA (Salmon, 2008). Compatible SA is the notion that not all actors need to know everything about a situation but need to possess the SA needed for their specific task but also need to be aware of the SA requirements of other actors within their team (Salmon, 2008). While compatible SA describes the relevant information that needs to be exchanged, transactive SA describes how this exchange can happen through communication, information requesting, information sharing, negotiations and other interactions— also known as SA transactions (Salmon, 2008).

According to the model DSA is viewed as the "system’s collective knowledge regarding a situation that comprises each element’s compatible awareness of that situation"(Salmon et al., 2008b), or "awareness of the situation comprising each element’s compatible portion of SA required for task performance" (Salmon et al., 2008b). The development and maintenance of DSA during task performance is done through transactions among system elements. These transactions refer to the exchange of SA-related information through communication and interaction (Salmon et al., 2008b). Each element holds a portion of the SA that is critical not only to their own task, goals and roles but also to the entire system’s performance (Salmon et al., 2008b). This awareness is not shared but differs based on goals, roles and tasks being undertaken, experience, training and the resultant schema(Salmon et al., 2008b). Each agent’s awareness is different but compatible with one another and is collectively required for the system to achieve its goal and desired performance (Salmon et al., 2008b). The model proposes that, in addition to the individual factors, task factors like stress and work load, system factors like goals, design and procedures, and team factors including shared mental models, communication and collaboration affect the development and maintenance of DSA (Salmon et al., 2008b).

We have introduced three prominent models of SA in group settings. In the next section we will analyse these models with respect to applicability to socio technical systems

### 2.2.3 Overall discussion on SA models in individual and group settings

The wide range of theoretical perspectives on both individual and collaborative SA models reveal that there is a lack of a unified, universally accepted definition and theory of SA (Salmon et al., 2008b).

If we observe SA models, regardless of their individual or group nature, they can be grouped under two dominant SA perspectives— the cognitive perspective and the interactionist perspective (Stanton et al., 2010), that are described in the next paragraph. Although a third perspective known as the engineering perspective of SA has been proposed by some researchers it lacks published material, and it was studied mostly in the military domain (Stanton et al., 2010). Therefore we shall describe two dominant SA perspectives and their drawbacks with respect to applying them to socio-technical systems,

1. *The cognitive or "in-mind" perspective of SA.*

   The most prominent, well-cited and well-adopted individual and group models of SA belong to the cognitive perspective of SA (Stanton et al., 2010). Endsley (1995)'s three level individual SA model, Endsley and Jones (1997)'s SSA model and Salas et al. (1995a)'s Team SA fall into this category. Proponents of this perspective treat SA as a human cognitive construct, and view SA as a phenomenon that occurs 'in the mind' of actor and they describe the SA framework based on the idea that human being is an information processor (Noyes and Bransby, 2001). This perspective provides a rich description of the key cognitive elements of decision-making in complex systems at least for individual SA and the various factors that affect individuals while making such complex decisions (Noyes and Bransby, 2001). Nevertheless, there is a lot of confusion within the cognitive perspective supporters, whether SA is a product or a process (Noyes and Bransby, 2001). The unit of analysis is the individual, and SA is closely linked to mental models and schemas that are difficult to understand and measure (Noyes and Bransby, 2001; Endsley et al., 2003). The 'in-mind' perspective of SA from an individual operator perspective, although not perfect, has been extensively studied and well described in the literature (Salmon et al., 2008b). The main problem with cognitive perspective arises when it has to be applied to collaborative settings, especially to complex socio-technical systems (Stanton et al., 2010). Team SA is a summation of individual SA, awareness of other team members, and awareness of the overall team situation (Salmon et al., 2008b). Team SA has been theorized with co-located teams in mind. Therefore, although Team SA may be useful to study SA in simple, small-scale collaborative scenarios and it is not suitable to scale up Team SA to scenarios in socio technical systems since teams can be geographically and temporally distributed and culturally heterogeneous (Salmon et al., 2008b; Carayon, 2006). Shared SA or SSA is an extension of Endsley's three level individual SA model and is the widely adopted SA model for group settings (Parasuraman et al., 2008). Although this model attempts to understand SSA in teams, further research is required to develop a theory based, empirically validated approach to model SSA in complex systems (Bolstad et al., 2005). Endsley's idea of SA in group settings is an an additive approach, where the overall SA is the sum of the shared SA (based on shared mental models) of the team members (Stanton et al., 2010). This additive approach is challenged by (Salas et al., 1995a) who states that SA in complex systems is "far more complex than combining the situation awareness of individual team members". It is very difficult to scale up Shared SA to socio technical systems (Salmon et al., 2008b).

2. *The interactionist or "in-system" perspective of SA.*

   A strong alternative approach to the cognitive perspective of SA is the interactionist perspective or the systems perspective of SA, especially for socio technical systems (Stanton et al., 2010). The foundation of this perspective lies within the distributed cognition theory of Hutchins (1995). The main message of Hutchins (1995) is that cognition is not limited to the minds of individuals but becomes a function that is achieved by the coordination between human and technological actors working within a complex socio-technical system. It has been further developed as distributed SA or DSA by Stanton et al. (2006) and Salmon (2008). The key characteristic of DSA is that it moves away from the individual as the unit of analysis towards the whole system as an unit of analysis to study SA (Stanton et al., 2006). All actors in the system— both human and non-human can develop SA by interacting or transacting with each other (Stanton et al., 2006). Although DSA has been considered to be the best alternative to study SA in sociotechnical systems (Stanton et al., 2006; Salmon, 2008), it is a very complex construct and unlike Endlsey's 3 level model it is hard to explain, measure and to use (Stanton et al., 2010). Distributed SA or DSA approach to study SA in collaborative settings is proposed to be the most suitable to represent SA in socio technical systems, since it takes the systems approach rather than an individual approach (Salmon et al., 2008b). However, the concepts of DSA are not very different from those of SSA, although they are presented through a different theoretical perspective (Endsley, 2015a). (Salmon et al., 2008b) criticises the shared mental models and schema approach of Endsley and Jones (1997)'s SSA model, but uses schema theory as one of the foundations of DSA (Salmon, 2008), that directly contradicts their criticism. Stanton et al. (2005, 2006, 2015) also agree that the DSA approach is not a completely different approach to SA in group settings, but can be viewed as a complementary theory to SSA. Additionally, one of the assumptions of DSA researchers is that they don't make a difference between the cognitive, emotive, trust and behavioural constructs of human and non-human actors (Stanton et al., 2006). This assumption can raise doubts DSA's presumed reputation (Salmon et al., 2008b) to be the right SA approach in socio technical systems where a large part of complexity arises due to the necessary presence of human actors together with their heterogeneity in terms of background, culture, personality, skills etc. (Vicente, 1999). Although computer science is advancing towards creating human to non-human interaction as close as possible to human to human interaction, it is still a unfulfilled wish in the artificial intelligence community (Hoc, 2001; Alvarado-Valencia and Barrero, 2014).

In addition to the insufficiency in theory, there is another strong motivation to study SA in socio technical systems. SA has been conceived in the military and air-force domain, which can be described as a command and control regime (Salas and Dietz, 2011). Command and control involves a hierarchical power structure, where an actor has to respond to a changing situation and command their sub-ordinates for further action. It is largely procedural in nature and often heavily depends on protocol (Alberts and Hayes, 2003). However this characteristic of command and control widely contrasts with that of socio-technical systems, where human and non-human actors work together to produce both physical and social outcomes. The actors in socio technical systems are more autonomous, dependent on each other, may have conflicting goals and ideas but need to cooperate among themselves to produce goods and services (Appelbaum, 1997). SA has been applied to non-military application like anaesthesiology, air-traffic control, energy distribution, process control, and emergency services (Gaba et al., 1995; Kaber et al., 2006; Salmon et al., 2008a; Patrick and Morgan, 2010; Blandford and Wong, 2004). These studies have been limited to the existing SA models and don't necessarily view SA from a socio technical perspective because they all comprise team with a shared goal to begin with, they don't discuss the differences between team members, and don't place any restrictions on information sharing. This means they leave out some of the characteristics of socio technical system that actually make them complex.

We can infer from the above discussion that existing individual and group SA models though containing useful elements to describe and study SA in individuals and teams, may prove impractical when applied to the description and assessment of SA in group settings in socio technical systems. This notion is also shared by Salmon et al. (2008b) and Chatzimichailidou et al. (2015b). Much further work is required in order to comprehensively describe the concept of SA in complex socio technical systems, particularly focusing on real world collaborative tasks (Salmon et al., 2008b; Chatzimichailidou et al., 2015b).

In order to address this challenge we would like to propose a theoretical framework that represents SA in socio technical systems. Our intention is not to replace the existing SA models, but to use the useful elements of each of them and supplement if necessary in relation to the characteristics of socio technical systems.

## 2.3 Framework to represent SA in socio technical systems

From the discussions in chapter 1 and in this chapter so far, it is clear that SA is an essential prerequisite to decision making in socio technical systems and appropriate SA models and frameworks are unavailable to describe SA in these systems. We have also deduced that the two main research gaps regarding SA in socio-technical systems are the diverging and in congruent research perspectives, and limited application of SA in socio-technical systems. Therefore based on the synthesis of the current models of SA we would like to propose a SA framework that would be more suitable for socio-technical systems by unifying several prominent theories, and adding missing elements. The proposed framework is shown in Figure 2.7. Socio technical systems consists of individual actors, and teams comprising individual actors (Appelbaum, 1997). We represent these 3 divisions of actors in our framework at individual, team and system level, illustrated in Figure 2.7. SA is not a standalone construct (Endsley, 1995; Endsley and Garland, 2000). Several factors affect the development and maintenance of SA (Endsley, 1995; Endsley and Garland, 2000). Therefore we also included these import individual, team and environment factors that affect SA in our framework.

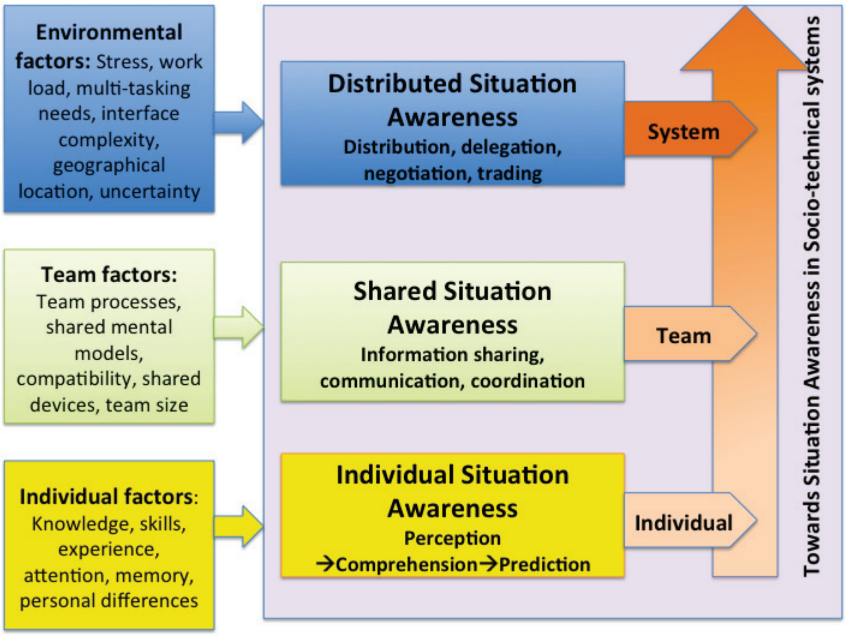



Figure 2.7: Situation Awareness Framework for socio-technical systems

To describe the individual SA in socio-technical system we adopt the established three level model of Endsley (1995), where SA comprises of perception, comprehension and prediction elements that we have discussed earlier in this chapter. The individual factors include knowledge of individuals, skills, previous experience, attention, memory capacity, personal differences like personality type (Endsley, 1995; Bolstad and Endsley, 2003).

Moving from the individual to the team level in the framework, Shared SA can be useful to describe the collaborative SA in teams (Salmon et al., 2008b). A team can be defined as a distinguishable set of two or more individuals who interact dynamically, interdependently, and adaptively towards a common goal, and each individual has been assigned a specific role or function to perform (Cannon-Bowers et al., 1995). Teams can develop Shared SA or a common operational picture by being aware of the shared requirements of the team. Information sharing between individuals will speed up the decision making based on shared understanding and allow individual operations to be more responsive to dynamic situations (Endsley and Jones, 1997). In addition to information sharing, another important team process to achieve shared SA is communication. Information sharing and communication go hand-in-hand (Nofi, 2000). Cooperative practices between individuals in a team, such as providing mutual support when a difficult situation arises, have been found to increase Shared SA of the team members (Salas et al., 2005).

Team processes, shared mental models, compatibility among team members, types of shared devices and the size of teams affect the shared SA of team members (Bolstad and Endsley, 2003). We have already described their significance in the earlier part of this chapter. They represent the social component of socio technical systems where homogeneous and heterogeneous teams need to work together.

As we move up to the systems level of the socio technical system, we have to choose an alternative approach to SA, as shared SA cannot be scaled up to study SA in complex socio-technical systems (Salmon et al., 2008b). Therefore we opt for distributed SA as the apt perspective to describe SA in socio-technical systems at the system level. However, since the drawback of DSA is the lack of differentiation between human and non-human actors, we add the necessary 'human' elements in the framework to compensate for this drawback. Distribution is the most important characteristics of DSA along with delegation. This corresponds to the concept of DSA that not all actors need to have the same shared understanding of a particular situation. Different actors are delegated different roles and they posses different SA based on their role in the system (Stanton et al., 2006). Although the system has an overarching high-level goal, not all actors need to have the same goal in a DSA environment (Stanton et al., 2006). Therefore trading becomes very important to develop SA, where trade-offs are discussed and agreements are reached between actors (Boy, 2009). Trading determines type and frequency of interaction among actors. A key mechanism for trading is known as negotiation, where actors create a common frame of reference, establish rules for trading and create coordination mechanisms (Endsley, 1995; Boy, 2009).

For the overall collaborative SA, environment factors such as uncertainty of the situation, multi-tasking needs of the work environment, geographical location of teams, complexity of technical interfaces affect SA (Bolstad and Endsley, 2003). This reflects the characteristics of socio technical systems in terms of uncertainty, geographical distribution and task complexity.

We have now described our SA framework for socio technical systems. This framework has to be tested in scenarios that require dynamic or naturalistic decision making in a socio technical system for us to study the development of SA, and the factors affecting it in such a system. In order to achieve this, we need a method for the assessment of SA in socio technical systems. We analysed several SA assessment methods— SA requirements analysis techniques, freeze probe techniques, real-time probe techniques, self-rating techniques, real-time probing techniques, observer-rating techniques, performance measures, process indices and collaborative SA measures Stanton et al. (2005); Salmon et al. (2009). These methods are described and analysed in Appendix A. We arrived at the conclusion that there is not a single method that accurately describes and measures SA in socio technical systems. Following the lead of Perla et al. (2000), we use simulation gaming to study SA in socio technical systems. The remainder of this thesis will be dedicated to testing parts of this SA framework together with the research questions posed in Chapter 1 using simulation gaming. The following chapter will describe the position of simulation gaming as a research method for socio technical systems and will introduce the design process adopted for the develop of three games used to test the SA framework and to answer the research questions.

CHAPTER 3

# DESIGNING SIMULATION GAMES FOR RESEARCH

We have mentioned in chapters 1 and 2 that we have chosen simulation gaming as a research method to test our SA theoretical framework in the context of intermodal transport operations. In this chapter we will provide a detailed explanation about the rationale behind this choice. We will begin the chapter by introducing the background and history of simulation gaming. Subsequently we will clarify the terms and definitions used in simulation gaming research. We will then discuss the back ground and theoretical perspectives of simulation gaming as a research method. Following the discussion, we will present our design process for developing simulation games that have been used in this research work.

## 3.1 Background and history of simulation gaming

The term "game" is very familiar to us, and doesn't need an explanation that it has been used for centuries to denote playful diversion or amusement (Duke, 1974). Huizinga (1952) famously said "play is older than culture". The evolution of games from a form of play to a serious undertaking can be traced back to military games since the stone age (Smith, 2010; Duke, 1974). The games that are used for serious purposes are synonymous to simulation games (Harteveld, 2011). The military has been using simulation games for training, analysis of tactics, strategy development, mission preparation and systems analysis for centuries (Smith, 2010). Although the origins of military simulation games are not precisely known, Weiner (1959) believes that the earliest military simulation games can be dated back to 3500 BCE, in reference to the Chinese game of WEI HAI that comprised abstract tokens that players manipulated to gain territorial advantage over their opponent (Weiner, 1959). Around 500 BCE, a more defined military war game known as CHATURANGA emerged in India, that has been credited to be the predecessor of the modern day chess (Smith, 2010). A throw of dice introduced chance, and verisimilitude was created by using playing pieces that resembled miniaturized soldiers, cavalry, elephants etc. (Wolfe and Crookall, 1998). The use of these ancient games was limited to entertainment in parlours, and games that would train forces for combat strategies were introduced in the 17th and 18th centuries in the form of war games used as tools to improve military thinking and to enable military training (Wolfe and Crookall, 1998; Duke, 1974; Smith, 2010). Examples include Christopher Weikmann's KOENIGSPIEL (1664), C. L. Helwig's WAR CHESS(1780) and Baron von Reisswitz's KRIEGSSPIEL (1811) (Smith, 2010). In the 20th century, it is widely acknowledged that both the allies and axis powers used military simulation games during World War I and more prominently for preparations before and during World War II (Perla, 1990).

The modern era of simulation games began in the 1950's through the integration of military/war games, computer science and operational research (Wolfe and Crookall, 1998). The term 'gaming' started being used to describe the activity of using games for serious purposes (Duke, 1974). Inspired by the military example, the business environment was quick to adopt gaming for training, strategy development, policy making, decision making and analysis (Duke, 1974). First examples of modern business games can be traced back to 1932 in Europe and 1955 in the United States (Faria et al., 2009). In 1932, Mary Birshstein, a pioneer in business simulation games, developed a simulation game to train managers at the Ligovo typewriter factory on how to handle production problems at the assembly line (Faria et al., 2009). In the United States, RAND corporation developed a business simulation game in 1955 known as MONOPOLOGS, to train inventory managers of logistic systems (Faria et al., 2009). In academia, the first recorded use of simulation games at an institution of higher education was that of TOP MANAGEMENT DECISION GAME, in a business policy course at the University of Washington in 1957 (Watson, 1981).

Supported by new educational theories that preferred active learning methods, experience and reflection of experience as learning process, simulation games have become a commonly employed teaching method throughout the world (Wolfe and Crookall, 1998). The 1970's saw the rise of digital games as a mainstream medium (Harteveld, 2011). This stimulated a lot of interest in academics and professionals to explore potential uses given their scalability (Egenfeldt-Nielsen, 2007). Although education and training applications took full force, people also began to realize that games are potentially powerful tools for many other serious purposes (Harteveld, 2012):

Shubik (1983) and Ståhl et al. (1983) worked on the taxonomy listed below to distinguish games based on their serious purpose or use,

1. **Training games** have been widely used in industry, military and education to train participants regarding a specific problem or a task without going into conceptual details (Shubik, 1983).

2. **Teaching games** have been used to teach students or participants about wider concepts and abstract ideas about a particular subject rather than focussing on a single problem statement like the training games (Shubik, 1983).

3. **Experimentation games** are aimed at testing theories or other general hypotheses (Ståhl et al., 1983). Although less robust than classical experimental testing, experimental games can be used to run a formal experiment not to test the value of some parameter or a particular hypothesis, but to find out what happens to the system when you do not have too many intervening variables interacting at the same time (Shubik, 1983).

4. **Research games** have the purpose of obtaining data or empirical material concerning a fairly broad subject area (Ståhl et al., 1983). A research game should deal with a situation or a scenario that is sufficiently realistic. The players of the game should be familiar with the type of decision involved, although they aren't necessarily the actual decision makers themselves (Ståhl et al., 1983).

5. **Operational games** are used for aiding decision making, planning, and policy implementation in specific situations (Ståhl et al., 1983). To be more specific, operational games can be used for policy formulation, dress rehearsals or actual testing of plans, sensitivity analysis, commentary on plans, demonstration of plans, idea generation, changing attitudes, model testing, establishing communication, testing personnel during recruitment etc. (Shubik, 1983; Ståhl et al., 1983).

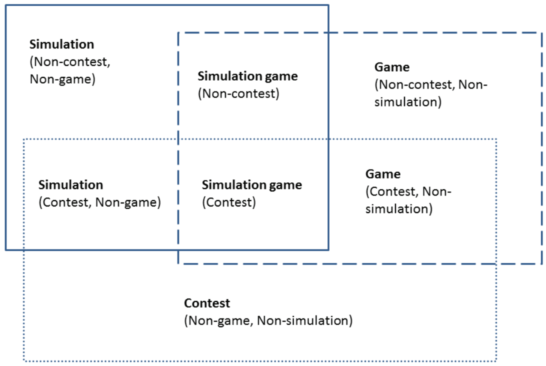
Klabbers (2009) compiled a random list of various disciplines and departments in academic research that use simulation games for a variety of academic and research purposes: architecture (& building); biology; business administration; cognitive economics; cognitive engineering; communication; computer science; computing arts and design sciences; design & environment; economics; education; environmental information; information science; information systems; integration of technology in education; interactive arts; international relations; language; linguistics; management; marketing; mathematical economics; media studies; natural resource management; policy studies; organizational behaviour; political science; project management; psychology (leadership/work & organization); public administration; research methodology and methods; social psychology; social sciences; sociology; systems agronomics; systems management; teacher studies; technology education; telecommunication; and urban planning.

Depending on the field of application, several terms like serious games, simulation games, game-simulations, gaming simulations, business simulations are used interchangeably in literature to refer to games used for a certain serious purpose (Greenblat and Duke, 1975). The multitude of terms can be confusing for readers, so we would like to clarify the terms by defining them, and presenting our choice of terms in the following sub-section.

### 3.1.1 Simulation gaming: Clarifying terms and definitions

We would like to begin the clarification of terms by discussing the two terms, 'simulation' and 'game'. Raser (1969) considers simulation and games to be special kinds of models. In a broad sense, a model is a representation of a system that specifies the components of the system as well as the relationships between them (Bailey, 2008). A 'game' is not necessarily a model, and in popular use, is often played for entertainment (Harteveld, 2011). A simulation however is a model that operates over a period of time representing the structure (components and their relationships) of a system and the way the change in one variable or component of the system affects the other variables or components in the system (Bailey, 2008). A simulation aims at representing a system as realistic as possible and doesn't involve human participants (Bailey, 2008). If such a simulation model can be operated through human subjects it could be called a simulation game, and it can be more tentative, and less accurate and realistic than a simulation model to incorporate the human subjects (Raser, 1969). Shirts (1975) introduced an additional concept known as 'contest' or 'competition' as a distinguishing factor. He described a classification schema that is illustrated in Figure 3.1

Figure 3.1: Classification schema for simulations, games and contests (Shirts, 1975)




The seven different classifications of Shirts (1975) are explained as follows,

1. **Simulation** (Non-contest,non-game), in simple terms, simulates or models reality. In the traditional sense, simulation uses mathematical or quasi-mathematical equations to represent physical, industrial and social systems (Shirts, 1975). However film, literature, painting, sculpture can be also considered as simulation since they tend to represent reality with varying levels of abstraction (Shirts, 1975).

2. To describe a **Game** (Non-contest, non-simulation), Shirts (1975) uses Suits (1967)'s definition of a game as an "activity directed toward bringing about a specific state of affairs, using only means permitted by specific rules". The means employed to reach a specific state need not be efficient, but should create a sense of entertainment among the 'players' (Shirts, 1975). Examples of non-contest games include children's games like "Truth or Dare" and many warm-up theatre or drama games.

3. The essence of a **Contest** (Non-game, non-simulation) is competition. The contest could between human being vs human being, human being vs. nature, human being vs. him/herself, and nature vs. nature. Examples include business competition, human being's struggle to adapt to nature's challenges, Darwinian natural selection etc. (Shirts, 1975).

4. **Game** (Contest, non-simulation) varies from a pure contest due to the importance given to standardized rules that need to be abided for "fair" competition and winning (Shirts, 1975). Football, chess, scrabble are a good examples of such games.

5. **Contest** (Simulation, non-game) is a category that uses simulations to compare and judge between available methods. For example, an industrial engineer simulates a contest between two methods of warehousing for a product to determine the efficiency of each of them (Shirts, 1975).

6. **Simulation game** (Non-contest) is a type of game designed to represent reality in a playful fashion without competition. An interesting example is the "Ring-a-ring-a-roses" game played by children, which represents the black plague of the middle ages. The ring around the roses is the pustule, the pocketful of posies is the pus, "ashes" is the pustule going grey or black, and after that "all fall down" means everyone dies (Shirts, 1975).

7. **Simulation game** (Contest) is the most prominent type of game used for education, scientific and other serious purposes. Simulation games represent a real system at a certain level of abstraction, where participants have to abide by certain rules to 'win' the game by managing their limited resources of money, time, influence and time within the game (Shirts, 1975). SimCity is a popular example.

In our research work when we talk about games, we refer to simulation games that have an element of competition or contest. This is because our research domain is socio technical systems where actors need to make decisions in an environment with limited time and resources. We recognize a simulation game to be "a conscious endeavour to reproduce the central characteristics of a system in order to understand, experiment with and/or predict the behaviour of that system" (Duke, 1980). It is a method in which human participants enact a specific role in a simulated environment (Duke and Geurts, 2004). We would also like to clarify the difference between the usage of the terms game and gaming. We consider a simulation game to be an artefact and simulation gaming to be an activity or a process that uses simulation games to achieve a serious purpose. We follow Greenblat and Duke (1975)'s definition of simulation gaming, where they define simulation gaming as a combination of two techniques: simulation and serious gaming— "The set of rules governing the play of the game and the scenario setting the game environment act to constrain behaviours in the game so that the game activity simulates a more complex system" (Greenblat and Duke, 1975).

Our serious purpose is to use simulation gaming as a research method to study SA in complex systems. In the following section we will elaborate on the background of simulation gaming as a research, applications, advantages and disadvantages and theoretical perspectives on the subject.

## 3.2 Simulation gaming as a research method

Research methods are strategies of inquiry that are types of qualitative, quantitative or mixed methods designs or models that provide specific direction for procedures in a research design (Creswell, 2013). Procedures in the research design include crystallization of the research problem, research environment set-up, experimental set-up, data collection & storage and analysis (Emory and Cooper, 1991). In the following sub-section, we will explore the position of simulation gaming in literature regarding its use as a research method.

### 3.2.1 Background, applications and advantages

Simulation gaming is generally not considered as a standard research method in literature, although it has the characteristics to be one (Greenblat and Duke, 1975). Making an analogy to the characteristics of a standard research method, the research problem is the game objective, the research environment is the game itself, the experimental set-up is the game session, data collection and data analysis can be done from observation and game logs.

In the words of Greenblat and Duke (1975) "The design of a simulation game itself is a systematic translation of understandings into an operating model, and the subsequent examination of the model through observation of play it can lead to a refining of theoretical formulations and consequently to a higher level of social scientific understanding."

If we look into the literature, the fields that were among the first to adopt simulation gaming as a research method were the military, business studies. One of the well known works on using simulation gaming as a research method is that of Raser (1969) focussing on military applications in the early 60's. He lists the following characteristics of simulation games that make them apt for research,

1. It is easier and **cheaper** to study and experiment a problem within a

simulation game than in reality.

2. Simulation games make certain phenomena more **visible** for **observation** and measurement in an otherwise complex, chaotic real-world system.

3. They allow for the design of **controlled experiments** that would be impossible in real world, enabling researchers to gain elaborate insights into how the system operates.

4. Simulation games offer a **safe** environment to produce laboratory analogues of dangerous phenomenon that we need to explore.

Babb et al. (1966) identified the potential of using simulation games for research in business applications. He provided several examples of research studies conducted on a supermarket management game and a dairy farm-supply chain game at the Purdue University, the following characteristics that makes simulation gaming a suitable research method for business studies have been summarized by Babb et al. (1966):

1. Simulation gaming is well suited for the study of market structures, psychological attributes, and other variables affecting the conduct or **behaviour** of organizations. The researcher can measure the behaviour in a **controlled setting**, which would difficult or impossible in real life. Studies on complex decision processes in organizations that are otherwise difficult can be simplified using simulation gaming.

2. **Decision making** in a simulation gaming session can be interrupted, dissected, and **reconstructed**. This provides the opportunity for the researcher to study the organizational effects, the effect of information sharing and other factors on complex decision making processes in complex systems.

3. Organizational patterns, role of individual and team members, leadership patterns, methods of resolving conflict, **differences** in performance among **individuals** and **teams** could be identified from many standpoints within a simulation gaming session.

Simulation gaming has been subsequently used for research in the fields of social science and policy making (Greenblat, 1975). Greenblat is a proponent of using simulation gaming as a research method for social research. She believes that simulation gaming as a research method has been largely ignored in methods and techniques of social research. To address this gap, Greenblat (1975) proposed a formalized framework on the use of simulation gaming for research, albeit focussing on social research only.

In her framework, Greenblat (1975) proposes four main modes of conducting social research using simulation gaming,

- **Hypothesis testing—** The researcher sets up hypotheses and gathers data in the form of behavioural and verbal units from the simulation gaming sessions to test their hypotheses.
- **Theory construction—** The researcher observes and abstracts from the behaviour and communication of players of a gaming session to build or define their theory.
- **System specification—** The researcher guides experts in the design of a new game or a re-design of an old game. He/she will then synthesise their contributions and present the specification of the system perceived by the experts.
- **Phenomenological data generation—** The researchers guides the respondents that belong to a certain system in the new design or redesign of a game. He/she measures the elements that are included. The data generated in this manner is known as phenomenological data as it represents the system the way respondents perceive it.

In all the 4 research modes above, the researcher either uses an existing game or designs a new game for conducting research with "players". Greenblat (1975) states that her framework can be generalized to more research areas.

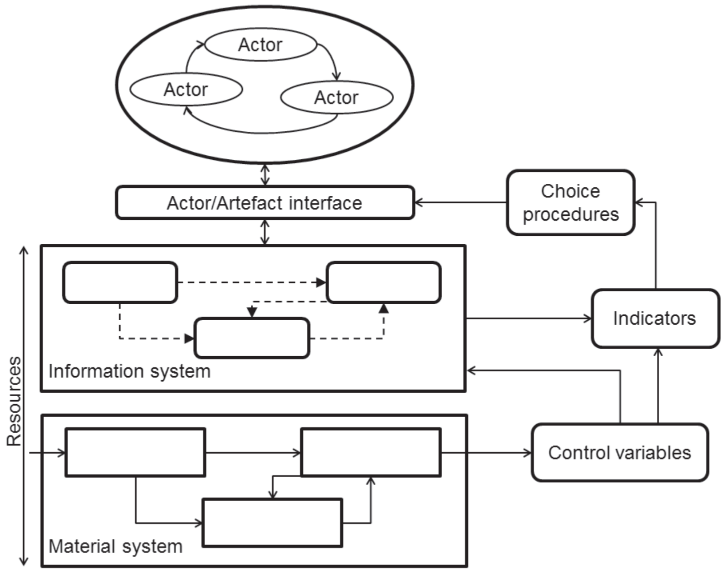
More than any of the above mentioned research areas, Klabbers (2006) claims that simulation gaming is an effective research method to study complex systems. This vision was earlier shared by Duke (1974), who proposes simulation gaming to study issues that are complex, future-oriented and of a systems nature. The last two decades saw the rise of interdisciplinary and multi-disciplinary fields of study to answer the complex questions facing a technologically advancing society. In this regard gaming has been influential as a research approach to study complexities in socio-technical systems that are inherently multi-disciplinary (Klabbers, 2006). It addresses questions of human behaviour in the context of organizational action, social change and technical development (Klabbers, 2009). Simulation gaming is well equipped to perform multi-disciplinary research that integrates different perspectives, concepts, theories, data, information, methods, techniques and tools from two or more disciplines to understand and solve problems whose solutions are beyond the scope of a single discipline (Klabbers, 2009). Examples include research studies in international relations (Starkey and Blake, 2001) and utilities deregulation (Wenzler et al., 2005).

Albeit the use of simulation gaming in several research studies in various fields, theoretical foundations on the subject have been scarce in literature (Klabbers, 2009). However a handful of researchers like Klabbers (2009), Peters et al. (1998), Vissers et al. (2001) have provided insightful theoretical perspectives on simulation gaming for research, focussing mainly on complex systems. Since our research interest lies in studying socio technical systems that can be categorised as complex systems, we will discuss these ideas in the following sub-section. This is a first step towards proposing simulation gaming as a suitable research method to study socio technical systems.

### 3.2.2 Simulation gaming: A research method for studying complex systems?

Simulation gaming has been used extensively for training and teaching purposes in many fields, but its usage as a method of enquiry or research method has been limited (Klabbers, 2009). The main reason for this shortcoming is that simulation gaming is built on foundations from several disciplines social and behavioural sciences, information and computer sciences, design and engineering (Klabbers, 2009). Thematic diversity, theoretical and methodological pluralism are quoted as weak credentials for simulation gaming to be an established scientific method for research (Klabbers, 2009). Paradoxically, the claimed weaknesses of simulation gaming happen to be its greatest strengths because simulation gaming is influential in developing knowledge and experience across disciplines, dealing with practical issues, which is the crux of interdisciplinary or multi-disciplinary research (Klabbers, 2009). Interdisciplinary enquiry is inspired by the drive to answer complex questions in a complex socio-technical environment and requires researchers to integrate perspectives, concepts, theories, data, information, methods, tools from more than one discipline to explore problems (Klabbers, 2009). In this context, simulation gaming is an influential method of interdisciplinary scientific enquiry for complex systems (Klabbers, 2009). This representation can also be applied to socio technical systems since Klabbers use complex systems synonymous to socio technical systems. Klabbers (2009) proposes a framework to represent a complex system from the perspective of simulation gaming, shown in figure 3.2

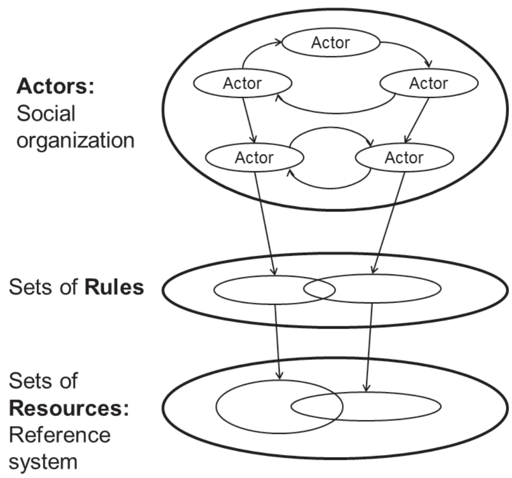
Figure 3.2: Representation of a socio technical system from the simulation gaming perspective (Klabbers, 2006)




Socio technical systems are anchored in the attitudes, perceptions, beliefs, habits of human beings who interact with each other and with the environment around them (Klabbers, 2009). This representation is an extension of the Katz and Kahn (1978)'s work on social organizations. In addition to social interactions, Klabbers (2009) discusses the interactions between human beings and their technical environment. In Figure 3.2, we notice that a socio technical system is seen as a boundary-maintaining entity with interacting social and technical sub-systems. Within the social sub-system, actors establish local boundaries that separate them from each other and their environment. Boundaries define system activity (Klabbers, 2009). For instance, in companies, each of the various divisions are responsible for a specific functional area like finance and production. The sub-systems interact with each other by means of interfaces (Klabbers, 2009). At the interface transaction processes consist of transfer of materials, energy, money and information. If we make an analogy between a container terminal to the system represented in Figure 3.2, the material flow represents the movement of containers in the terminal with the use of cranes, trucks, and automated guided vehicles. The control of these processes is automated in fully automated terminals. The process automation in the form of control algorithms is embedded in the information sub-system. As long as the terminal functions with an acceptable range of the control variables, the systems runs on its own. Human operators receive the status of the operations through indicators through information and control panels and may need to intervene if they notice anything out of the ordinary. They have the option to change the parameters that control the container flow or modify the decision rules. This representation can be extended to other socio-technical systems like chemical plants, hospitals, universities and banks (Klabbers, 2009).

A model to represent such a system in the form of a game or a simulation has also been proposed by Klabbers (2009), illustrated in Fig 3.3.

Figure 3.3: A general model of games and simulations to represent socio technical systems (Klabbers, 2006)

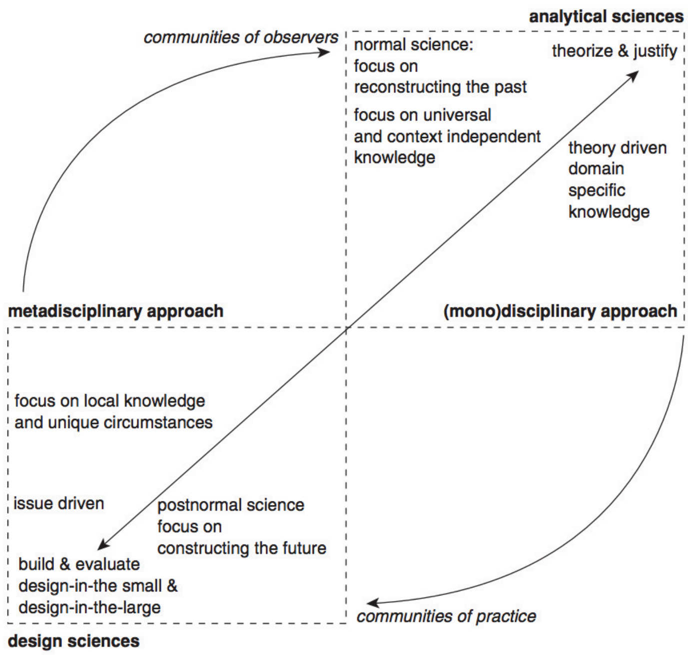



A game or a simulation representing a socio technical system consist of three inter-connected building blocks— actors, rules and resources (Klabbers, 2009).

The roles in a simulation game present the actors that form the social sub-system of a socio-technical system (Klabbers, 2009). Roles provide a context for the participant in the game to interpret the position of an actor in the system. The role structure provides shape to the theoretical structure of interactions between actors in a real system (Klabbers, 2009). The rules of the game define the relationships between the various roles, as well the relationship between the roles and the resources. They also specify the communication, coordination and competition protocols of the game (Klabbers, 2009). Conventions, procedures, codes of conduct can be part of the rules of the game (Klabbers, 2009). Resources represent the technical sub-systems of the socio-technical system. The information and material sub-systems are combined to be represented by resources (Klabbers, 2009). If we choose for a simulation, the resources can be modelled by mathematical formulae, on the other hand, if we choose for a simulation game we can represent the resources as game pieces to be moved in a board game or a simplified version of the real processes as a game mechanic in a digital version. By changing the rules, we can transform or modify the way the roles and resources behave. This provides an ideal platform to conduct research as rules provide effective control variables (Klabbers, 2009). In this form simulation gaming can be very well classified as a laboratory style type of research method. Laboratory style research is a powerful way of doing science, especially in pure sciences like physics and chemistry where artefacts and phenomenon are created, and tested enabling scientific discoveries (Hacking, 2002). The laboratory style of research is also used for testing theories in social and behavioural sciences , economics, cognitive sciences etc. (Klabbers, 2009). In this regard, simulation gaming is an apt example of a laboratory type of research method to study individual, organizational and social behaviour and test theories in social and behavioural sciences using the hypthetico-deductive method (Klabbers, 2009). In the words of Godfrey-Smith (2009), hypothetico-deductive method is a research method where researchers "come up with conjectures (hypotheses), and then deduce observational predictions from those conjectures". If the predictions come out as the theory says then the theory is supported, if not, the theory is rejected (Godfrey-Smith, 2009). The more tests a theory passes, the more confidence we can have in its truth (Godfrey-Smith, 2009).

We can deduce from the above discussion that a simulation game is both an artefact and a laboratory (testing platform) to conduct scientific research. This notion is supported by Klabbers (2009), who states that simulation gaming can take a dual position in connection to the two main branches of science– design science and analytical science. The objective of a simulation gaming project can be two fold— either to design an artefact, which can be a game in our case, that can be used to change existing situations to preferred ones, or to use the artefact to generate outcomes that can be used to test theories and hypotheses while applying laboratory style of reasoning (Klabbers, 2006). This notion is represented in Figure 3.4. If we examine the lines of enquiry

Figure 3.4: Framework combining design and analytical sciences in gaming research (Klabbers, 2006)




of the two branches of sciences closely, the design science style of enquiry is issue driven, often multi-disciplinary and does not produce universal and context-independent knowledge. Research activities of design science include developing and assessing artefacts, models, methods and procedures (Klabbers, 2009). Design science attempts to create artefacts that serve human purposes to change real world situations (March and Smith, 1995). The artefacts are assessed against the criteria of value or utility: Does the artefact work? Does it improve the current situation or process? Does it improve existing human and social capacities? Does it trigger new skills and knowledge?(March and Smith, 1995; Klabbers, 2009). Design science comprises communities of practitioners who like to shape the future by designing and evaluating solutions in an iterative fashion by keeping close contact with professionals in the problem field (Klabbers, 2006). They usually have an esteemed position in the society due to the tangible and utilitarian nature of their work, but remain quite low in the academic and scientific ladder (Klabbers, 2009).

On the other hand, the science of analysis is theory driven, and employed within a specific domain, and is often mono disciplinary (e.g. natural sciences). The science of analysis aims at understanding reality. It consists of communities of observers who take a distance from the problem, make claims about the nature of reality through models, theories etc. and try to substantiate or reject the claims based on observed facts (March and Smith, 1995). This process of discovery and justification forms the crux of analytical science and scientific studies based on analytical science make extensive use of the hypothetico-deductive method (March and Smith, 1995). Analytical science uses research methods but does not create them (methodological tools for research are often created by the design science communities of practice) (March and Smith, 1995).

Although the two branches of science are methodologically different, the overall aim of science is to generate knowledge to understand the complex world we live in, help solve societal problems and to address public needs (Klabbers, 2006). Simulation gaming as a research method is in a unique position to bring communities of observers and practitioners together. From the Figure 3.4 we can observe that both the communities influence each other and can benefit from each other.

Within our research context, we place ourselves more along the communities of observers, that consider simulation games to be artefacts that allow us to test our hypotheses and theories regarding Situation Awareness in socio technical systems, using our case study of intermodal transport operations in container terminals. In that case we have two options— first, to use existing simulation game(s) to answer our research questions and test our SA framework proposed in Chapter 1 and 2 or second, to design simulation game(s) that explicitly encompass our theoretical ideas, and those simulation game(s) can become laboratory style tools to test these theories. The second approach is a purer form of the analytical science approach, because the content and meaning of the theory fit together in the frame of the game (Klabbers, 2006). In comparison, in the first approach a simulation game would be a more of a tool to test the formal aspects of the theory (Klabbers, 2006). Therefore we will design simulation games to test our theories and answer our research questions regarding SA in socio technical systems.

In this section we have discussed the usefulness of simulation gaming to study complex systems and have clarified the position of simulation gaming within the two branches of scientific enquiry,and the need for designing simulation games for the research presented in this book. Based on the ideas gathered from the theoretical perspectives of this section, we will present a design process that we will use to develop the simulation games used for this research.

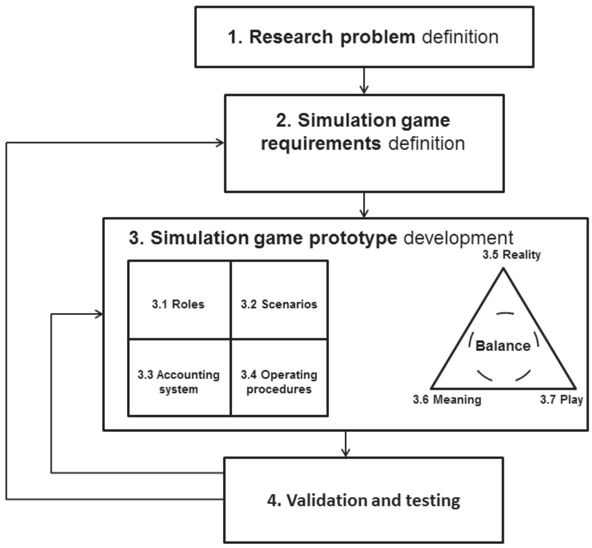
## 3.3 Design process for simulation games used for research

We know from the design science perspective that a design process aims at creating an artefact to be used for a specific purpose. In our case, we would like to create simulation games to conduct research on complex systems. Designing simulation games is a science, an art and a craft (Klabbers, 2009). Given the creative nature of game design, most of the simulation games with a serious purpose have been developed without a comprehensive design process or philosophy (Harteveld et al., 2010). Referring to our position as communities of observers in Figure 3.4, we have to base our design process on a more procedural and theory-driven approach instead of a fully creative approach. We were able to find very few results on this topic in literature. The seminal work on game design process of analogue games was done by Duke and Geurts (2004) based on Duke (1974) in the field of policy and management. It consists of 5 phases and 21 detailed steps. The five phases are summarized below from Duke and Geurts (2004) and Duke (2011),

- **Phase 1: Setting the stage for the project—** 1. Project organization 2. Problem definition 3. Defining objectives 4. Identifying different solutions 5. Setting the specifications
- **Phase 2: Clarifying the problem—** 6. Definition of a conceptual model 7. Visualization of the conceptual model 8. Negotiation with clients on scope
- **Phase 3: Designing the game—** 9. Creation of a first prototype design of the game using the conceptual model 10. Definition of gaming elements 11. Consultation with existing techniques 12. Format selection 13. Documentation of game idea
- **Phase 4: Developing the exercise—** 14. Building, testing and modification of the prototype 15. Technical evaluation 16. Preparation of a professional version
- **Phase 5: Implementation—** 17. Integration of the game to the real world context 18. Game facilitation 19. Dissemination 20. Protection of game design 21. Final documentation and closure

Although this deliberate design process provides some useful guidelines, it's not perfect. One of the main shortcomings is the water-flow model of the process.

Figure 3.5: Design approach for simulation games used for research




Design is an iterative process, and requires building, testing of mock-ups, and redesigning based on the feedback from tests and is not an isolated single step (Klabbers, 2009). Additionally, in our case, validation becomes key to substantiate simulation gaming to be a research method. Duke and Geurts (2004)'s design process is aimed mainly at analogue policy games. The steps are too detailed, and may not be relevant for all simulation games. For our purpose, many of the 21 steps become obsolete. In addition, this process doesn't provide guidance about the components of a game prototype, or how it can be evaluated and validated, which are very crucial for a simulation game used for research purposes. In order to address these issues, we propose our approach to designing simulation games for research, in Figure 3.5. We gave numbers to each of the design stages and elements in the figure to guide the reader through the explanation.

We begin with defining the **research objective** (1) of the simulation game that we would like to design. An example could be, we would like to design a game to study the influence of Situational Awareness on the decision making of actors during disruptions in a container terminal. We then describe the **game requirements** (2)— who will be the test subjects (students, professionals) in our research, what kind of game will it be and in what platform will it be played (board game, digital, mobile/tablet). Defining the game requirements helped us to think of the design and implementation of the experimental session with the simulation game at an early stage. The following step is the design of the game **prototype** (3). We will present the architecture or the components of our simulation game. We have discussed in the previous section that a complex system can be modelled as a simulation game in the generic form of actors, rules and resources. Although this representation is in line with our research objective, we would like the simulation game to have more specific components that reflect its role as a research method. Such a representation can be found in the work of Armstrong and Hobson (1973) who proposes the following components for a simulation game

- **Roles** (3.1). Participants assume roles that need not correspond to the roles they assume in real-life.
- **Scenarios** (3.2). The scenario in a game gives participants the information about a specific problem situation that provides a framework for the gaming exercise. The scenario may relate to a past, present or future situation. The element of role playing may influence how the scenario unfolds.
- **Accounting system** (3.3) in a game is designed to record decisions taking by the participants and the related consequences during the game play.
- **Operating procedures** (3.4) of a game define the rules of the game and definition of various roles, procedures to conduct the gaming exercise, and procedures for operating the accounting system.

Designing a simulation game to represent issues in a real world system is a difficult task, since its objective is beyond entertainment alone (Harteveld, 2012). In their capacity as models, simulation games encompass the theories of the systems they represent (Klabbers, 2009). According to Thorngate (1976)'s postulate of commensurate complexity, it is impossible for a social theory to be general, accurate and simple at the same time. Weick (1999) interpreted Thorngate (1976)'s postulate regarding research methods in the following manner,

- If a research method aims to be accurate and simple, results would not be generally applicable.
- If it aims to be general and simple, results would not be accurate and
- If it aims to be general and accurate, results would not be simple any more.

This creates a need for balancing trade-offs while designing a research method. In the context of simulation gaming, a similar design philosophy on balancing trade-offs for the design of simulation games has been developed by Harteveld (2012); Harteveld et al. (2010) known as he Triadic Game Design(TGD) approach that constitutes three core components: Reality, Meaning and Play. The TGD approach is all about balancing these three components that are described below to create a simulation game with a serious purpose(adapted from Harteveld (2012) and (Harteveld et al., 2010)),

- The **Reality** (3.5) component of the TGD approach describes how a game model connects to reality (Harteveld et al., 2010). People, organizations, objects, variables and their relationships have to be incorporated in the model to represent reality. The degree and detail of the representation of reality depends on the purpose of the game. For example, a game to promote fitness may need simple statistics on the amount of many calories people burnt per type of activity, while a game about educating medical students needs to contain every detail of the human body. The reality component is very domain-specific, so subject matter experts have to be included in game development, who can also verify if the representation of reality in a game. Any depiction of reality can be subjective, since a model of reality interpreted and translated by a group of designers, researchers and subject matter experts, maybe substantially different from another group's model (Harteveld et al., 2010). The model of reality serves as a conceptual model on which the game is based. It can change along the development process of the game based on changing requirements or design needs (Harteveld et al., 2010).
- The **Meaning** (3.7) of a game defines the purpose of the game (Harteveld et al., 2010). Therefore it is very important to understand ways to create this "meaning", to make sure the intended value of the game is achieved (Harteveld et al., 2010). The various values that can be pursued with games have already been discussed earlier in this chapter. In our context,

the purpose of our game is to acquire knowledge about Situation Awareness in complex systems and test related theories by data collection and observation through our simulation games.

- The term **Play** (3.8) is a larger concept which is open-ended and free-form type of activity (Harteveld et al., 2010). A game is a formalized form of play (Harteveld et al., 2010). Games and play activities form a continuum on a sliding scale of unregulated play to strict rules (Harteveld et al., 2010). To develop a game, one needs a conceptual model that describes the elements of a game, and how they relate to each other to create an experience for the player (Harteveld et al., 2010). Simulation games are hailed to be engaging, immersive and fun (Harteveld et al., 2010). The play component of TGD guides game developers to think of ways to keep the entertainment and engaging values even in games for a purpose. In addition to the conceptual design, technical implementation and various game platforms need to be considered to execute the desired 'play' (Harteveld et al., 2010).

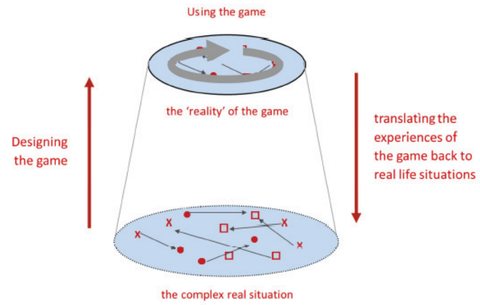
All the three components are inherently connected to each other and depend on each other. If meaning is not related to reality and play then the purpose of a game makes no sense, and the game play experience will not be useful. If Play does not have some abstraction derived from the Reality, it becomes unplayable (Harteveld et al., 2010).

We have adopted the TGD approach to design our simulation games used for SA research in socio technical systems. The roles, scenarios, accounting system and operating procedures of our simulation game should be designed concurrently. They need to be constantly balanced between reality, meaning and play and adjust the game design has to be adjusted accordingly (Harteveld, 2011). This process should be continued until we arrive at a realistic, meaningful and playable game.

Given that our simulation games will be a models of a reference system (real world system) to study that system, it is important to translate the findings from the gaming sessions to the reference system. We need to draw valid conclusions about the reference system on the basis of information gathered in a simulation game Peters et al. (1998) (See Figure 3.6).

The extent to which we can translate these finding to reality, marks the validity of the simulation game to conduct research (Peters et al., 1998) . Our design process therefore focusses considerably on the validation and testing

Figure 3.6: Designing a game and applying in reality




of the simulation games, to iteratively improve the game design to achieve our research purpose. It is the final and crucial step in our design approach shown in Figure 3.5. We will explain our approach to validation in the following sub-section.

### 3.3.1 Validation

Validation of simulation game is challenging since conventional approaches to validity have been developed outside the field of simulation and gaming (Peters et al., 1998; Vissers et al., 2001). "Validation usually means that some more or less standardized, widely accepted validity types are used to assess the validity of, usually, instruments for data collection" (Peters and van de Westelaken, 2011). Research methods are generally checked against content, predictive, concurrent, and construct validity, sometimes together with internal and external validity (Vissers et al., 2001). These notions of validity come from the fields of social, psychological and educational research (Peters and van de Westelaken, 2011). "The concept of validity in relation to simulations and games as a simplified model of a complex reference system is hardly elaborated in the literature" (Peters and van de Westelaken, 2011).

Exceptionally, Raser (1969) proposed four criteria for the validity of simulation gaming for conducting research.

1. **Psychological or face validity—** A simulation game should provide an environment that seems sufficiently realistic, otherwise the players might display a completely different behaviour than they would in real life. This could be interpreted as face validity of the game.

2. **Process validity—** The processes in the simulation game need to be isomorphic to those observed in the reference system.

3. **Structural or construct validity—** A simulation game is valid to the extent that its structure (the theory and assumptions on which it is built) can be shown to be isomorphic (the model and the system need not be similar, but congruent) to that of the reference system it represents.

4. **Predictive validity—** The simulation game should have the capacity to make a good estimate of what can happen in the reference system, given a specific scenario or situation. This is usually done by recreating known situations in the game, and by comparing the results of the game to those of the real situation (Peters and van de Westelaken, 2011).

The work of Raser (1969) is arguably one of the very few scientific works that sheds some light on validity of simulation games, although it is unclear how to apply each of the four criteria proposed by Raser (Peters and van de Westelaken, 2011). Peters et al. (1998), Vissers et al. (2001) and Peters and van de Westelaken (2011) argue that, with respect to simulation games validation is not the activity of testing against one or more standardized criteria of validity. Rather, it results from the motivation and objective to design and justify the various steps in a research project. They take an constructive approach, where they move away from standardized validity criteria, and view validation to be a line of reasoning that supports the design, selection, and the use of research instruments and methods (Vissers et al., 2001). The following guidelines have been proposed by Peters et al. (1998) for the validation of simulation games:

1. **Work systematically**. Researchers have to thoroughly analyse the structure and processes of the reference system. Subject matter experts should be involved in the game design together with the researchers.

2. **Discuss explicitly**. Researchers should engage with subject matter experts and future users of the simulation game to discuss the game concept and gather their opinions. The discussion should be based on the four criteria of validity proposed by Raser (1969).

3. **Test extensively**. Simulation games need to be tested extensively to make sure if the game works as planned, if the participants understand the instructions, if the game can be executed within the time limit etc. If possible the tests should include subject matter experts and potential users of the game.

Relating to the above guidelines, (Peters and van de Westelaken, 2011) complied an extensive, if not complete check list of questions that can be consulted by researchers during the game design process to validate their simulation game. This list can be found in Appendix B.

Our game design approach is congruent to the validation philosophy of Peters et al. (1998), Vissers et al. (2001) and Peters and van de Westelaken (2011) since we adopt an iterative game design, balancing the reality, meaning and play components using subject matter experts, as well as extensive testing to collect feedback to improve the game design. Therefore we will adopt the guidelines of Peters et al. (1998) and consult the check list of Peters and van de Westelaken (2011) for the validation of our simulation games. Using this approach, we have designed and used simulation games for studying SA in socio technical systems in this thesis. In the following section, we will explain our general research approach and a brief introduction to the three simulation games developed and used in this research.

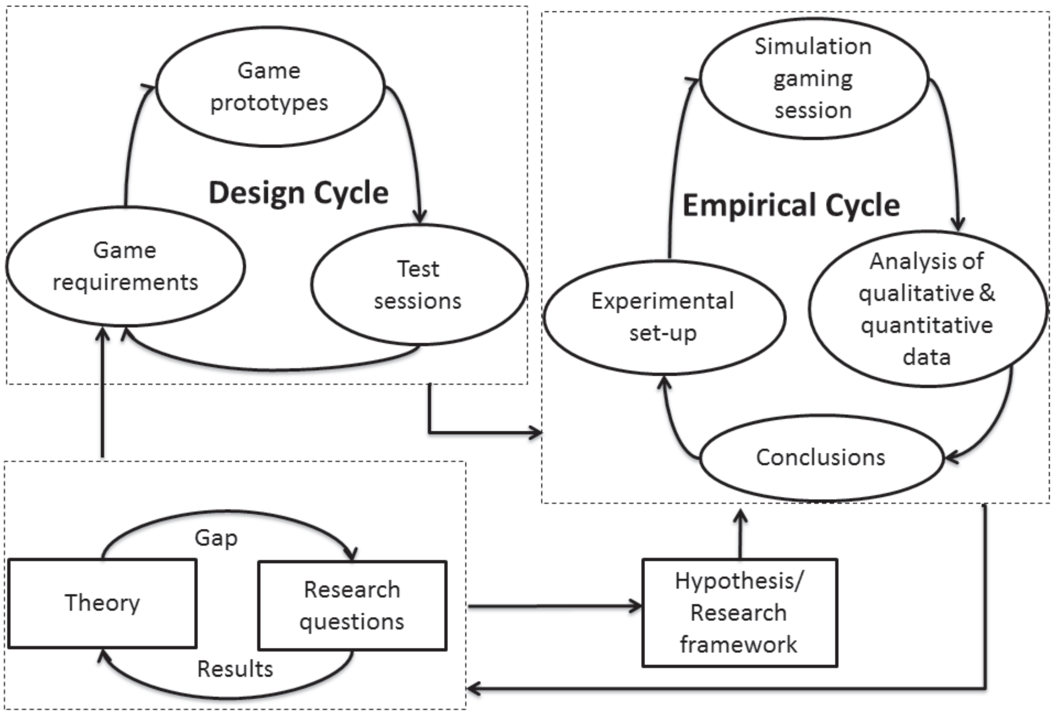
## 3.4 Research process using simulation gaming

Our research process for this thesis consists of a design component and an empirical component, compatible with the philosophical stance of simulation gaming being at the cross roads of design and analytical sciences. Our research process is represented in Figure 3.7.

The first step in our research process is the identification of the research gaps in the study of SA in socio technical systems by examining the various theoretical perspectives available in literature. These gaps then lead to research questions in chapter 1 and a new framework to study SA in socio technical systems in chapter 2. The research questions and the framework provide the research objective and game requirements for the simulations games to be designed. The design cycle follows the design approach discussed in this chapter. The design of the simulation games is an iterative process with test sessions and validations. The feedback from these sessions modify the game requirements and the design. The design cycle is culminated with a functional simulation game that is able to answer one or more of the specified research questions, and to test the SA framework. This approach can be viewed as an adaptation of Von Alan et al. (2004)'s design approach to simulation gaming.

The next component of our research process is the empirical cycle. The simulation games developed in the design cycle will be used in the empirical cycle. In the empirical cycle, we design experimental sessions to answer the

Figure 3.7: Illustration of the research process




different research questions and test parts of the SA framework. The execution of these experiments are in the form of simulation gaming sessions, that contain briefing of the game, experimental procedure, administration of questionnaires for additional data collection and for participant feedback and a de-briefing session. The simulation gaming sessions ends with a debriefing session, where the researchers engage with the participants to reflect on their experience. Sometimes the gaming sessions are video taped, and observed for further analysis. The quantitative and qualitative data produced in the simulation gaming sessions is analysed to reach conclusions regarding the answers to research questions, to test SA framework, the experience of the participants, the session quality etc. These results can help to improve the experimental set-up. After a few test rounds, we need to arrive at a standard experimental set-up that will be used for the actual data collection. The results of the empirical cycle are then contrasted with the research gap identified in chapters 1 and 2. Depending on the results, the answers to the research questions could contribute to the SA theory in socio technical systems.

In the course of this thesis work, we developed three simulation games and conducted experimental sessions with them towards answering the research questions. the subsequent chapters will focus on this development of these games, description of the sessions, and analysis of results pertaining to specific research questions.

The three simulation games are two digital and one analogue game. Yard Crane Scheduler 1 (YCS1), Yard Crane Scheduler 3 (YCS3) are the digital game and the disruption management board game.

The YCS1 game is a single player, web-based microgame has been used to study the individual component of Situational Awareness in socio technical systems as well as factors affecting performance in such systems. The game is set in the environment of a container terminal, where players need to align the various planning operations under varying workload conditions. YCS3 game is a four-person multi-player version of YCS1 game. YCS3 has been used to study team performance, and the effects of the different modes of Situation Awareness on the performance of teams. In addition, factors affecting team performance have also been studied. Chapter 4 describes the detailed design process of YCS1 and YCS3. Chapters 6 and 7 describe the set-up of the experimental study, and the quantitative analysis and results of the study using YCS1 and YCS3 respectively. The board game is a multi-player table top game. We have used this game to test the role of SA on the performance of co-located teams in a container terminal during disruptions. The design process, evaluation and validation of the disruption game is presented in chapter 5 and the experimental set-up together with the qualitative results can be found in chapter 8.

CHAPTER 4

# YARD CRANE SCHEDULER GAMES: DESIGN AND EVALUATION OF YCS1 AND YCS3

We have established in the earlier chapters that simulation gaming will be the key research method to study SA in socio technical systems in our research work. We will answer the research questions proposed in chapter 1 and test the SA framework proposed in chapter 2 by conducting empirical studies with three simulation games developed within this research. In this chapter we will introduce two of the three games, Yard Crane Scheduler 1 (YCS1) and Yard Crane Scheduler 3 (YCS3) developed for this research. We will describe the design, development, validation and deployment of these games based on the design approach described in Figure 3.5 in Chapter 3. We will begin our description with the research problem and game requirements that represent the first two stages of the approach.

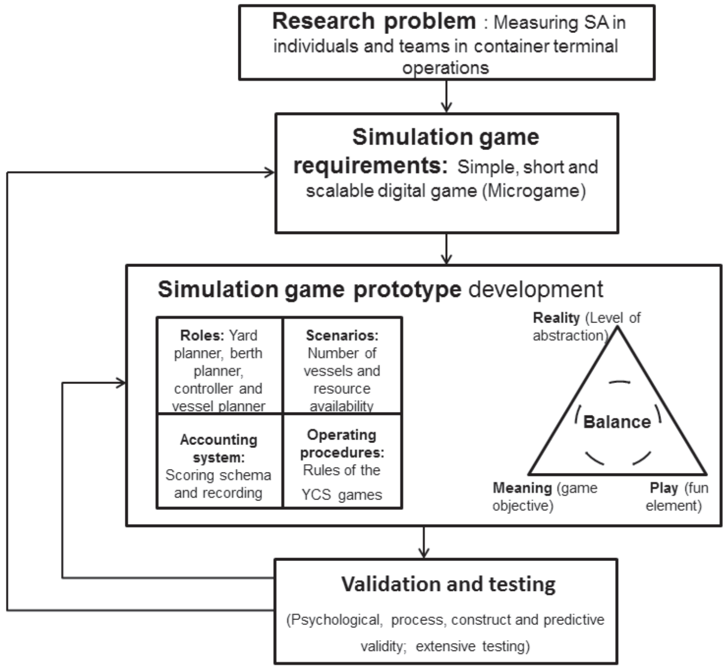
## 4.1 Iterative game design process for the YCS games

### 4.1.1 Game requirements

Our overall research objective is to assess the role of SA on decision making and performance and the factors affecting SA among individual actors, teams and groups in the operational processes of socio technical systems. Our case study is the operational planning of intermodal transport operations in container terminals. We have to design simulation games to assess SA in these complex planning operations in individuals and in teams. The simulation games will serve as a performance measure of SA within the environment of a socio technical system.

In this regard the games should sufficiently represent the various interdependencies and complexity of container terminal operations. They also should make the players experience time pressure while making critical decisions to represent the complex work environment of operational planning in container terminals. The participants need to have some background on container terminals since naturalistic decision making in socio technical systems requires basic subject matter knowledge.The participant group that fit this criterion are professionals and students in the field of supply chain, logistics and transportation, an umbrella field that comprises container terminal operations as well. Our games should be relatively simple to play, that do not require special computer gaming skills to play because we would like to measure SA related performance and not game playing proficiency. Short games that can present the required information to the participants are proven to be more effective for the studying and understanding complex systems (Lukosch et al., 2016). Such short games have been found to encourage the engagement and motivation of participants during studies (Lukosch et al., 2016). Therefore we chose the format of Microgames— short games or mini games that have the potential to transfer a complex game objective within a short amount of time to the players of the game (Lukosch et al., 2016). This is also very advantageous from the perspective of researchers, because more data can be collected due to the short time needed to administer such games. If we need to use these games for large and varied groups of participants, scalability and portability is another key requirement Creswell (2013). Therefore we decided to develop web based digital microgames that can be easily administered with minimal temporal, geographical, and technical constraints. The researchers should also have control over the game sessions and the access to the web based games. We have already discussed in chapter 3 that, simulation gaming is not only an instrument to conducted research but an integrated activity. Therefore we need an platform to host the games that supports the briefing, de-briefing, additional data collection using surveys, and related activities that are a part of a simulation gaming session. The platform should also register the actions taken by the participants during game play and their scores tied with time stamps for further analysis. To host the games, we used an online portal known as "Whitebox" that was specially developed to meet the requirements of a simulation

Figure 4.1: Game design process specific to YCS games




gaming session by InThere, a Dutch gaming company in collaboration with the researchers involved in this thesis work. Two microgames— Yard Crane Scheduler 1 (YCS1) and Yard Crane Scheduler 3 (YCS3) were developed and hosted in the Whitebox to conduct SA research in individual and group settings. YCS1 is a single player game that requires participants to align several planning processes in a container terminal, under time pressure and varying work loads. YCS3 is a multi-player game that is an extension of YCS1. YCS3 is played by 4 players who take the different planning roles in a container terminal who need to align the planning processes under time pressure and varying work load. Both games are conceptually similar, so we will describe them simultaneously in this chapter. We will now discuss the iterative design process of YCS1 and YCS3 that represents the third stage of our design approach in a modified of Figure 3.5 version specific to YCS games in Figure 4.1.

### 4.1.2 Game prototyping of the YCS games

Our game design process follows an iterative and balanced approach described in Chapter 3. We built the key components of the game— roles, scenarios, operating procedures and accounting system (Armstrong and Hobson, 1973) with the Triadic Game Design (TGD) philosophy of Harteveld (2011).

The first step of the iterative design process began with a so-called game storm, a brainstorming session together with three researchers, four subject matter experts from the container terminal business and two professional game designers to discuss the research objectives, game requirements and to define the first version of the key game components using the TGD philosophy. We will first define our prototypes together with our validation and testing process and will finally comment whether we achieved the balance between reality, meaning and play.

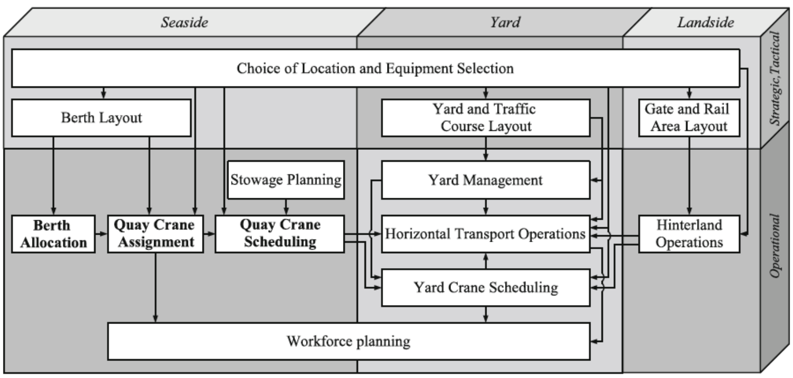
The first game storm sessions began with defining the reality component of the game, namely making decisions on what aspects of the reference system, in our case the container terminal, should be represented in the game. Our simulation games are designed to be used for research purposes, so the presence of subject matter experts from the beginning is very important to make sure the element of reality is sufficiently present in the game (Peters et al., 1998). The subject matter experts focussed mainly on the level of realism that needs to be present in the game. The researchers led the discussion on the research objectives that need to be accomplished through the game. The game designers weighed in their experiences regarding playability and created a rough schema with ideas on how to embed these objectives in a sufficiently realistic game that is playable. An impression of a game designer during the game storm can be viewed in Figure 4.2.

Figure 4.2: Game designer in action at a game storm session

The first version of all key game components was defined in the first game storm session that led to a conceptual game design model. This concept was again discussed with the subject matter experts. The first prototype of the YCS1 game was developed based on several discussions and feedback sessions. This prototype was further evaluated by subject matter experts and students in the supply chain, logistics and transportation domain (see also the sub-section on testing and validity of the YCS game). The discussion with subject matter experts was inspired by the list of questions presented in Appendix B. Then the game was redesigned to accommodate the suggestions and shortcomings encountered during the testing and validation sessions. After four iterations, we reached a playable single player version, YCS1. The design of the multi-player version of the game didn't have a separate game storm session since the requirements were already defined in the game storm session of YCS1. The YCS3 went through four iterations before it was accepted to be usable by the researchers. In the following sub-section we will define the key components of the final versions of YCS1 and YCS3.

### Roles

Figure 4.3: Planning problems in container terminals (Meisel, 2009)




Operations planning in container terminals is very complex. Some of the planning problems in a container terminal have been illustrated in Figure 4.3. Simulation games are an abstraction of reality (Duke, 1980), therefore it is not possible to represent all the planning problems in a playable game (Harteveld, 2011). Based on literature and consultations with professions in the container terminal industry, we carefully chose the important roles that need to be represented in operational planning of container terminals. These roles are described below:

- **Berth planner** is responsible for deciding the mooring slot and time slot for the ships at the quay (sea-side) where they can be served with a planned number of quay cranes
- **Yard planner** has to allocate the storage spots in the yard for import, export and transshipment containers
- **Vessel planner**'s job is to plan the order of unloading and loading of the containers from and onto the ship while guarding stability and safety of the vessel
- **Resource planner** or **controller** has to dispatch the required equipment and manpower for the operations planned by the berth, yard and vessel planners.

In YCS1, the role of the vessel planner was automated to reduce the cognitive overload for the individual players. In YCS3 all the four roles are present.

We will now describe the scenarios and operating procedures of the two games.

**Scenarios and operating procedures**

We would like to introduce the container terminal equipment represented in the games because they are important to describe the scenarios and operating procedures in both games.

The various equipment and vehicles used in the terminal have been incorporated in the games are as follows,

- Quay Cranes (QCs) are located on the quayside or the waterside of the terminal. QCs load and unload containers on/off the ships. These cranes are mounted on rails and cannot pass over each other, both in reality and in the game. There are 3 QCs in the game.
- Automated Guided Vehicles (AGVs) are driverless trucks that transport containers from the ship to the yard and vice-versa. AGVs are automated and don't require any planning (in the game). Whenever a crane is at

work, an AGV arrives at that spot to either pick up or drop off a container. There are 10 functional AGVs in the game.

- Rail Mounted Gantry cranes (RMGs) or yard cranes are located in the yard to stack containers in the yard. They pick up the containers from AGVs and place them in the yard. They also retrieve containers out of the yard and place them on AGVs which then carry them towards the quayside. RMGs can only move along the container block as they are rail mounted. If RMGs need to change to a parallel block, players need to drag them until the end of a block and drag them sideways to the required parallel block.

- Trucks are involved with landslide or hinterland transportation. In the game trucks arrive to pick up containers that are designated for hinterland transportation.

We will now discuss the scenarios and operating procedures of YCS1 and YCS3.

**YCS1**: Deep sea vessels arrive to load and unload containers in the terminal. All the containers to be unloaded from the ships are known as import containers. Export containers in the yard that need to be loaded onto the ship are marked with an arrow symbol. In this game, the yard is 1 tier high and loading and unloading of ships is not done simultaneously. The task for the player is to make sure the ship is serviced as soon as possible, while using the terminal resources efficiently. The containers to be unloaded by every ship need planning and resource allocation on the yard side, quay side and land side of the terminal. The arrival times and departure times are indicated for each ship on the right hand side of the screen. Consistent with real planning operations, the state of all resources has to be monitored in parallel, while making decisions about locations of QCs, RMGs, and import, export, and transfer containers. Each game takes 6-8 minutes to complete. The difficulty levels of the YCS games are called missions. There are 8 missions of the YCS1 game with 1 being the easiest and 8 the hardest. The level of difficulty is based on the number of ships, number of containers, and the dock time of the ships. The game functions in two modes– Planning mode and operational mode. Players can enter the planning mode by clicking on any of the individual ships and can return to the operational mode similarly with a click on a ship. The two different modes are shown in Figures 4.4 and 4.5. The various tasks in the game are described below:

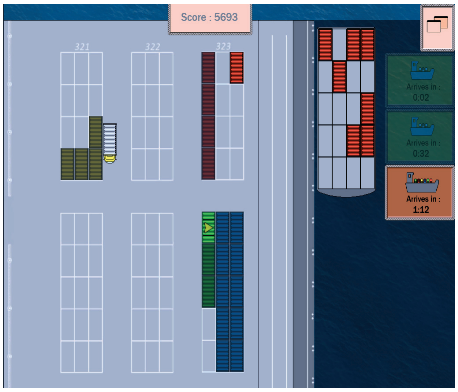



Figure 4.4: Planning mode of the YCS game

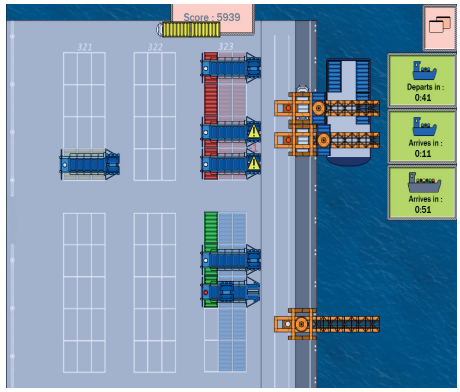



Figure 4.5: Operational mode of the YCS game

**Seaside/Quay side tasks**

The sea side or the quay side tasks in a terminal involve berth planning and allocation of QCs. Berth planning is the allocation of a berthing slot or a mooring slot and a berthing time window for arriving ships. The time windows and the mooring slots are pre-determined in the game. However players have to allocate QCs for every ship to load and unload containers on/off the AGVs.

**Yard tasks**

Players need to plan the location of the import containers in the yard for all the arriving ships. The arrival times are clearly indicated on the right hand side of the screen. The colour of the ship is matched with the containers that it carries. Players can click on each ship to enter the planning mode. To plan the containers they have to drag and drop each container and place it in the yard in any available space in the 6 container blocks. If the border around the ship symbol is red, the planning is not complete. If the border is green then the planning is complete. The choice of storage location for each container is an important decision that is dependent on several factors such as distance to the ship, position of the mooring slot of the ship, and the available resources. In addition to planning the location of containers in the yard, players need to allocate RMGs to storage spots of each of the unloaded containers. Export containers in the yard that need to be loaded onto the ships, are marked by an arrow symbol. They don't require location planning in the ship, as this part is automated in the game. The players should only allocate yard cranes, on top of these export containers for them to be picked up by AGVs towards the quay to the ships.

**Landside tasks**

Trucks arrive into the yard to collect yellow containers from the yard to transport them into the hinterland. Trucks can wait only for a limited amount of time in the yard. As soon as a truck arrives at a designated location for a pick-up, a timer starts running. Players have to make sure the required container is loaded onto the truck before a time out occurs.

We will now discuss the role and task variations for YCS3.

**YCS3**: YCS3 is similar to the single player YCS1 game in terms of layout and game play but has some variations regarding roles, especially that of the vessel planner. In YCS1, the role of the vessel planner wasn't visible to the player. In YCS3, the role of the vessel planner is to plan the unloading order of the containers. High priority containers have a gold label, medium priority containers have a silver label and low priority containers have a bronze label. The YCS3 games also doesn't have export containers and trucks that carry containers into the hinterland.

In the YCS1 game, the individual player could view all plans and operations of all the roles, whereas in the YCS3, each role has a different access to various planning and operational tasks. The berth planner can only access the quay cranes, while controller can only access the yard cranes. The yard planner can plan the containers from the ship on the yard, and vessel planner needs to decide on the order in which the containers need to be unloaded. The controller cannot allocate yard cranes if yard planner didn't make a yard plan, and the berth planner cannot unload the ships if the vessel planner hasn't allocated an unloading order. This aspect is illustrated in Figures 4.6 and 4.7.

In the next sub section we will introduce the accounting system of the game that contains information regarding scoring and other data that has been collected during the game sessions.

### Accounting system

All the tasks in the YCS1 and YCS3 games are interdependent. Even if one of the planning and resource allocation tasks is not complete a container cannot be handled, which is the case even in reality. Coordination and alignment of all these tasks is the main challenge for players. In order to stress the importance of alignment of tasks and integrated planning, and to represent the tangible effects on the performance of the container terminal, the scoring of YCS1 was

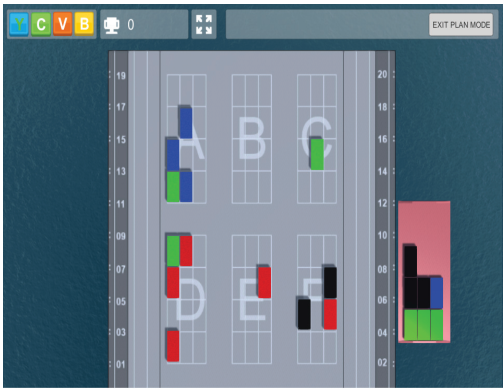
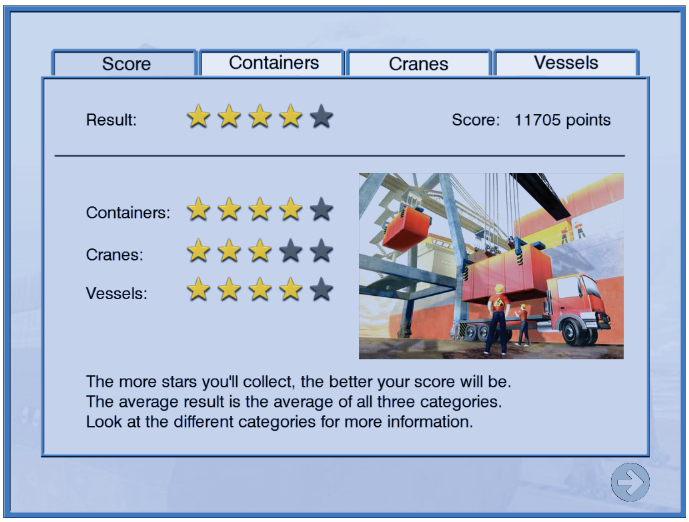



Figure 4.6: Planning screen of all players except vessel planner


Figure 4.7: Planning screen of vessel planner

designed in the following manner:

Figure 4.8: Screenshot of the score page of YCS1




- The game begins with an initial score of 1000 points. As shown in Figure 4.8 the score of YCS1 is broken down into efficiency of handling containers, cranes(resources) and vessels (ships), an unseen score is the bonus points award for the trucks picking up yellow containers. Based on the points received for the container handling, player receive stars. 5 starts indicate superior performance while 1star indicates poor performance.

- **Containers**.The number of containers handled within a time shift is very important for the overall throughput of the container terminal. Therefore in the game, 100 points are awarded for each container that is successfully handled, which means the container is loaded off a ship and placed in the yard and vice-versa. For every container that wasn't handled a penalty of 100 points is given to the player.
- **Cranes (Resources)**. Optimal resources utilization is very crucial for the performance of the container terminal. As discussed in the introductory section one of the issues faced by container terminals is the over utilization of some resources and under utilisation of some others. To emphasize this issues, for every resource (QCs, RMGs and AGVs) that is idle, 1 penalty point is given for every second it remains idle. If a resource is idle, then a yellow warning sign appears on top of the QCs and RMGs it to notify the player.
- **Vessels (Ships)**. Ship turnaround time is very important for terminal business, since customer satisfaction is heavily dependent on it. Therefore in the game, for every second the ship is handled earlier than the scheduled departure time, 100 points are awarded per container on the ship.
- **Bonus**. Efficient and timely transfer of containers onto the hinterland is critical to maintain smooth yard operations. Ignoring this would cause queues and jams outside the container terminal blocking entry and exit of containers. Therefore the trucks that arrive in the yard to pick up the yellow containers bound towards the hinterland need to be handled within the limited time span. For every truck that leaves the yard with a container the player receives 100 bonus points.

The overall score of the YCS1 is the sum of the scores obtained in handling the container, resources, vessels and yellow containers, including negative points for unsuccessful handling. In addition to these scores several aspects of the game are recorded in the form of the game variables, to understand the behaviour of the players. The full description of all the variables recorded in the game are described in Appendix G.

The scoring mechanism of YCS3 is very similar to that of YCS1. The bonus points for ship turn around time, and points for successfully handling the containers remain the same. The penalties for idle resources, late ship departures and unsuccessful handling of containers are also the same. However in YCS3, there is no yellow truck that arrives to pick up containers for hinterland transportation. Also there are no export containers to be loaded onto the ships.

We have described the key components of the YCS1 and YCS3 games. We can now finally move to the testing and validation stage in our design approach.

### 4.1.3 Testing and validation of the YCS games

We have discussed the importance of validation of simulation games used for research in chapter 3. We followed the validation guidelines of (Vissers et al., 2001) and Peters et al. (1998) who propose that validation has to be part of the design process instead of its final step. Their guidelines recommend the use of subject matter experts during design process and for evaluation. They also propose to evaluate the game against Raser (1969)'s criteria for validity—psychological, structural, process and predictive validity. Their final guideline is to test the game extensively and to incorporate the useful feedback into the game design as much as possible. We test the YCS games, especially YCS1 extensively.

Figure 4.9: YCS1 test session with transport experts from Canada

Figure 4.10: YCS1 and YCS3 test sessions with students

The YCS1 game has been played more than 12,700 times by student participants, and over 5000 times by professionals in the container terminal industry. Impressions of the testing sessions are shown in Figures 5.4 and 5.5. Although YCS3 has not been tested as extensively as YCS1, it was built on similar principles and game mechanisms so we extend the validity of YCS1 to YCS3.

Table 4.1: Expert profiles

| Role | Years of professional experience |
|---|---|
| GM, Terminal Operating Systems | 25 |
| GM Operations, Africa & Middle East | 20 |
| Managing Director- IT | 17 |
| Technical Project Engineer - IT - Marine Terminals | 5 |
| Consultant for the port industry | 3 |

The opinion of subject matter experts is very important to test the validity of simulation games. We sent an extensive survey (Appendix C) to five subject matter experts that played the YCS1 game extensively to test the psychological and process validity of the YCS1 game. The profiles of these experts are shown in Table 4.1. We will now compare the YCS games against Raser (1969)'s validity criteria.

**Psychological or face validity**

A simulation game should provide an environment that seems sufficiently realistic to the real thing (Raser, 1969). Our visual representation of the game was based on the design of the operations area of a container terminal. We have contrasted the screenshot of YCS1 to the top view of the quay and yard area of a real container terminal in Figures 4.12 and 4.11.

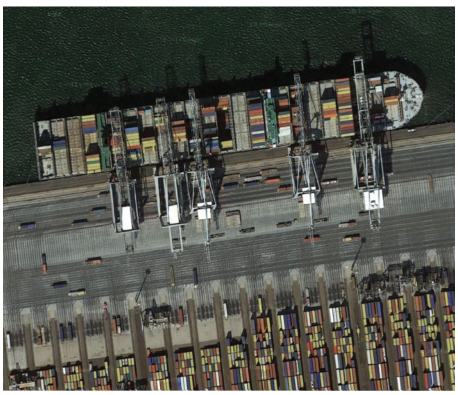


Figure 4.11: Top view of the quay and yard area of a container terminal


Figure 4.12: Screenshot of YCS1 game

We also asked the experts if they found the game sufficient realistic by keeping the game objective in mind (See Appendix C). Four out of five experts agreed that the reality of container terminal operations was sufficiently represented in the game. All five experts agreed that they could relate to the challenges in the game to those they encountered or observed in their real life experience. One expert noted the lack of disruptions that are fairly common in container terminals. We did not incorporate this suggestion for the YCS games to ensure their simplicity and brevity.

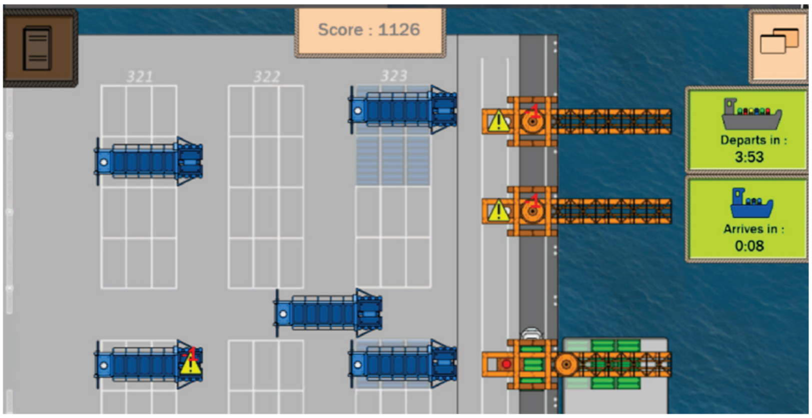
#### Process validity

The processes in the simulation game need to be isomorphic to those observed in the reference system (Raser, 1969). We asked the experts about the representation of processes, their interdependency and the way participants were scored to make a comparison with the real operations. We designed the processes based on the suggestions of subject matter experts in the game storm sessions. The final version was evaluated by a different set of experts in the field shown in Table 4.1. Four of the five experts stated that the processes in the container terminals were well represented given the time-frame of the game. All the five experts who evaluated the game stated that the interdependency in the processes has been well represented in the game. They all agreed on the scoring schema for containers, ship turn around time and bonus points for the trucks. All 5 experts disagreed on the negative points for idle resources and found it unrealistic. This evaluation was taken into account for the final version of the game where we weighed the benefits of removing the negative score. One of the purposes of the negative score was to test the SA of players regarding idle resources. Therefore, we decided to keep the negative score in spite of its artificiality since other aspects of the game were found to be sufficiently realistic. One expert suggested to add a rail and a gate to represent hinterland operations. Since this is out of our scope of container terminal operations we will use this for future research. Four out of five experts suggested that the game could actually be used for training employees and new recruits to train them for integrated planning operations. This shows their confidence in the representation of the processes in the game.

#### Structural or construct validity

Structural validity or construct validity is the degree to which a research instrument is isomorphic to the underpinning theory it seeks to assess (Raser, 1969; Salmon et al., 2009). Our simulation games aim at assessing SA.

Figure 4.13: Visual cues in the YCS1 game




We have already stated in chapter 2 that we have chosen Endsley (1995)'s three level model to represent individual SA and Endsley and Jones (1997)'s Shared SA model to represent SA in teams in socio technical systems. Therefore we will perform the construct validity of YCS1 with Endsley's three level model and YCS3's construct validity with Endsley and Jones (1997)'s model. We use Endsley (1995)'s 3 level model of SA to design our SA measure at the individual level. To prove construct validity, we will explain how we designed the game in accordance to the 3 SA levels of Endsley (1995)'s model— perception, comprehension and prediction. To facilitate the perception among the players, several visual cues as shown in Figure 4.13 are incorporated in the game. The arrival and departure of ships are shown as count down timers, warnings for idle resources are shown as yellow warning symbols, the colour of ship turns green once all containers are planned. Resources have a red dot on them if they are busy. In addition to these visual cues, sounds indicate loading and unloading operations and departure of ships. Players can perceive the status of the container terminal operations using these cues. The next stage is comprehension. Using these visual cues, players need to understand , what is the best course of action— for e.g. to reallocate a idle resource to a busy row in the yard, prioritize ships that have short waiting times. The final stage is prediction. The players should be able to predict the consequences of their actions, and should already prepare to change their plan if things don't go according to plan. At the individual level the YCS score captures the 3 levels of SA. The overall score is a reflection of the ability of a player to have the 3 levels of SA while making planning decisions in the YCS games.

At the team level, Shared SA model of Endsley and Jones (1997) states the importance of communication, information sharing, coordination, shared displays, and a shared working environment. The game is designed such that players have to be co-located and sit around a table to play the game which ensures a shared work environment. The players also have a shared display of sorts. The overall operations are visible to all players but individual planning process are only visible to the respective players. In the YCS3 game, players need to provide accurate and precise information regarding vessel unloading orders, location of containers, position of cranes under time pressure. All the tasks in YCS3 are interdependent so players should be aware of which players needs what information at what time. This means they have to share the right information at the right time to the right person to align and execute their plans successfully. This is an essential characteristic of collective SA of a team (Endsley et al., 2003).

**Predictive validity**

The simulation game should have the capacity to make a good estimate of what it theoretically intends to predict (Raser, 1969). Our prediction is that higher performance in the simulation game is an indicator of higher SA of an individual and team. We know that this is not always the case, and many other factors can contribute to higher or lower SA score. Therefore when we use a simulation game to measure SA, we have to be confident that higher SA indeed predicts higher performance or vice versa. This is the essence of the predictive validity. This can be done by correlating the game score with that of any other standardized SA measurement technique (Salmon et al., 2009). We chose to use Situation Awareness Rating Technique (SART) as an alternative SA measure for comparison. To check the predictive validity we tested the game with twenty two game design students in a technical university in the Netherlands.

The SART questionnaire as described in Appendix E consisted of 5-point Likert-scale questions, including a self-rating technique on SA, was answered by participants after playing a YCS game session. The SART measurement of SA consists of three aspects— Understanding of the situation (U), Demand of the situation (D), and Supply of information (S). The overall SA is calculate using the formula Situation Awareness, SA = U-(D-S) Althought the original SART had 10 questions, we adopted our questionnaire from the well cited work of Salmon et al. (2009), who do not measure information quality the SART questionnaire.

We found a significant positive correlation between the SART results and YCS score of participants with a background in supply chain, logistics and transportation (Pearson's $r = 0.338$, $p<0.01$, $N=22$). This indicates that students that achieved better performance in the YCS game had higher Situation Awareness.

Based on the above discussion we can conclude that the YCS games has performed well against the validity tests and can be considered to be reliable measures of SA in container terminal operations.

In the next sub-section we will discuss if the elements of reality, meaning and play of the triadic game design philosophy have been balanced in the games.

## 4.2 Reflection on the design cycle of the YCS games: Balancing reality, meaning and play

The yard crane scheduler games were designed, developed and evaluated together with a professional game design company and a consultancy for the container terminal industry. The research objective was quite clear already in the first game storming session because the experts from the consultancy substantiated it with the real world problems in the container terminal regarding lack of awareness and a holistic picture of integrated planning operations among the planning departments in container terminals. The first prototype of the YCS1 game was developed within two months after a few follow up meetings regarding the processes and roles in the container terminals. The first prototype was already quite satisfactory in terms of reality, meaning and play. We tested the prototype with students and experts. The following versions of the game were made to incorporate suggestions from expert validation and testing to reduce technical glitches, improve visualization and improve the scoring system. Given the single player nature of the game, balancing the game and designing the scoring system to capture the various game metrics was relatively straight forward. The most challenging aspect of the game development was the design of the data collection and storage mechanism to perform controlled studies. The game developer designed an online portal exclusively for our research project where a participant can login with credentials provided by the researcher. The platform could host several games, and can incorporate surveys, briefing and debriefing materials. The researcher also had control over the visibility of the games, scoring and widgets in the portal. The data from a gaming session is saved in an online database that could be downloaded by the researcher in the form of a spreadsheet.

After YCS1 was tested extensively and used to study SA in individual actors, we developed YCS3 as a multi-player extension of YCS1. Although the game concept was very similar, we had to surpass several design challenges for YCS3. One of the main issues was related to the balancing of the game to allocate equal number of tasks to all roles while making realistic assumptions on the processes and tasks in the game with respect to the actual ones in the container terminal operations. In the first prototype of YCS3 only the berth planner and yard planner had most of the tasks that meant the players donning the roles of vessel planner and controller had few tasks, so the game was not interesting for them. In the following prototype we reduced the roles to three by combining the roles of vessel planner and controller but with further consultation with experts we found that it was not realistic. So we had to redesign the game, slightly different from YCS1 to increase the tasks of vessel planner and create dependencies between players that is more aligned to real world operations. YCS3 faced several and severe technical problems. The game designer was an expert at developing single player game, so the multi-player game posed several technical challenges that were hard to solve by the game designer. After five iterations and redesign cycles we had a playable, realistic and meaningful YCS3 game. The data collection regime of YCS3 was similar to that of YCS1 since YCS3 could also be hosted in the online portal used for our research purposes.

YCS1 will be used in Chapter 6 to study SA, and factors affects SA and decision-making of individual actors while YCS3 will be used in Chapter 7 to study the same topic within teams in the context of intermodal operations in container terminals.

In the following chapter we will introduce the third and final game of this research project— the disruption management board game.

CHAPTER 5

# DISRUPTION MANAGEMENT BOARD GAME: DESIGN AND EVALUATION OF THE MULTI-PLAYER TABLETOP BOARD GAME

In this chapter we will explain the design and evaluation process of the board game that was developed for this research work. Similar to YCS1 and YCS3 we will follow the design approach described in Chapter 3 to introduce the the design, development, validation of the game.

## 5.1 The iterative design process of the disruption board game

### 5.1.1 Game requirements

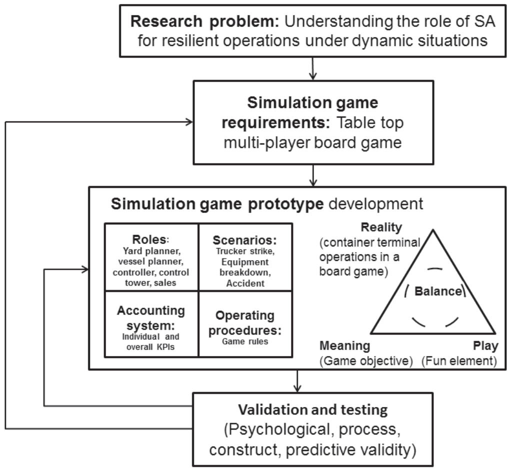
The disruption board game was developed to understand the decision making of actors involved in operational planning in container terminals under dynamic situations. The researchers will use the disruption game to study the effect of SA on the operational resilience of teams and groups within complex systems when faced with unexpected disruptions. The target participants of this game are academic researchers, students and professionals in the transportation, logistics and supply chain domain. We have already discussed in Chapter 2 that teams or groups that function from the same location have several characteristics including a shared physical environment, presence of non verbal communication, and social cohesion. We decided on a table top board game format because it can represent these characteristics (Magerkurth et al., 2004; Shaer and Hornecker, 2010).

Tabletop board games can provide rich social situations because players usually sit together around a table and can look at each other to interpret mimics and gestures which may help them understand each others' actions even without verbal communication (Magerkurth et al., 2004). The social cohesion is also prominent since they may laugh together or confront each other based on the decisions made during the game play (Magerkurth et al., 2004). Tabletop games usually require a game master, who steers the gaming with a dynamic form of story telling making the game reactive to the decisions of the players in a fun manner (Tychsen et al., 2005). The main objective of the board game is to represent dynamic situations in a container terminal. We have already discussed in Chapter 1 that socio technical systems are characterised by uncertainty, vulnerability and dynamism. We represent these characteristics in the game by scenarios in the game that disrupt the normal flow of operations in a container terminal in an unexpected manner. The decision making of the players who assume the roles of planning personnel that have to manage the disruptions at varying SA configurations will be studied using this game. Additionally, the processes and factors affecting their decision making will also be reported after analysing the board game play sessions. The iterative game design process below will describe the development and contents of the disruption board game in detail.

### 5.1.2 Game prototype development

We started the design of the board game using knowledge from literature study and brainstorming sessions with three subject matter experts in the container terminal business. Based on this, we synthesized the various disruptions that can affect container terminal operations. Then we had to translate the management of these challenges under different SA configurations to contextualize the game play. The development of the game took over 8 months since it was an iterative process with design, evaluation and validation cycles. During this process we discarded four game prototypes because the right balance between

Figure 5.1: Design approach specific to the disruption management board game




reality, meaning and play wasn't achieved.

In this chapter we will discuss the final version of the board game that was deemed satisfactory to study SA in container terminal operations without losing the element of playability. The final version is a 5-player tabletop board game set in the ambience of a container terminal configurations. We will now describe the various game elements based on the design approach (Figure 3.5) version specific to the board game in Figure 5.1.

### Roles

The roles in the board game are somewhat similar to the roles of YCS1 and YCS2 although there are additional roles of control tower and sales manager. The main reason to incorporate these extra roles in the game is to add an additional layer of realism where different departments within an organization have different priorities and goals. Therefore each of the roles has to not only work towards the organizational goal but also maximise the performance of their own role. This makes decision making more complex due to the need for trade-offs, deliberation and negotiations. The key roles in the disruption board game are:

- **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

- **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.[1]

- **Resource planner or Controller** has to reserve the required equipment and manpower for the operations planned by the yard planner and vessel planner. He/she 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

- **Control tower operator** has to monitor the planning and operational activities of the terminal. He/she has to keep track of all operations on the container terminal, and has to give permission for operations that violate existing plans

- **Sales manager** is responsible for the booking of containers that the terminal handles and for financial transactions between the clients and the terminal. He/she 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 roles described above have to operate under different scenarios that unfold during the game. These scenarios are described below.

### Scenarios

The game consists of three key scenarios that are interwoven in the game play. The game begins with one of the scenarios, while a new scenario unfolds at a different level of the game play.

[1] Additionally, the role of berth planner has been integrated into the vessel planner in this game. Berth planner is responsible for deciding the mooring slot and time slot for the ships at the quay (sea-side) where they can be served with a planned number of quay cranes. This decision was made because for better playability. On this regard, we consulted two subject matter expert from a port operations consultancy firm and they agreed that this decision was not very unrealistic.

1. **Equipment failure**. An AGV (Automated Guided Vehicle) breaks down in the container terminal. The operations cannot continue until either the AGV is repaired/removed from the location or an alternative path is designed for rerouting. The cause is unknown and needs to be investigated. Equipment failures cause operational backlogs and queues. The situation is critical with respect to terminal safety since repairs in automated areas are dangerous due to the presence of heavy unmanned vehicles. Therefore such areas need to be cordoned off before a repair crew is dispatched there.

2. **Accident in the terminal**. A worker has been injured in an accident, and all the operations of the terminal are shut down until the whole situation is assessed. Operations of the terminal are seriously affected by such a disruption, as a safe operating environment needs to be established again, operational efficiency has to be improved to account for backlogs, while not making customers wait too long. Customers also need to be informed properly regarding the possible delays and related consequences due to the disruption.

3. **Truckers' strike**. This is the most severe of the disruption scenarios as it creates the most ripple effects in the transport network. Truckers are external stakeholders consolidated by a strong union. They announce an indefinite strike to improve their working conditions and wages. Trucks are crucial for hinterland transportation. A strike could mean that containers pile up in the yard and that the terminal has to look for alternative ways to transport the containers. It is obvious that operational efficiency and customer satisfaction are affected, but safety is also affected because the high workload and stress, and adoption of alternative methods of transportation could create confusion and chaos in the terminal, which in turn affect the safety of the operating environment. The degree of severity implies event complexity. As each disruption unfolds, participants need to manage many more operations, and process more information from different sources.

The various rules and scoring system of the game related to the decisions that need to be taken by the roles described above for mitigating the various scenarios are described below.

### 5.1.3 Operating procedures and accounting system

The disruption board game begins in a 'business as usual' situation. When the game unfolds, disruptions start occurring that drastically affect individual operations as well as the operation of the entire organization.The unfolding of the game is modelled using the concept of rounds. With each round, the event complexity increases and disruption situation escalates, unless some action by the players is taken. Five rounds make one level. Each level is used to represent different levels (individual, shared and distributed) of SA to study their impact on the decision making process. At the end of each level, the disruption situation further escalates as a new disruption occurs. Every player has an individual score and the organizational scores are represented by three Key Performance Indicators (KPIs) that are safety of the terminal operations, customer satisfaction and performance or profitability of operations. The organizational game board illustrated in Figure 5.2 will be placed in the centre of the table visible to all participants. Each of the participants has their individual game board, an example can be viewed in Figure 5.3. At the start of the game, all the individual and organizational scores are set to a maximum score of 10 points. The scores decline after every round, and can only be increased by mitigation actions of participants. In each round, every player receives exclusive information in the form of information cards, which he or she could choose to share with other players during the game play. Through these cards information can be exchanged using e-mail, phone, or a conference call. Limited tokens are given to each participant. These tokens need to be 'spent' to communicate using information cards. Compared to a phone call, e-mail costs fewer tokens but has a lower chance of being read immediately. The chance is determined by a throw of dice. After the players finishing sharing information, they can choose to use one of their action cards or the joker card to mitigate the situation based on the information they have. For each round every player has 2 decision options (A or B) in the form of action cards to mitigate the escalating situation. Every player also has a 'Joker' card option which can only be used in the place of options A or B. The joker card always offers a better alternative to options A and B, but can only be used once during the game play. Therefore players need to be strategic about the timing of its use. The effects of disruption on the system have been modeled as the game scores or KPIs (Key Performance Indicators). Examples of action cards include "Cordon off the automated area until the repairs are done"; "Call the ambulance to attend for the injured"; "Organize alternative transport options for the containers" etc.

The action cards are designed such that they will increase one or more or-

Figure 5.2: Disruption board game example contents

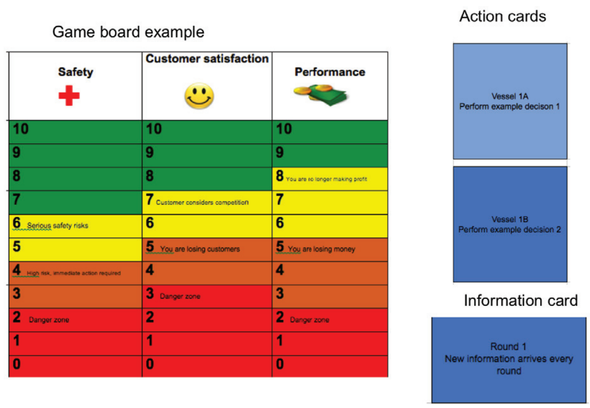
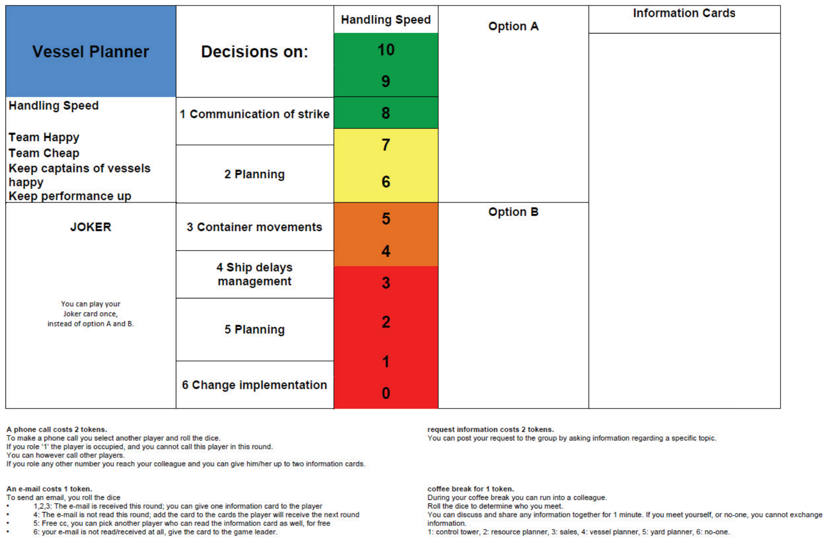



Figure 5.3: Individual game board example




ganizational KPIs (safety, performance and customer satisfaction shown in Figure 5.2) and decrease the other(s). Referring to the example action cards, the cordoning off action increases the safety of the operations but the productivity of operations is negatively affected. Therefore the profitability reduces together with the customer satisfaction because customers may face delays due to reduced productivity. The organizing alternative transport option increases customer satisfaction but reduces the terminal profitability. Players have to make a trade-off to make sure all the three organizational KPIs are balanced. In order to make the 'right' decision and 'win' the game, participants need to manage information, communicate and coordinate if necessary, monitor the effects of disruptions and take the right decisions at the right time to mitigate the negative effects on all the three KPIs. The organizational score increases or decreases based on the individual scores. An MS Excel based scoring model has been designed to compute various individual and organizational scores for various decision options. 5 rounds constitute one level. In every successive level of the game a new disruption unfolds in addition to the existing disruptions creating an even more complex scenario for information exchange, coordination, effect control and decision-making.

The summary of the rules and scoring:

- There are individual game boards for each participant as well as an overall game board for the container terminal system with KPIs, containing varying information and rules based on the level of the game play
- The KPIs are all maximum at the start of the game, they decrease after every round, and can be increased by the right decisions of the participants on the mitigation actions
- Participants have information cards as well as action cards, the former used for communication, the latter for performing mitigation actions
- Communication can be done via e-mail or phone, or as a conference, with differing effectiveness and costs. Tokens are given to participants, which need to be used to communicate. This shows that communication costs time and resources.
- The information cards contain details about the disruption. After a round of information sharing decisions need to be taken by the participants on the mitigation actions
- Mitigation/ action cards vary for each round in every level. They contain 3 choices from which participants need to choose one mitigation action card
- Based on the actions of the participants scores are altered at the end of every round

The roles, scenarios, operating procedures and accounting systems described above were finalized after several iterative design improvements of the board game. In the following sub section we will discuss the testing and validation of the game.

### 5.1.4 Testing and validation of the board game

Figure 5.4: Board game session with students in the United States

Figure 5.5: Board game session with transport experts

The disruption management board game was tested in several academic and professional settings. The participant profile and related institutions are represented in Table 5.1. The researchers from the technical university in the Netherlands were used mostly for prototype testing. The professionals and the American university students were used to test and validate the final version of the board game. The issues faced by these participants were observed and the game design was further updated twice based on the feedback from these sessions. We reflect on this design process at the end of this chapter.

#### Psychological or face validity

We used a post-game survey (shown in chapter D) to validate the board game as a valid research instrument with experts from the container terminal industry. We chose five experts with varied levels of work experience to answer the survey. The profiles of the experts are listed in Table 5.2. Four out of five experts agreed that they could relate well to concepts and disruptions presented in the game to their real life professional experience. One of the experts also commented that the goals of the game as well as the actions in the game are close to reality. The roles in the game were already face validated based on literature studies.

Table 5.1: Overview of the test sessions with the board game

| Number of participants | Participants' profile | Location | Type of data from the session |
|---|---|---|---|
| 15 | Academic researchers and students | Technical university in the Netherlands | Observational data |
| 30 | Professionals from transport and supply chain industry | Conferences organised by the Dutch Institute of Advanced Logistics | Observational & survey data |
| 80 | Undergraduate, master and graduate students majoring in supply chain, logistics and transportation | Business school in a large American university | Observational & survey data |

**Process validity**

We designed the processes in the board game based on literature review on terminal operations and consulted five experts in the container terminal business. Communication and information sharing under time pressure and limited resources have been modelled in the rules of the game. The interdependencies between various planning departments have been modeled in terms of scores. The mitigation actions of participants not only affect their individual KPIs but also affect, either positively or negatively, the KPIs of other players. All the individual KPIs contribute to one or more of the overall KPIs of the container terminal. The game is designed such that strategic decisions need to be made on operational problems. Therefore the processes of container terminals are not visible during the game play. Additionally, there is no 'right' or 'wrong' decision. We modelled the decisions such that they improve one KPI while sacrificing the others. This decision not only introduces a dilemma during the decision making during the game that enhances the playability but it is also makes the decision making more realistic. We wanted to make sure that the decisions modelled in the game are relevant in the real world. When we checked this aspect in our expert survey, all the five experts from the validation survey stated that the learning principles of the game regarding decision making during disruptions can be helpful to handle real world disruptions. This shows that expert trust in the process validity of the game.

Table 5.2: Expert profiles related to the board game validation

| | Age | Gender | Profession | Experience |
|---|---|---|---|---|
| **Expert 1** | 40 | Male | Researcher, Maritime logistics | 16 |
| **Expert 2** | 33 | Male | Project manager, Container terminal | 8 |
| **Expert 3** | 26 | Female | Consultant, Logistics at TNO | 3 |
| **Expert 4** | 26 | Male | Event coordinator, DINALOG | 2 |
| **Expert 5** | 23 | Female | Intern, Consultancy for container terminals | 1 |

**Structural or construct validity**

The disruption management board game has been designed to study the role of SA in decision making during dynamic situations in container terminals. The game is designed such that it can be played at an individual, shared SA and distributed SA levels. Communication, information sharing mechanisms and the type of game boards can be changed to created these SA levels. The formation of shared mental models in the 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. In the Shared SA mode the individual KPI scores and the team score can be viewed by all players. Mitigating each disruption needs a careful alignment of tasks between the five players. If certain steps are skipped, or necessary information is 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.

In the distributed SA version of the game, players cannot see the scores of others through the game board, and as a result there is more emphasis on the individual scores. Distribution is implemented by giving different players different pieces of information (through game cards) about the disruption, which other players cannot see. 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. 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 costs attached to communicating. Players have only 10 tokens each, which makes communication much more of a burden.

**Predictive validity**

Measuring SA in a collective environment is complex (Salmon et al., 2009). We did not conduct predictive validity for the disruption board game because the game was designed to observe how teams and groups balance their KPIs, and not focus on a single winning strategy. Therefore we couldn't run a meaningful predictive validity test due to this characteristic of the scoring mechanism of the board game.

Based on the evidence from the testing and validation process we argue that the disruption board game can be used to study SA in team and group settings. The subsequent chapter is based on the disruption management board game, where we used it to study the decision making of actors within teams and groups of a container terminal. We will now conclude this chapter by reflecting on the design cycle of the disruption management board game.

## 5.2 Reflection on the design cycle of the board game: Balance between reality, meaning and play

The research objective of the disruption management board game was to study the effect of various SA modes (individual, shared and distributed) on the decision making and performance of socio technical systems under dynamic situations. In our context the dynamic situations are disruptions to the operational processes of a container terminal, that is an example socio technical system. We had to shelve two prototypes before finalizing the final game that is described in this chapter.

For the first prototype we defined the roles in the game based on literature review and consultations with experts in the container terminal business. We searched newspapers and consulted scientific and technical journals for real world disruptions related to container terminals operations. We found many examples and chose trucker's strike, accident, and AGV break down because they represent various level of severity. The design of the first prototype was similar to the final version, only that we provided 10 information cards and 10 action cards per player per round. To model the interdependencies we made the action cards dependent on each other— that means a player could not take an action if another player did not take a particular action card. The idea behind these design choice was to make the decision making processes as realistic as possible. We tested the game, but realized that it was very complicated for the players to understand the game mechanics and rules. The dependency between the action cards made many players idle because they couldn't play unless another player completed a particular action. We noted the scores manually and recited them to the players since there was no common game board. Additionally we noticed that the number of information and action cards created a large cognitive overload for the players and they lost the overview of the game. It was also not very 'fun' to play the game because the processes were extremely slow and complicated in the first prototype. Based on this experience we decided to reduce the number of action and information cards to five per player per round. We also introduced a spreadsheet to visualize the scores, that was projected on a wall where the game was played. The game master would enter the scores based on the actions of the players which was visible to everyone. When we tested this version, we found that although the complexity of the game reduced, it was still very complex for the participants to understand the rules easily. We also noticed that 'fun' element fo the game did not improve compared to the first prototype. The spreadsheet did not add value to the game play, and proved to be a hindrance because the game master would spend a few minutes after every round updating the spreadsheet which provided very little information while creating a lot of idle time for the participants.

In the first two versions we focussed too much on the reality and meaning of the game and missed the playability element. This made the prototypes very complex. Therefore in the final prototype, we further reduced the complexity by providing only two action cards and one information card per round. We modelled the interdependency between terminal processes in terms of scores, i.e, the action of one player can affect the score of another and vice versa. To add an additional action card and increase the 'play' element of the game we added a 'Joker' option. We also introduced objects like dice, communication tokens to create a ’fun’ environment. We also introduced individual and joint game boards and simplified the scoring systems instead of the spreadsheet. Pawns were placed on the game boards and the game master could change the scores easily using the pawns based on the actions of the players. When we tested this version of the game, we found that the participants had a very positive game experience. They understood the game objective very well after playing one or two rounds of the game and enjoyed playing the game. Therefore we finalized the third prototype to be our research instrument to study the role of SA in decision making under dynamic circumstances in container terminal operations.

We have already discussed in the earlier section that the game was tested several times and validated and became successful in achieving its’ objective.

Although the game was well received by both students and professionals in the supply chain, logistics and transportation business, it has a few limitations. The game master or the game facilitator has an critical role in the game play. He/she is the ’game engine’. This means a game facilitator should have a thorough understanding of the game and needs to be present always to steer the complex game processes. The evolution of the scores during the game is not traceable. The game master has to rely on memory or observer notes for debriefing. The board game requires all players to be present in a single room. While this fosters a common game experience, it imposes an unrealistic situation, as in reality the different persons could be distributed across the container terminal. The board game also presents scalability and portability issues. It is difficult to collect a large amount of data using the board game. Also modifications are hard to implement in the board game version. In future, we would like to transfer the board game to a scalable digital version.

Based on our experiences with the design cycle of the board game we can conclude that designing and testing a ’fun’ simulation game is very challenging and labour intensive.

*(Parts of this chapter have been extracted and adapted from Kurapati et al. (2015) and Verbraeck et al. (2016))*

Chapter 6

# Factors affecting SA and task performance in container terminal operations: An empirical study with the YCS1 game

## 6.1 Introduction

This chapter focusses on the individual SA and performance of actors in an operational situation in a socio technical work organization represented by planning operations in a container terminal.The study of individual task performance in these complex systems, involves analyses of the processes that underlie the acquisition, maintenance and transfer of skills required for a certain task (Adams et al., 1995). We have already established in Chapter 2 that SA plays an important role in this process from the perspective of naturalistic decision making. However, one of the major challenges faced by SA researchers, is to prove that improvement in task performance is actually the result of better SA of an individual actor because there are several factors that could influence SA and subsequently the task performance (Adams et al., 1995). Therefore we will explore the influence of four factors (multi-tasking ability, personality type, gender and culture) that are related to the characteristics of socio technical systems on SA and task performance. Within our research context this will be planning task performance in container terminal operations. The objective of this chapter is three fold– firstly to understand the effect of multi-tasking ability on SA and task performance, secondly to understand the moderating effect of personality type on the relationship between multi-tasking ability and task performance and finally to explore the role of gender and culture in task performance in socio technical systems, within the context of container terminal operations. These objectives fall within the individual SA configuration of the framework described in Chapter 2

We will begin the chapter with the research motivation to study these factors followed by the research design and methodology. The main research instrument of this study is the YCS1 game. We have already discussed in chapter 4 that we will use YCS1 as a performance measure to study SA in container terminal operations. The score of YCS1 represents the task performance of an individual actor that corresponds to the SA of the actor. We have validated YCS1 to be a SA performance measure in Chapter 4. We also used Multi Attribute Test Battery (MATB-II) software to measure the multi-tasking ability and TIPI questionnaire to measure the personality type. Gender and cultural identity were captured in a pre-game survey. We will describe the research instruments in detail. After outlining the design and execution of the gaming sessions using the research instruments we will present the results related to each of the factors. We will conclude the chapter with a discussion on the results with directions towards future work.

## 6.2 Factors affecting individual SA: Multi-tasking ability and personality type

We have already established in chapter 1 that container terminals can be categorized as socio technical work organizations. Operations processes in container terminals are complex, dynamic, inter-dependent, and technology dependent (Murty et al., 2005). Container planning is the main logistical operation in a container terminal and requires the combined use of expensive resources like cranes, terminal equipment, and manpower (Legato and Monaco, 2004). Employee performance has always been the backbone of container terminal productivity (Legato and Monaco, 2004). The three broad categories used for assessing job performance are task performance, contextual/citizen performance, and counter productive behaviour (Rotundo and Sackett, 2002). Task performance encompasses all the formally recognized activities related to a certain job that contribute to the organization's technical core. In other words, all job related activities that lead to increased production of goods or provision of services. The contextual or citizen performance relates to the interpersonal behaviour within teams or at social situations at work. Counter productive behaviour consists of all activities that compromise the integrity of the organization (Rotundo and Sackett, 2002). In our study we will limit our focus to only task performance in container terminals.

Individual employees represent individual actors within the socio technical work organization context of a container terminal. Container terminal employees can be categorized into two categories— ground workers and core workers (Legato and Monaco, 2004; Turnbull and Weston, 1993). Typical ground workers are crane operators, checkers, deck men, straddle-carrier drivers, terminal truck drivers, and raisers while core workers are responsible for planning containers, allocation of resources to execute the planning and general management of the container terminal (Legato and Monaco, 2004). Until the advent of automation, employees of the terminals were usually responsible for a single main task, depending on their experience and skills (Legato and Monaco, 2004; Turnbull and Weston, 1993). With the adoption of modern and automated cargo handling systems, the tasks of the ground workforce are largely automated. This lead to the convergence of the ground and core workforce, creating a dire need for a renewed workforce that has to handle multiple tasks and needs to be well-trained and skilled to run the terminal (Turnbull and Weston, 1993). Task performance in such a complex environment constitutes performing adaptive tasks that can be characterized by the following activities (Mavor et al., 1998):

- Assessing the current situation,
- Activating new tasks in response to recent events,
- Assessing task status to verify whether each task is being performed well,
- Terminating tasks with achieved or unachievable goals,
- Assessing task resource requirements,
- Prioritizing active tasks,
- Allocating resources to tasks in order of priority, and
- Updating the task agenda.

The adaptive task performance falls within the naturalistic decision making process of Klein (2008). It can be observed from the above activities that task performance requires task switching, prioritizing, and resource allocation that are part of the container planning operations in (semi) automated container terminals (Meisel, 2009). The challenges of handling these tasks and adapting to rapidly progressing port technologies put a lot of pressure on employees while the skill-set and attributes of employees required for superior task performance have not been well explored (Notteboom, 2012)

In such complex environments we have already discussed the role of SA on task performance. Factors like workload and job stressors affect SA and consequently the job performance. Although Endsley (1995) found that SA can significantly improve the performance of the operator, she agrees that the relationship between SA and performance is not direct in any system. Higher SA will significantly increase the probability of good performance but doesn't guarantee it (Endsley, 1995). A number of physical, cognitive, personal, environmental factors affect SA, that in turn affects the performance of an individual in a system. A full list of these factors and their effects in unavailable, although some factors have been identified (Endsley, 1995). The main individual factors that affect SA that are workspace design, complexity of tasks, workload and stress, multiple tasks for a role, personality, previous knowledge and subject expertise, attention, working memory (Endsley, 1995). Some of the well researched factors are attention, working memory, workload and workspace design. However, most of the findings are theory based, and lack strong empirical backing (Adams et al., 1995). This is mainly because human factors researchers focus on technical solutions towards improving task performance like improving user interfaces, providing better visual cues without focussing on the personal and social context of the individual actor (Moray, 2000). Also, the impact or role of situation awareness and factors that affect SA and task performance in the operations phase of socio technical systems remains largely unexplored (Carayon, 2006). This also holds true in the context of container terminal operations because we haven't found research that studies SA and task performance in container terminal operations to the best of our knowledge.

In this chapter we will study four personal and social factors pertaining to individuals— multi-tasking ability, personality type, gender and culture that represent several aspects of socio technical systems. We will shortly describe the motivation to study the role of these factors on SA and task performance in socio technical systems.

- **Multi-tasking ability** represents the complexity of tasks within a socio technical work organization. The increasing adoption of Information and Communication Technologies (ICT) since the 1990's has made multi-tasking indispensable at the workplace (Appelbaum et al., 2008). Computer-based multi-tasking skills in particular have become a prerequisite for most job descriptions. Organizations find multi-tasking a highly desirable skill in prospective employees (Adler and Benbunan-Fich, 2012; Appelbaum et al., 2008). Since all planning tasks in a container terminal are supported by ICT, we focus our interest on computer-based multi-tasking. In our research context, multitasking is defined as the ability of an individual to perform several independent yet concurrent computer-supported tasks (Adler and Benbunan-Fich, 2012). The degree of concurrence varies between sequential, parallel, and interleaved type of tasks. Sequential tasks have almost zero concurrency, but they set the base line for multi-tasking. Parallel tasks represent true multi-tasking, but humans are not able to fully divide their attention to perform different tasks in parallel (Adler and Benbunan-Fich, 2012). Interleaved tasks best describe human multi-tasking, where attention to one task is temporarily suspended to allocate attention to the other tasks (Salvucci and Taatgen, 2010). In this way the originally task is resumed, after briefly being abandoned, after the user attends another task (Salvucci and Taatgen, 2010). This is supported by Oberauer and Kliegl (2004), who state that human cognitive processes do not allow for parallel cognitive operations, and by Ophir et al. (2009), considering simultaneously performing multiple tasks a challenge for human cognition. In our research, we consider multi-tasking to be interleaved. Although multi-tasking is a highly valued skill in organizations, its effect on SA and performance has not been established thoroughly. Studies on this topic are limited and the available evidence is inconsistent and contradictory (Adler and Benbunan-Fich, 2012; Appelbaum et al., 2008). Therefore we will study the effect of multi-tasking ability on SA and task performance in container terminal operations.

- **Personality type** signifies individual differences among individual actors that could affect their decision making and task performance in socio technical work organizations. Personality can be defined as "the sum of physical, mental, emotional and social characteristics possessed by a person that uniquely influences his cognitions, motivations, and performance in any environment" (Othman et al., 2012). The Big Five model is the most validate theory of personality type and constitutes the degree to which every individual varies within the following five traits: (Goldberg, 1990).

1. Extraversion: An individual scoring high on extraversion would typically be quite talkative, assertive, sociable, adventurous, energetic etc.;
2. Agreeableness: An agreeable person can best described as good natured, generous, tolerant, honest, courteous, etc.;
3. Conscientiousness: Individuals with high conscientiousness are usually orderly, consistent, responsible, mature, sophisticated, formal, reliable, dependable, etc.;
4. Emotional Stability: Individuals with high emotional stability are typically calm, callous, poised, self-reliant, etc.;
5. Openness to Experience: Individuals who are more open to new experiences are usually creative, original, curious, artistic, imaginative, independent, etc.

Personality type is seen as a very important behaviour moderator of employee performance in organizations (Mavor et al., 1998; Jex, 1998). Direct effects of personality have been studied since the 1960s, although the prediction of job performance using personality type has been long debated (Penney et al., 2011). However, a multitude of empirical studies strongly supports the predictive capability of the Big Five model of personality with respect to job performance (Hurtz and Donovan, 2000). Personality type remains to be a very important influencer of employee behaviour and task performance in the workplace (Othman et al., 2012; Penney et al., 2011). However the role of personality type on SA and task performance has not been studied extensively especially in the context of socio technical work organizations like container terminals. As discussed earlier, although the direct effects of personality on job performance have been debated (Penney et al., 2011), researchers agree that personality type influences the performance of individuals in a given environment (Penney et al., 2011; Hurtz and Donovan, 2000; Othman et al., 2012). A moderating variable is a quantitative or a qualitative variable that affects the strength and direction of the relationship between two variables. Therefore we are very interested to understand both the direct and indirect effects of personality type task performance in container terminal planning operations.

- **Gender and culture** form a major part of the heterogeneity attribute of socio technical systems. The participation level of women in the work-force has been unprecedented. Men and women have very different relationship and experiences with technological tasks (Williams and Edge, 1996). The basis for traditional division of labour with men in leading roles in technological work environments is not scientific (Williams and Edge, 1996). There is limited empirical research on gender differences and task performance in socio technical work organizations (Williams and Edge, 1996). Similarly socio technical work organizations have employees with different cultures, backgrounds and values that adds to the heterogeneity of the organization (Carayon, 2006). Gender and culture are important social factors that influence the way a technical system is designed and operated (Williams and Edge, 1996). However there is a deficiency of studies that explore the role of gender and culture in the operational phase of socio technical systems to understand their influence on SA and task performance. We will explore the role of these factors on the task performance in container terminal operations in our study.

We will now describe our research design and methodology towards studying the role of the above factors on SA and planning task performance in container terminal operations.

## 6.3 Experimental design and set-up

### 6.3.1 Participants

Our research population consists of bachelor and master students specializing in supply chain, logistics and transportation in the Netherlands and the United States. Our experiments have been conducted in a controlled setting, with classes of 37 bachelor and 96 master students from the Transport and Logistics domain, from Universities in the Netherlands and the United States. The nationalities of the students included Dutch, Chinese, American, Indian, Finnish, German, Greek, Columbian, Costa Rican, Taiwanese, South Korean, Syrian, Vietnamese, Pakistani and Ecuadorian. We assume that these students will be future professionals in the supply chain, logistics, and transportation field and believe that they will encounter similar complex planning issues like container terminal planning tasks in their future jobs. 68 students were male, and 65 students were female. 41 additional students participated in a pre-test of the experimental session. Their results were excluded from the reported data. We assume that these students will be future professionals in the supply chain, logistics and transportation field and believe that they will encounter similar complex planning issues like that of port planning in their future jobs. 41 students participated in the pre-test of the experimental session. A total of 142 students participated in the actual study, however we could use only the data from 133 students, due to incomplete surveys and student refusal to provide data to the study. We also conducted sessions with 45 students who had no background in supply chain, logistics and transportations but will not consider their data for this study because the assumption underlying the studies on SA and naturalistic decision making is that the participants have some form of subject knowledge.

### 6.3.2 Research instruments

We have already discussed in Chapter 4 that YCS1 game will be used to measure the planning task performance in container terminal operations. It also serves as an indirect SA performance measure. We used the SART survey described in Appendix E for the subjective measurement of SA to compare with the YCS1 game score to validate YCS1 as a reliable measure for individual SA in planning operations in container terminals. In addition to YCS1 we will describe the various research instruments used in our study to measure personality type and multi-tasking ability. Gender and culture was measured in a pre-game survey that was used to collect the demographics of the participants together with the personality type questionnaire.

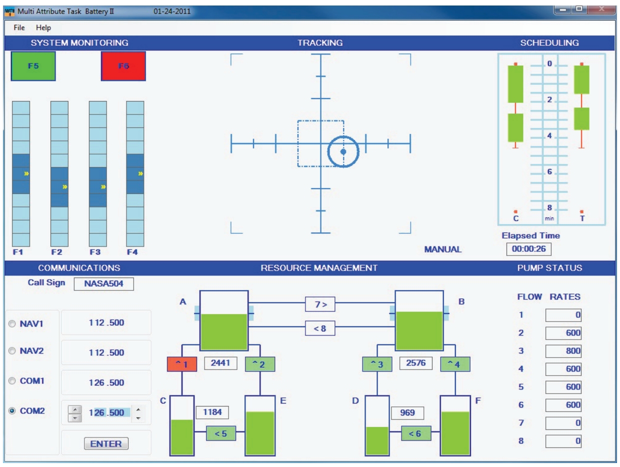
#### Measuring personality traits: the TIPI questionnaire

Several extensive tests are available for the measurement of personality traits. Examples include the 240-item NEO Personality, Inventory, Revised (NEO-PI-R), the 44-item Big Five Inventory test (BFI), and the 100-item Trait Descriptive Adjective test (TDA) (Gosling et al., 2003). Most of these tests are time consuming, expensive and may sometimes need a trained professional to administer them. The design and set-up of the research motivated us to seek an openly available personality test that is very short but well tested and validated. Our search led us to the Ten-Item Personality Inventory (TIPI). As with every brief measure, somewhat diminished psychometric properties are the main limitations of TIPI (Gosling et al., 2003). However, the test has widely been adopted by the research community with over 1,000 citations since its publication. Participants are asked to describe their personality with 10 adjectives pairs. They have to choose a number between 1 and 7 for each pair, with 1 signifying total disagreement and 7 meaning total agreement. The scores for each of the Big-Five traits are calculated based on the responses. The TIPI questionnaire is a part of the pre-game questionnaire described in Appendix E.

### Measuring multi-tasking ability with MATB-II

The Multi Attribute Test Battery (MATB-II) was chosen as the research instrument for measuring multi-tasking ability. MATB was developed in the early 90's for laboratory studies of operator performance and workload, including tasks representational for the aviation domain (Comstock Jr and Arnegard, 1992). MATB was upgraded to MATB-II following a wide acceptance from research communities not limited to space and aircraft applications. MATB and MATB-II have been used in over 130 research studies on human performance related to multi-tasking and complex tasks (Santiago-Espada et al., 2011).

Figure 6.1: MATB-II start screen (Santiago-Espada et al., 2011)




Based on our search for a validated tool to capture multi-tasking ability, we found that MATB-II is an apt tool that clearly represents computer-based multi-tasking of complex tasks. The software was requested from the subsidiary website of NASA (http://matb.larc.nasa.gov/). As illustrated in Figure 6.1, MATB-II is a computer based multi-tasking exercise, which requires the simultaneous performance of systems monitoring, tracking, dynamic resource management, and communication tasks. The detailed description of the tasks is provided in Appendix F.

*MATB composite score*[1] Although many studies have used MATB and MATB-II to analyze multitasking abilities and workload, most of their findings were based on the individual performance indicators of each of the four tasks in the MATB-II exercise (Harris et al., 1995; Caldwell and Ramspott, 1998; Fairclough et al., 2005). Therefore, we decided to design a composite MATB score that is more valuable at measuring the combined performance of all the four tasks instead of measuring the performance for individual tasks which is counter-intuitive to the concept of multi-tasking. We modelled the composite MATB score as the sum of the four task performance scores. We made sure that the task performance scores were normalized on a scale from zero to one, resulting in an overall score of zero to four. A high overall score can only be obtained when participants do well on all four tasks by paying attention to the status of the different tasks at the same time and simultaneously reacting on the visual and auditive cues that are provided. Participants had to use motor skills (joystick, keyboard, mouse), recognition skills (colours, gauges, call sign), tracking skills (follow target, view fuel level changes, view pump statuses), and calculation skills (which pumps to open and close) in parallel. The task performance scores were calculated by measuring the performance of each of the tasks in terms of deviations from task goals. The deviations in SYSMON and COMM are quite straightforward to understand— the task goal is no errors, so the number of errors accounts for the deviation— but we had to clearly define them for RESMAN and TRACK consistent with their task goals. Each of the task performance scores is calculated as follows.

1. **SYSMON score**

   MATB measures the variables ST, the number of timeouts, or lack of response, during the systems monitoring task, and $S_e$, the number of errors related to the response to the changes in the boxes and scales. Participants are given a two second grace period to avoid counting double clicks as two errors. The total number of errors $S = S_t + S_e$ is normalized to $S_{norm}$ where $0 \leq S_{norm} \leq 1$, by dividing it by the highest number of possible errors, $S_{max}$, defined as the number of errors in the 'do nothing' scenario. This score is obtained when participants either do not react to any of the system monitoring tasks, or choose the wrong reaction on every one of them. If necessary, the normalized score is capped between zero and one as participants can theoretically make more errors than

[1] The author would like to thank Prof. Alexander Verbreack and Prof. Thomas Corsi for their extensive contribution towards designing the MATB composite score

the number of tasks. In that case they will receive a zero score. $S_{norm}$ is now defined as (higher is better):

$S_{norm} = 1 - min\left(1, \frac{S_t + S_e}{S_{max}}\right)$

2. **TRACK score**

   MATB measures the deviation $T_i$ from the center point every 15 seconds, or 20 times in total during the five-minute experiment. The root-mean-square deviation $T_{RMS}$, is calculated and normalized to $T_{norm}$, where $0 \leq T_{norm} \leq 1$. If $T_{norm}$ is one, then the target was perfectly positioned on the center point during the entire exercise. The maximum outlier score $T_{maxRMS}$ is the root-mean-square of the distance of the cursor position from the center point, when the participants completely ignore the tracking task ('do nothing' scenario). The tracking score is modeled as (higher is better) $T_{norm} = 1 - min\left[1, \frac{\sqrt{\frac{1}{20}\sum_{i=1}^{20} {T_i}^2}}{T_{maxRMS}}\right]$

3. RESMAN score MATB measures the deviation from the required fuel levels of 2,500 liters in both tanks A and B every 30 seconds during the exercise, or 10 times in total,. Assume that $R_{b,i}$ indicates the fuel level for tank A at sample i, and $R_{b,i}$ indicates the same for tank B. We can then calculate the absolute fractional deviation $F_{t,i}$ of each tank content compared to the 2,500 liter target level. The normalized deviation score $R_{norm}$ (higher is better) is calculated by dividing the sum of $F_{a,i}$ and $F_{b,i}$ over 10 observations by $R_{max}$, the deviation when no action is taken by the participant, and capped at zero in case the participant does worse than the 'do nothing' scenario.

   $R_{norm} = 1 - min\left[1, \sum_{i=1}^{20}\left(\frac{\frac{|R_{a,i}-2500|}{2500} + \frac{|R_{b,i}-2500|}{2500}}{R_{max}}\right)\right]$

4. **COMM score**

   MATB measures the number of communication errors C, e.g. as a result of time outs, wrong radio choice, wrong frequency choice or a response to the wrong call sign. C is normalized to $C_{norm}$, where $0 \leq C_{norm} \leq 1$ by dividing it by the number of communication tasks $C_t$ to which the participant should react, plus the number of 'false' call signs $C_f$ to which the participant should not react. The COMM score, where higher is better, is then defined as:

   $C_{norm} = 1 - min\left(1, \frac{C}{C_t + C_f}\right)$

5. **MATB_COMP**

   The composite score of multi-tasking ability MATB_COMP score is defined on a scale from 0 to 4 as the sum of the standardized individual task scores:

   MATB_COMP = SYSMON score+ TRACK score+RESMAN score+COMM score

   MATB_COMP = $S_{\text{norm}} + T_{\text{norm}} + R_{\text{norm}} + C_{\text{norm}}$

### 6.3.3 Design of the gaming session

We designed a quasi-experimental setting to realize our research objective following a strict and pre-defined protocol and script defined in Appendix E. Participants were asked to complete a pre-survey that collected their demographic information as well as their personality traits using the Ten-Item Personality Inventory (TIPI) test. Following the pre-survey, they were provided with a detailed briefing of their multi-tasking exercise and were asked to execute the exercise using a software tool known as Multi Attribute Test Battery (MATB-II). After MATB-II, the participants were presented with a briefing lecture on container terminal planning operations, and the YCS1 game that was used to assess their SA by the means of the YCS1 score. They were given a tutorial on how to use the YCS1 tool and to practice it. Two exercises with varying levels of difficulty (mission 1 and mission 2) were provided to the participants after the tutorial session. They completed mission 1 twice to get acquainted with the YCS environment and the controls. They were allowed to ask questions and clear their doubts regarding the functionality of YCS1. The scores of mission 1 were not counted for the data analysis. The participants then had to complete the difficult mission 2 twice. The highest score of mission 2 was considered for evaluating the performance of the participants in the planning operations. After the YCS1 exercise, the participants were presented with a de-briefing lecture to gather their insights and strategies related to YCS1 and to discuss the challenges in planning operations. The experiment took about 2hr 15 minutes to execute. We received the approval of the Institutional Review Board of the University of Maryland and Human Research Ethics Committee of the Delft University of Technology to conduct this research study with students. The ethics check list, together with the script of the experiment are to be found in Appendix E. Participation was voluntary, and the participants were compensated by a weighted lottery method. This means that the number of raffles entered in the lottery for each student was proportional to their highest score in the mission 2 of YCS1.

## 6.4 Results: Correlations and multiple regression analysis

We analysed the data collected from the gaming sessions using correlations, hierarchical regression, pair-wise and group-wise comparisons. In order to understand the role of individual SA on planner task performance we first performed a correlation between the YCS1 score and the SART score of the participants. We found a significant positive correlation between the SART score and YCS1 score of participants (Pearson's r = 0.321, $p<0.01$, N=107). Other correlations looked at the direct effects of the various factors on the planning task performance and SA represented by the YCS1 score. Table 6.1 represents the correlations between the factors(including individual components of the MATB score) and YCS1 score. We can observe that the MATB composite score has a strong positive correlation with the YCS1 score (Pearson's R=0.427, $p<0.01$). The personality trait Emotional Stability also has a significant positive correlation on the YCS1 score (Pearson's R=0.217, $p<0.05$). Although correlations point at the factors that have a significant direct impact on the YCS1 score, they don't explain the variance in the YCS1 score and we cannot predict the role of categorical variables like gender and culture and cannot model the relationships between the various factors. We have already discussed that personality type is known to be an important behaviour moderating variable. A moderating variable is a quantitative or a qualitative variable that affects the strength and direction of the relationship between two variables (Baron and Kenny, 1986). Therefore we will use multiple regression to understand the moderating effect of personality type on the relationship between multi-tasking ability and planning task performance.

Multiple regression was used to assess the relationship between a group of independent variables on a dependent variable, after accounting the effects of other control variables on the dependent variable. The set of independent variables consisted of multi-tasking ability MATB_COMP and each of the five personality traits. The dependent variable was the planner task performance, measured by the YCS score. We used age and gender as control variables for the first step of the regression analysis. In the next step, the MATB composite score was inserted. In the subsequent step, personality type was added as a moderating variable. Since the Big 5 consists of five independent traits, investigated the interaction effects of each of the personality traits on the relationship between multi-tasking ability and planner task performance. Model 1 indicated that gender had a significant influence on the performance. The results of the regression are shown in Table 6.2. We will describe the results

Table 6.1: Correlations between various factors and YCS1 score

| | Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Age | 1 | | | | | | | |
| 2 | YCS1 score | 0.048 | 1 | | | | | | |
| 3 | MATB composite score | 0.075 | 0.427** | 1 | | | | | |
| 4 | Extraversion | 0.048 | -0.024 | 0.196* | 1 | | | | |
| 5 | Agreeableness | -0.113 | -0.133 | -0.011 | -0.136 | 1 | . | | |
| 6 | Conscientiousness | -0.055 | 0.107 | 0.115 | -0.076 | 0.104 | 1 | | |
| 7 | Emotional stability | -0.051* | 0.217* | 0.137 | 0.096 | 0.08 | 0.200* | 1 | |
| 8 | Openness to experience | 0.035 | -0.142 | 0.051 | .204* | 0.086 | 0.035 | 0.057 | 1 |

$*p < 0.05$
$**p < 0.01$

related to each of these factors.

### 6.4.1 Multi-tasking ability

We have already observed from the correlation analysis that multi-taking ability of participants represented by the MATB score has a significant positive correlation with planning task performance. We can observe from Model 2 in Table 6.2, 25.7% of the variance in planner task performance (represented by the YCS1 score) is explained by two significant variables gender and multi-tasking ability. Gender explains 11.7% of the variance ($p<0.01$). The age of the participants had no significant effect on the planner task performance. The participants belonged to a homogeneous age range, since they were students of bachelor and master programs of the American and Dutch universities. An additional 14% of the variance that is statistically significant ($p<0.01$) was explained by the multi-tasking ability represented by the MATB score. Results from the correlation and the multiple regression analysis showed that multi-tasking ability had a significant positive effect on the planner task performance.

### 6.4.2 Personality traits

The direct effect of personality traits on planner task performance can be observed from the correlation results in Table 6.1. Among the five personality traits we have already seen that only emotional stability has a significant positive correlation with planner task performance represented by the YCS1 score. To interpret the moderating effects of each of the five traits on the relationship between multi-tasking ability and planning task performance we have to refer to model 3 in Table 6.2. Model 3(a) that examined the moderating effect of conscientiousness does not explain significant additional variance in the planner task performance. Similarly models 3(b), 3(c), 3(d) that examined the moderating effect of emotional stability, agreeableness and extraversion respectively do not explain any significant additional variance. Openness to experience as a moderating variable, shown in model 3(e) explained an additional 2.4% of the variance in the YCS1 score, which is statistically significant ($p<0.05$). However this moderating effect was negative. The negative moderation/interaction effect of openness to experience is illustrated in a graph, shown in Figure 6.2.

The dependent variable planner task performance (YCS score) is on the y-axis, while the moderating variable, openness to experience is on the x-axis. Multi-tasking ability (MATB score) of the participants is divided into 3 categories: 1. High multi-tasking ability, if the MATB score is higher than

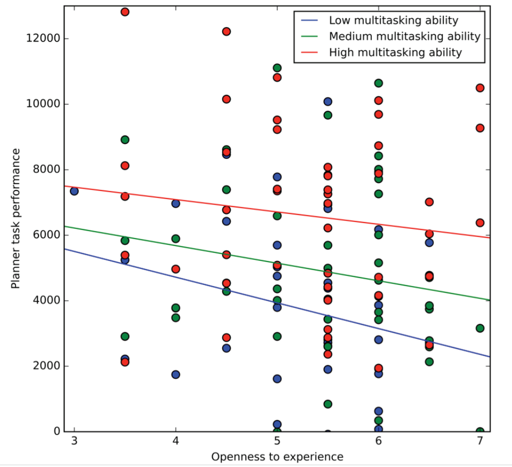
Table 6.2: Hierarchical regression: Personality trait as a moderating variable

| DV: YCS1 score | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | Model 1 | | Model 2 | | Model 3(a) | | Model 3(b) | | Model 3(c) | | Model 3(d) | | Model 3(e) | |
| | $\beta$ | t-value | $\beta$ | t-value | $\beta$ | t-value | $\beta$ | t-value | $\beta$ | t-value | $\beta$ | t-value | $\beta$ | t-value |
| Step 1 | | | | | | | | | | | | | | |
| Age | -0.109 | -1.297 | -0.12 | -1.552 | -0.118 | -1.512 | -0.112 | -1.438 | -0.127 | -1.631 | -0.116 | -1.489 | -0.114 | -1.491 |
| Gender | -0.344 | -4.113** | -0.253 | -3.169** | -0.258 | -3.218** | -0.232 | -2.837** | -0.232 | -2.858** | -0.243 | -3.018** | -0.255 | -3.230** |
| Step 2 | | | | | | | | | | | | | | |
| Multi tasking ability | | | 0.373 | 4.724** | 0.309 | 2.810** | 0.3 | 2.967** | 0.458 | 4.459** | 0.44 | 4.276** | 0.556 | 4.803** |
| Step 3 | | | | | | | | | | | | | | |
| Personality traits[a] | | | | | 0.089 | 0.832 | 0.118 | 1.414 | -0.129 | -1.293 | -0.102 | -1.017 | -0.244 | -2.135* |
| $R^2$ | 0.117 | | 0.247 | | 0.251 | | 0.255 | | 0.257 | | 0.253 | | 0.273 | |
| Change in $R^2$ | 0.117 | | 0.13 | | 0.004 | | 0.008 | | 0.01 | | 0.006 | | 0.026 | |
| F value of change in $R^2$ | 8.630** | | 22.319** | | 0.693 | | 1.303 | | 1.671 | | 1.033 | | 4.559* | |

$*p < 0.05$
$**p < 0.01$

[a]Multi tasking ability with each of the personality traits as moderating variables a) MATB×Conscientiousness b) MATB×Emotional stability c) MATB×Agreeableness d) MATB×Extraversion e) MATB×Openness to experience

Figure 6.2: Interaction effects of personality type on multitasking ability

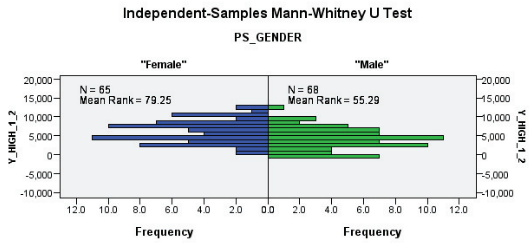



1 standard deviation than the average MATB score. It is represented by the red color. 2. Medium multi-tasking ability if the MATB score is between -1 and 1 standard deviation of the average MATB score. It is represented by the green color. 3. Low multi-tasking ability, if the MATB score is below -1 standard deviation of the average MATB score. The color blue represents this. The scatter plot of the graph in Figure shows the 3 categories of multi-tasking ability. The graph demonstrates that in most cases, high multi-tasking corresponds to high planner task performance. We can observe from Figure 6 that majority of the participants with YCS score higher than 8000 have high multi-tasking ability.

Players with high multi-tasking ability perform slightly worse on planner task performance when they have high openness to experience. A red regression line with a negative slope shows this trend. The same negative trend is observed for participants with medium (green line) and low (blue line) multi-tasking ability. The results show that, for a given multi-tasking ability, the planner task performance is negatively affected by the increase in openness to experience.

### 6.4.3 Gender

We have already mentioned earlier that gender explains 11.7% of the variance ($p<0.01$). Therefore it has a significant effect on the planning task performance represented by the YCS1 score. Given the dichotomous nature of gender we cannot compare the differences between male and female participants using the results from the multiple regression analysis. The average YCS1 score of




| | |
|---|---|
| Total N | 133 |
| Mann-Whitney U | 1,414.000 |
| Wilcoxon W | 3,760.000 |
| Test Statistic | 1,414.000 |
| Standard Error | 222.164 |
| Standardized Test Statistic | -3.583 |
| Asymptotic Sig. (2-sided test) | .000 |

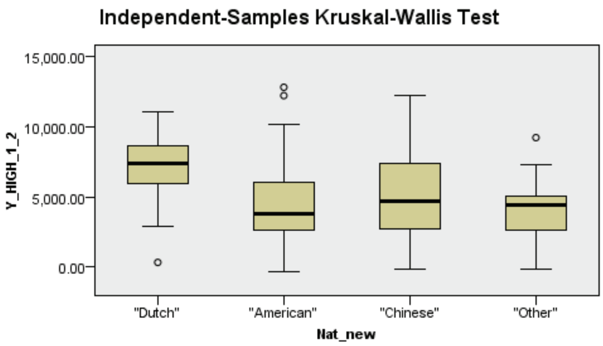
Figure 6.3: Comparing the YCS1 score between male and female participants: Mann Whitney U test

female participants is 6170.92, with a standard deviation of 2968.97, whereas the average YCS1 score of the male participants is 4201.2 with a standard deviation of 2801.87.

We used Mann-Whitney U test to determine any significant differences in YCS1 score between male and female participants. We chose to use the non-parametric Mann-Whitney U test (based on medians) to compare the two groups instead of a T-test (based on means) because the YCS1 score was not normally distributed among female participants (see Figure G.1). Median YCS1 score was significantly different between males and females with $U = 1414$ , $p = 0$ shown in Figure 6.3. This shows that female participants significantly outperformed males participants in planning task performance represented by the YCS1 score.

### 6.4.4 Nationality

To compare the cultural differences in the game performance, we divided the participants based on nationality. The 4 major groups from our results belong to Chinese (39), American (37), Dutch (28) and Other (30) nationalities. We employed the Kruskal Wallis H test, which is a non-parametric statistical test to compare different groups since YCS1 score is not normally distributed across all nationality groups (see Figure G.2).




| | |
|---|---|
| Total N | 129 |
| Test Statistic | 22.023 |
| Degrees of Freedom | 3 |
| Asymptotic Sig. (2-sided test) | .000 |

Figure 6.4: Comparing the distribution of YCS1 score among different nationalities: Kruskal Wallis H test

Although the test shows that YCS1 score is not uniformly distributed among participants of different nationalities, it doesn't represent how well each of the groups performed against each other. Therefore we need to perform a post hoc test using Dunn (1964)'s procedure of pairwise comparisons with Bonferroni correction. The results of the post hoc test are represented in Figure 6.5.

The test results are represented in Figure 6.4. Mean ranks of Dutch, American, Chinese and Other are 93.7, 54.43, 63.46 and 51.6 respectively. By visual inspection of the mean ranks we can observe that the YCS1 scores are different among the groups. This difference is also statistically significant with $\chi^2(3) = 22.023, p = 0$.

This post hoc analysis revealed statistically significant differences in median YCS1 scores between the Dutch and Other (p = 0), Dutch and American (p = 0) and Dutch and Chinese (p = .008) nationality groups. This shows that the Dutch participants outperformed their Chinese and American counterparts in planner task performance represented by the YCS1 score. We will not consider the 'Other' nationality in our explanation because it is a heterogeneous group of several nationalities.

| Sample1-Sample2 | Test Statistic | Std. Error | Std. Test Statistic | Sig. | Adj.Sig. |
|---|---|---|---|---|---|
| "Other"-"American" | 2.832 | 9.678 | .293 | .770 | 1.000 |
| "Other"-"Chinese" | 11.862 | 9.578 | 1.238 | .216 | 1.000 |
| "Other"-"Dutch" | 41.471 | 10.286 | 4.032 | .000 | .000 |
| "American"-"Chinese" | -9.029 | 8.579 | -1.052 | .293 | 1.000 |
| "American"-"Dutch" | 38.639 | 9.364 | 4.126 | .000 | .000 |
| "Chinese"-"Dutch" | 29.610 | 9.260 | 3.198 | .001 | .008 |

Figure 6.5: Post hoc analysis with Bonferroni correction: Pairwise comparison of groups

### 6.4.5 Summary of results

Our results indicated that participants with individual SA of participants has a significant positive correlation with the YCS1 score. multi-tasking ability has a significant positive correlation to planner task performance represented by the YCS1 scores. Among the personality traits, emotional stability has a direct and statistically significant positive correlation with planner task performance. Openness to experience has a negative moderating effect on the relationship between multi-tasking ability and planner task performance. Gender and culture also have a significant influence on the planner task performance. Female participants performed significantly better than their male counterparts. Dutch participants outperformed their Chinese and American colleagues significantly. We will discuss and explain these results in the following section that will provide conclusions and recommendations based on the results.

## 6.5 Summary and discussion

The task performance of employees at marine container terminals play a crucial role in achieving a high level of productivity and competitiveness of container terminals. Planners within container terminals have a direct effect on terminal performance since they plan and manage resources in a complex and dynamic environment. Task performance of planners, therefore, has a direct impact on organizational goal accomplishment. SA and task performance are closely related. It is important to understand the factors that affect SA and task performance. A thorough understanding of these factors would further strengthen the relationship between SA and performance. We can make a tangible and clear contribution to the otherwise fuzzy and complex concept of SA. This is especially important within our case study of container terminal operations. Modern container terminals are driven by technology and market developments such as automation, commodity mix, and horizontal and vertical integration of terminal logistics, increasing the complexity and dynamics in logistic operations and planning tasks. Adaptive planning is highly desirable for employees to handle the complexity and dynamics of continuously changing tasks in these socio technical systems (Rouse et al., 1992). Although the need for adaptive and integrated planning tasks of container terminal operations is well established, the role of SA and the factors affecting superior planner task performance at such tasks is largely unknown. Our research made an attempt at closing this gap.

We explored the role of SA, multi-tasking ability, personality type, gender and culture on planner task performance and therefore on SA because the YCS1 score has been designed to be an indirect performance measurement of SA.

Based on our results we can conclude that individual SA has a strong correlation with individual planner task performance. This is consistent with Endsley (1995)'s SA model on decision making where she states that SA is an essential pre-requisite to individual decision making that drives performance. This finding confirms our choice of choosing the three level SA model of Endsley to represent individual SA in container terminal operations. Our finding on individual SA is not surprising, but the results on the factors affecting SA and planner task performance are novel and require the spotlight for discussion below.

Multi-tasking ability has a strong relation with superior planner task performance. This finding is consistent with the crucial role of multi-tasking ability on performance in other domains. Irrespective of the domain, actors in complex systems need to coordinate the performance of multiple tasks and cognitive demands on actors are likely to increase in the future (Chiappe et al., 2012a; Liu et al., 2009). Although automation reduces physical workload, it increases cognitive workload (McCarley and Wickens, 2005; Dehais et al., 2012). The capacity for attention to perform multiple tasks can be enhanced (Bavelier et al., 2012). Therefore, a key recommendation from our study to the management of container terminals is to provide training programs to employees to enhance their multi-tasking ability to have a better SA and performance under a complex and dynamic workload. We suggest the use of simulation games as a effective training instruments. This recommendation is consistent with the advice of Bavelier et al. (2012) and Chiappe et al. (2012b).

With respect to personality traits we found that emotional stability has a significant positive correlation planner task performance and subsequent to SA. Earlier studies like Hurtz and Donovan (2000), Tett et al. (1991) have shown a weak positive correlation between emotional stability and task performance. However the occupational description of the tasks in these studies don't correspond to the stressful and complex nature of tasks in socio technical systems. In such systems (Cote and Miners, 2006) stresses the importance of emotional stability on task performance and states that actors with high emotional stability perform well at stressful tasks even though their cognitive skills are not exceptional. Therefore we can conclude that emotional stability of individual actors is essential for superior task performance and SA in container terminal planning operations. When we observe the moderating effect of personality traits, openness to experience has a negative influence on the relationship between multi-tasking ability and planner task performance. Previous studies have positively associated openness to experience with superior performance of creative tasks (Baer and Oldham, 2006; LePine et al., 2000; George and Zhou, 2001). The planning tasks in container terminals are not purely creative in nature, however, as they are bound by rules and deadlines. Although we cannot make a strong recommendation regarding this personality trait, employers may benefit from considering personality traits as well as other skills such as multi-tasking ability while allocating tasks to employees.

Gender and culture differences also played a major role in planner task performance in our study. Gender difference in planning performance had been explained by Naglieri and Rojahn (2001), where they found a better performance of girls in planning and attention scales as result of a test based on the Planning, Attention, Simultaneous, Successive (PASS) cognitive-processing theory. Women performed better on verbal and memory tasks, while men did better on spatial cognition and spatial learning (Naglieri and Rojahn, 2001). The same study showed that men and women used different strategies in a planning task, which was represented in their brain activity. It cannot be said whether this is a biological or a social phenomenon, with both genders learning different approaches towards complex planning tasks throughout their life Boghi et al. (2006). From these studies, we can draw the conclusion that different cognitive approaches towards planning tasks could be an explanation for the differences found in our study. However there is plenty of unexplained variance between men and women that might be related rather to individual differences than to gender differences (Unterrainer et al., 2005). We are aware of the fact that being a woman or a man does not necessarily mean that the one or other performs better or worse based only because of her or his biological sex, but that social and individual differences also play a very important or even more important role (Unterrainer et al., 2005). Although our results showed a significant difference between male and female participants we cannot make a strong recommendation on this aspect before we can further analyse related theories that include neurological, cognitive and sociocultural aspects that could influence the differences (see Naglieri and Rojahn (2001)).

Regarding the effect of cultural differences we have demonstrated that Dutch participants performed significantly better than their American and Chinese counterparts. Based on Hofstede et al. (1991)'s theory on cultural dimensions the Dutch have a small power distance, are more individualistic, with higher level of tolerance for uncertainty, and are cooperation-oriented. The culture of the USA is characterized with a comparable power distance, being highly individualistic, but have less uncertainty tolerance than the Dutch and are achievement-oriented (Hofstede et al., 1991). The Chinese have quite a high power distance ratio, are collectivist in nature, low tolerance for uncertainty and are results oriented (Hofstede et al., 1991).

Therefore the main (individual related) cultural difference between the Dutch and the American and Chinese participants seems to be uncertainty avoidance. Cultures with low tolerance to uncertainty are more rigid in their behaviour, while cultures with high tolerance are more flexible (Hofstede et al., 1991). With respect to the YCS1 game, to achieve a good score, a player needs to adopt a flexible planning strategy, where he/she needs to pay attention to the arriving ships, and constantly reallocate containers and resources. This could be one possible explanation of the superior performance of Dutch participants over the Americans and Chinese. We have to be cautious regarding interpreting this result because culture is a complex artefact not limited to nationality alone. Merriam-Webster dictionary defines culture as "beliefs, arts, customs of a particular group, place or time, a particular society that has its own beliefs, ways of life, art, etc., a way of thinking, behaving or working that exists in a place, group or organization". While some studies (Cox et al., 1991; Earley, 1994) have studied the role of cultural differences in team and group performance and behaviour, we were not successful in finding studies that explained individual performance and behaviour related to culture. After all, culture is a collective phenomenon (Hofstede et al., 1991). However instead of focussing on the nationality, it maybe interesting to explore the role of uncertainty avoidance of an individual actor on planner task performance in socio technical work organizations because uncertainty is a key characteristic of socio technical systems.

Based on our results, we conclude that individual SA is an essential pre-requisite for decision making and task performance of planners in container terminals. The management of container terminals can benefit by considering the effects of multi-tasking ability, personality type, gender and cultural differences while design and allocation of tasks and training programs to support SA and superior task performance of individual actors in their socio technical work organizations.

It should be noted that the YCS1 game is a single player game, where some personality traits like agreeableness and extraversion and cultural traits like cooperation and power distance, and aspects of team or group work which is a major part of socio technical systems cannot be observed. Therefore we incorporated a multi-player component in our simulation environment to provide a more realistic environment to study SA and planner task performance in container terminals which is a socio technical work organization. We will use the multi-player game YCS3 to conduct this study that will form the core of the following chapter.

*A large part of this chapter is based on an article titled* ***" Relating Planner Task Performance for Container Terminal Operations to Multi-Tasking Skills and Personality Type "*** *that was submitted to Transportation Research part F journal*

Chapter 7

# The role of SSA and DSA and related factors in team task performance in container planning operations: A study with YCS3 game

We have discussed about the role of individual SA and related individual factors that affect the decision making and task performance of planners in container terminal operations in chapter 6. In this chapter we will shift our focus to teams. We will test our SA framework in Chapter 2 by comparing and contrasting the decision making and performance of team members involved in complex planning tasks of a container terminal under different SA configurations using the YCS3 game. The two SA configurations that will be tested are the SSA and DSA configurations from the SA framework in Chapter 2. We also will also study the factors like personality type, gender, culture, and team processes like communication, mutual support, situation monitoring that affects SA and task performance in teams.

## 7.1 Teams and SA in sociotechnical systems

A team consists of two or more individuals that have specific roles or functions who work together dynamically and interdependently towards achieving a shared goal Salas et al. (1995a). The significance of teams, teamwork and team performance is unprecedented in today's socio technical work organizations (Salas et al., 2008). This largely because when the task environment is vague and ill-defined, stressful and when multiple and quick decisions have to be made under time pressure where the collective insights of team members are most likely to be superior than that of an individual (Katzenbach and Smith, 1993; Salas et al., 2008). Performance of socio technical organizations increasingly depends on the performance of its teams (Appelbaum, 1997; Salas and Fiore, 2004).

Team performance is characterized as the extent to which team members engage in individual and team level task-work and teamwork processes (Kozlowski and Bell, 2003). While individual and team tasks are quite straightforward to define, teamwork is a set of interrelated cognitions, attitudes and behaviours that contribute to the dynamic processes leading to team performance (Salas et al., 2008). In this chapter we will focus only on the task performance of teams or team task performance because we assembled teams with members that may not be familiar with each other.

Situation Awareness has been credited to be one of the key theoretical concepts that explain how teams adapt their processes under varying task conditions and times pressure in socio technical systems (Entin and Serfaty, 1999; Endsley, 2015a; Stanton et al., 2004). However research on Situation Awareness in teams, especially in socio technical systems has not been well represented in literature Carayon (2006); Stanton et al. (2015); Chatzimichailidou et al. (2015a); Neville and Salmon (2015). In addition to SA, several factors like team composition (team size, personality type, cultural factors), work structure (team norms, communication structure, work assignments) and task characteristics (workload, task type, task interdependencies) have a strong influence on team performance (Salas et al., 2008). In his seminal work on team performance Salas et al. (2005) conducted an extensive literature survey to proposes the "big five" factors that explain team performance additional to three team coordination mechanism. The big five factors are team leadership (Cannon-Bowers et al., 1995), mutual performance/ situation monitoring (McIntyre and Salas, 1995), backup behaviour/ mutual support Marks et al. (2001); Johnston and Briggs (1968), adaptability Campion et al. (1993); Cannon-Bowers et al. (1995), and team orientation (Campion et al., 1993; Driskell and Salas, 1992). The three coordinating mechanisms are shared mental models/ team mental models (Mathieu et al., 2000), mutual trust (Bandow, 2001) and closed loop communication (McIntyre and Salas, 1995). We will briefly describe each of the five factors and the three coordinating mechanisms.

The five important team factors influencing team performance according to Salas et al. (2008) are:

1. **Team leadership** refers to the ability of a team member to direct and coordinate the activities of other team members and provide a motivating and positive work environment where all team members can improve their knowledge and skills (Cannon-Bowers et al., 1995).
2. **Mutual performance monitoring/ situation monitoring** is the ability of a team member to monitor the team performance at a give time and provide feedback to other team members if necessary (McIntyre and Salas, 1995).
3. **Backup behaviour/ mutual support** is the ability to understand the difficulties faced by other team members and offer support for the related tasks (Marks et al., 2001).
4. **Adaptability** is the ability to adjust strategies and constantly look to improve the task performance based on new information Campion et al. (1993).
5. **Team orientation** reflects the attitude of team members towards the team and their willingness to work toward a shared goal through coordination and utilization of inputs from other team members (Driskell and Salas, 1992).

The three coordinating team mechanisms are:

1. **Shared mental models** is a mechanism through which team members describe, explain and predict events in their environment to create a common operational picture of their environment often by using shared displays and by sharing the work environment Mathieu et al. (2000); Bolstad and Endsley (1999).
2. **Mutual trust** is the belief among team members that each one of them will perform the tasks well in a timely manner and protect each others' interests (Bandow, 2001).

3. **Close loop communication** involves the exchange of information between team members and making sure that the required information is received to the related team member (McIntyre and Salas, 1995).

We will not explore team leader ship and team orientation because the teams in our context are not long term and have been set up ad hoc for the study. The adaptability of teams is partially measured by the overall team score of YCS3. Therefore we will focus on the effects of situation monitoring and mutual support on team task performance. We will look into the role of share mental models and close looped communication from a qualitative perspective. We were unable to assess the role of mutual trust in our study. Overall, the key objectives of this chapter is to study the following,

1. The influence of the two SA configurations (SSA and DSA) on team task performance of complex planning operations in a container terminals.
2. The role of personality type, gender and cultural differences in team task performance under different SA configurations
3. The role of team factors— situation monitoring and mutual support and the role of coordinating mechanisms— shared mental models and closed loop communication in team task performance under different SA configurations.

We will now discuss the research design and methodology towards fulling our research objectives.

## 7.2 Experimental design and set-up of gaming sessions

### 7.2.1 Participants

The sample population of this study was drawn from the students of the Master program of Transportation, Infrastructure and Logistics at the Delft University of Technology. A total of 27 students participated in this study. One student had to be excluded from the study due to identification problem due to incomplete questionnaire data. 24 students completed all the questionnaires, where 2 students did not provide necessary responses in the pre and post game surveys.

Of the 26 students, 11 were female and 15 were male. The mean age of the participants was 23.3 with a standard deviation of 1.7. The majority of the participants were Dutch (20), followed by three Chinese students, and one each from Belgium, Mexico and Greece. The students received partial course credit for their participation. The researchers acted as 'guest lecturers' and were not in a direct power relation with the students and were not involved in the evaluation of students for the partial credit. The study was approved by the Human Research Ethics Committee (HREC) of the Delft University of Technology. The following sub-section will describe the various research instruments used for the study.

### 7.2.2 Research instruments

**Multi-player Yard Crane Scheduler (YCS3)**

The YCS3 game was used to measure the individual and team performance of actors involved in container terminal planning operations. YCS3 is a 4 person online game for planning container terminal operations, where the 4 participants need to align their activities and plan to achieve superior task performance. The score of the YCS3 is considered as a measure for team task performance and an indirect measure of SA. The development and evaluation of YCS3 has been discussed in chapter 4.

**Pre-survey: Demographics, experience, personality type**

The pre-survey used in this study was used to collect demographic information of the participants such as age, gender, education level, professional experience, experience with games and personality type. The pre-survey includes the Ten-Item Personality inventory (TIPI) to measure the personality type.

**TeamSTEPPS Team Perceptions Questionnaire (T-TPQ)**

Based on our literature review, the only validated instrument that measured teamwork constructs based on Salas et al. (2005)'s 5 team performance constructs was the TeamSTEPPS Team Perceptions Questionnaire (T-TPQ). The T-TPQ is a result of TeamSTEPPS, an evidence-based teamwork system developed by the US Department of Health and Human Services, aimed at improving communication and teamwork skills of teams (Battles and King, 2010). It was originally aimed at the healthcare industry but has been used in other fields to evaluate team performance and provide training for teams (Battles and King, 2010). The main constructs of T-TPQ are team structure, leadership, situation monitoring, mutual support and communication. Questions related to each of these constructs are answered by the participants after a particular task (see Appendix H). T-TPQ is therefore a subjective rating scale of team factors that influence team performance. In our research, we did not focus on team structure and leadership, since teams were quite uniform in terms of size and the different roles donned by the participants had an equal footing, with no power differences. Therefore we designed our T-TPQ questionnaire focussing on communication, situation monitoring and mutual support.

**Video recording of the game play**

Video recording is a valuable research tool, that allows the researcher to record and replay the pictures and sounds of an event under study (Penn-Edwards, 2004). Spontaneous and transitory information, which is difficult to script during a research activity can be captured using videos. Recording and analyzing such information can assist our understanding of human behaviour and nature as intangible factors such as gender, cultural, characteristic roles can be better observed using videos (Penn-Edwards, 2004). In our study we used videos for observational recording, where we followed subjects engaged in an activity— in our case, a team of 4 participants trying to align their activities and plans in a container terminal, within different configurations of Situation Awareness game play of YCS3. The observational recording provided material used to interpret and evaluate the behaviour of participants during the 3 SA configurations of game play in a qualitative manner.

The research design and procedure of this study using the above research instruments will be explained in the following sub-section.

### 7.2.3 Experimental design

Our research design is quasi-experimental since the sample population was not randomly drawn. The experimental session begins with a short briefing lecture explaining operations in container terminals and the various planning roles involved to manage these operations. All the participants are provided with laptops. They are directed to play the online game YCS1, which is a single player version of YCS3 (for details on YCS1 refers to chapter 5). YCS1 acts as a tutorial to the players before they play YCS3, so that all the participants are on an equal footing to play YCS3. After playing YCS1, participants are divided into teams of 4. There are 7 teams in total. Each team is seated around a table in a bridge game format. Participants begin the experiment by answering a pre-survey that collects demographics, professional, simulation gaming experience and personality type information. Each team has to play the YCS3 game at varying configurations of SA– 'A', 'B', 'C' (summarized in Table 7.1). The YCS3 game has different scenarios for the different levels of game play with the same level of complexity in order to control for learning bias. The various SA configurations of game play are further explained below.

Table 7.1: The three SA configurations of game play

| | |
|---|---|
| Configuration 'A' | Base level game play where players make individualistic decisions |
| Configuration 'B' | Shared SA level of game play, where all the information can be communicated through a shared display |
| Configuration 'C' | Distributed SA level of game play, where only relevant information is shared between relevant participants without a common operational picture |

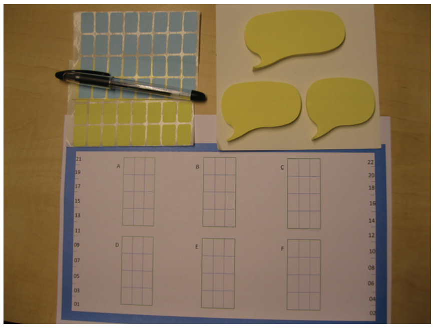
**Configuration 'A': Base level SA game play**

In the base level of the game play, all the players are required to plan their activities individually with the available information, without interacting with other team members. This level of game play sets the base line for team task performance, based on individual decisions of the team members with no means of communication or interaction.

**Configuration 'B': SSA level of game play**

Shared SA or a common operational picture among team members is developed by the means of shared mental models and shared displays (Bolstad and Endsley, 1999; Nofi, 2000). In this configuration of the game play, participants were provided with materials that can help them create a common operational picture of their activities. The materials included a printed A3 size sheet of the layout of the container terminal as represented in the game (except the cranes and ships), 6 conservation bubble sticky notes per player, several coloured stickers to represent containers. The sticky notes were used to pass messages between players, while all team players viewed the messages since they can be placed on the common sheet. The stickers were used to communicate regarding the container positions in the ship, and the yard. The materials provided for the players in the 'B' configuration are shown in Figure 7.1.

Figure 7.1: The materials provided to the players during the SSA level of game play



**Configuration 'C': DSA level of game play**

Configuration C is based on the premise of Salmon (2008)'s Distributed SA that all the team members need not have shared awareness of the team activity, but can interact with each other regarding a specific task, exchange relevant information to enable appropriate decision making. In this configuration of the game play, the materials shown in Figure 7.1 were removed. Participants were allowed to communicate with each other, without having access to a shared platform that represents their team activity.

To control for a bias related to the order in which the participants played the game, we divided the 7 teams into two groups. Teams 1, 2, 3 and 4 belong to group 1 while Teams 5. 6 and 7 belong to group 2. Group 1 played the game in the order of 'A', 'B', 'C' configuration of game play. Group 2 played the game starting with 'A', followed by 'C' and finished with the 'B' configuration of game play. After finishing the 3 levels of the game play, the participants were asked to fill in a post-game survey which consisted of a SART survey, as well as T-TPQ questionnaire to measure their SA as wells as their perception of communication, situation monitoring and mutual support during the game play.

## 7.3 Quantitative and qualitative results

The results of the experimental sessions were analysed by a mixed-methods approach, given the relatively small size of the sample population. "Mixed methods research is an intellectual and practical synthesis based on quantitative and qualitative research. It recognizes the importance of traditional

Figure 7.2: Impression of the research activity

Figure 7.3: A team working together

quantitative and qualitative, but offers a third paradigm that will provide the most informative, complete , balanced and useful research results" (Johnson et al., 2007). The third paradigm is a combination of quantitative and qualitative methods of data collection and data analysis in a empirical research project (Johnson et al., 2007). In our case the quantitative data included the measurements from the pre and post game surveys, TIPI & T-TPQ questionnaires, individual and team game scores. The qualitative data came from the video recordings of all the levels of game play and the materials provided for the teams during SSA level of game play. We will analyse the data collected from the various research instruments in a quantitative manner, followed by a qualitative analysis to further validate the quantitative results with respect to the various research objectives proposed in the introduction section.

### 7.3.1 Quantitative results

In this sub-section we will analyze all the quantitative data related to the research objectives. The relevant quantitative data from the pre-survey, together with the TIPI questionnaire included information on the age, gender, nationality, personality type, experience with supply chain operations and port planning operations. The group was homogeneous in terms of age, port planning and supply chain experience since they all belonged o the same master program. The post game questionnaire provided team member's perception on the level of situation monitoring and mutual support. The log from the YCS3 game provided the individual and team scores of all the participants at various SA configurations of game play. The team score, sum of the individual team member score represented the team task performance at planning container terminal operations. We will first analyse the scores at different SA levels.

**The differences in task performance at various SA configurations**

The descriptive statistics of the individual and team scores are shown in Table 7.2. YCS3_IND_A, YCS3_IND_B, YCS3_IND_ are the individual scores of team members during the three different SA configurations of the YCS3 game play. Whereas, the YCS3_TEAM_A, YCS3_TEAM_B, and YCS3_TEAM_C represents the team scores at the different SA configurations of the game play.

Table 7.2: Descriptive statistics of the individual and team scores at different SA levels of YCS3 game play

| N=26 (IND), N=7 (TEAM) | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|
| YCS3_IND_A | -270 | 2002 | 867.5 | 705.67 |
| YCS3_IND_B | 122 | 1840 | 1014.2 | 631 |
| YCS3_IND_C | -1546 | 2584 | 1238.5 | 1068.7 |
| YCS3_TEAM_A | -1070 | 7839 | 3448 | 2843.3 |
| YCS3_TEAM_B | 1087 | 7236 | 3912.5 | 2558.1 |
| YCS3_TEAM_C | -1546 | 10239 | 5279.7 | 3792.8 |

We can observe that the mean individual and team scores progressively improved from SA configuration A to B and to C, with highest mean scores reported at the C configuration of game play. It is important to remember that we have also controlled for the order in which the participants play the game at the three SA configuration levels.

Our test sample is relatively small, and the YCS3 scores are not normally distributed, see Figure G.3. Therefore we performed the non-parametric Wilcoxon signed-rank tests to compare the differences between the individual scores at various SA configurations.

The Wilcoxon signed-rank test is used to compute the median of differences between two different treatments for the same group. If we observed the results from Table 7.3 we can see that that there is a significant median increase in YCS3 individual score in SA configuration C compared to SA configuration A ($z = 2.327$, $p = .02$) as well as SA configurations B ($z = -2.070$, $p = .038$). There was no significant mean increase between the individual YCS 3scores of the A and B SA configurations of the game play due to a relatively high p value of

Table 7.3: Pairwise comparisons of individual YCS3 scores: Wilcoxon signed-rank test

| Related samples Wilcoxon signed-rank test | | | | | |
|---|---|---|---|---|---|
| Pairwise comparision of individual YCS3 scores | N | Test statistic | Std.error | z | p |
| Configuration A vs.B | 26 | 232.5 | 39.372 | 1.448 | .148 |
| Configuration C vs.A | 26 | 249 | 37.166 | 2.327 | .02* |
| Configuration B vs.C | 26 | 94 | 39.372 | -2.070 | .038* |

*p<.05

.148. From the results we can clearly see that team members performed their best in the 'C' SA configuration of the game play.

### 7.3.2 Role of personality type, gender and culture

**Personality type**

To understand the direct influence of personality type we performed a 2-tailed bivariate correlation between the big 5 personality traits extraversion (B5_EXTRAV), agreeableness (B5_AGREE), conscientiousness (B5_CONSC), emotional stability (B5_EMOT) and openness to experience(B5_OPEN) and individual scores of YCS3 at various SA configurations of game play. The results are shown in Table 7.4. In the table 'corr' refers to the Pearson's correlation coefficient, where are p value denotes the 2-tailed level of significance. We can observe that extraversion had a negative influence on all SA configurations of the game play. However this correlation doesn't explain any pattern since it was not very significant due to high p values. Agreeableness also had a negative correlation with all configurations of SA, but the correlation was also not significant. Conscientiousness had weak correlations with performance with very high p values, its effect was also not very significant.

Emotional stability, however appeared to have a significant correlation with the individual team member score (corr/p= .397*/.044) at 'C' SA configuration of the game play. Openness to experience doesn't have a significant correlation with individual scores at any SA configuration of game play, although the correlations showed a negative effect. We were unable to measure the indirect effects of personalty type due to the relatively small sample size.

Table 7.4: Relationship between personality traits and YCS3 scores: Correlations

| N = 26 | YCS3_IND_A corr/p | YCS3_IND_B corr/p | YCS3_IND_C corr/p |
|---|---|---|---|
| B5_EXTRAV | -.118/.566 | -.345/.085 | -.171/.403 |
| B5_AGREE | -.271/.180 | -.311/.121 | -.118/.565 |
| B5_CONSC | .047/.821 | .075/,715 | -.118/.564 |
| B5_EMOT | .298/.139 | .05/.8 | .397*/.044 |
| B5_OPEN | -.048/.816 | -.182/.374 | -.038/.853 |

**Gender**

We conducted the non-parametric Mann-Whitney U test to test if the YCS3 scores at different SA configurations were different for male and female participants. the null hypothesis of the Mann-Whitney U test is that 'there is no difference in YCS3 scores across gender at different SA configurations of the game play' The results of the Mann-Whitney U test for SA configuration 'A' were $U = 68$, $z = -.753$, $p = .474$, for SA configuration B were $U = 50.5$, $z = -1.661$, $p = .097$ and that of SA configuration C were $U = 60$, $z = -1.168$ and $p = .259$. None of these results were significant. Therefore we can retain the null hypothesis and state that the distribution of the individual scores of YCS3 were the same across both the male and female participants for all the three SA configurations.

**Culture**

The majority of the participants, 20 out of 26, were Dutch. Therefore we did not conduct any quantitative analysis on the effect of culture on the YCS3 score. However we observed the effect of cultural differences in our qualitative analysis using video taping. This will be explained in the later sections of this chapter.

### 7.3.3 The role of team factors: Situation monitoring, mutual support

The perception of the team members on the various factors that affect team performance was measured using the T-TPQ questionnaire. Situation monitoring, mutual support and mutual support were represented by SAMON, MUSPT. To understand the impact of each of these factors we performed a

Table 7.5: Relationship between team factors and YCS3 scores: Correlations

| | YCS3_IND_A corr/p | YCS3_IND_B corr/p | YCS3_IND_C corr/p |
|---|---|---|---|
| SAMON | n/a | .423*/.039 | .372/.073 |
| MUSPT | n/a | -.304/.149 | -.301/.154 |

2-tailed bivariate correlation analysis between these factors and the individual YCS3 scores at various SA configuration game play levels. The correlations are presented in Table 7.5. We chose to omit the scores at the baseline 'A' SA configuration of game play since it did not represent a team activity.

We can observe that (the perception of) situation monitoring had a strong positive relation with the individual YCS3 score at the 'B' configuration of SA game play (.423*/.039). Given the small sample size, there was a substantial positive correlation between situation monitoring and the YCS3 score at the 'C' configuration of SA game play (.372/.073). Although this correlation falls short of being statistically significant with $p = .073$, it was not negligible. The correlation between (the perception of) mutual support and individual YCS3 scores at 'B' (-.304/.149) and 'C' (-.301/.154) SA configurations were negative. Although the value of Pearson's R coefficient is sizeable in both cases, the correlation was not statistically significant due to high p values.

**Summary of the quantitative results**

We have observed from our quantitative results that the task performance of team members was the highest in the 'C' configuration or the Distributed SA level of game play. There was no significant difference in task performance between the baseline 'A' configuration (individual SA) and 'B' configuration (Shared SA) game play.

Emotional stability had a strong and significant positive correlation with the individual YCS3 score at the 'C' configurations of SA game play. All the other personality traits did not have any significant correlations with the individual YCS3 score at any configuration.

The distribution of the YCS3 score between male and female participants was the same. We couldn't assess the effect of culture quantitatively due to the high number of Dutch participants in the study that made the sample homogeneous.

Regarding team factors, (the perception of) situation monitoring had a significant positive correlation with individual YCS3 score at the 'B' SA configuration and a sizeable correlation with YCS3 score at 'C' configurations which was not statistically significant although the p value was reasonably small ($p = .073$) given the small sample size of 26.

The perception of mutual support in the participants had a negative and sizeable correlation with the individual YCS3 scores of participants at both the 'B' and 'C' configurations of SA game play. These correlations were however not statistically significant.

Although we have carefully conducted our quantitative analysis, we cannot make conclusive remarks about the results since the sample size was small and homogeneous. Additionally, team processes like shared mental models and communication could not be assessed with our quantitative results. Therefore we chose for a mixed methods approach where we seek to support our quantitative results using qualitative methods which will be explained in the following sub-section.

### 7.3.4 Qualitative results

We will first explain our method used for the qualitative analysis and will provide a summary that compares and contrasts the qualitative results with the quantitative results.

The qualitative results were based on the video recordings of the game sessions, together with the material used in the game play like sticky notes, stickers representing the containers and the descriptive comments of the participants on the score sheets (described in the research design). We analysed the three SA configurations of game play of two teams– team 1 (group 1) and team 5 (group 2), in order to substantiate our findings from the quantitative analysis. We chose one team each from group 1 and 2, to control for the bias in the order in which both teams played the three SA configurations of the YCS3 game. The following sub-sections give an overview of the data gathered from the video recordings, together with the materials used during the game play.

#### Results of the video analysis

We analysed the videos to understand difference in performance and the factors affecting team task performance at various configurations of SA. We transcribed the data based on this research objective. Transcription can be defined as a translation or transformation of sound/image from recordings to text (Duranti, 2006). This process is selective where only certain features of talk and interaction in the recordings are transcribed based on the research objective (Davidson, 2009). Selectivity in transcription is a practical necessity because it is impossible to record all features of talk and interaction from recordings (Davidson, 2009). Given our research objective we chose to focus on the following points for our transcription:

- In the 'A' configuration of SA game play, the participants were not allowed to interact with each other. All the game related information was logged in an online database, so the transcription is limited to events where participants don't follow rules, and if the moderator had to interrupt their activity. The ethnicity, gender, and the workstation number of the participants had to be noted down. This information did not change in the next two SA configurations of game play.

- In the 'B' configuration of SA game play, participants interacted with each other using various stationary materials like stickers and notes. The transcription procedure in this level was to note down who sent information to who, the area in which they placed the information (on the common board or to a specific recipient), and the time they took to perform this transaction. Interruption by the moderator, or any other event that interrupts the normal flow of the game play had to be noted down.

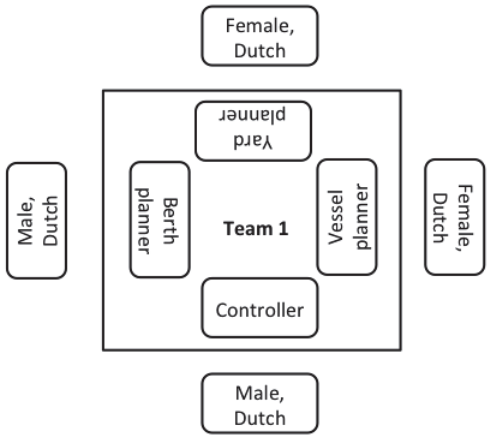
- In the 'C' configuration of SA game play, participants were only allowed to communicate verbally. At this level, the transcription procedure was to note down about the participants involved in a conversation, direction of flow of information (two-way discussion or negotiation, one-way direction), general topic of the conversation, time of the beginning of the conversation and the end. Similar to previous levels any interruption to the game play and team activity had to be noted down.

Following the above guidelines, we have transcribed the video recordings of the three SA configurations of YCS3 game play for teams 1 and 5. The detailed transcriptions are found in Appendix I. We have also summarized the essence of the transcription that is presented in the following paragraphs.

**Analysis of the transcription of the video recording of team 1 (group 1)**

Team 1 had a balanced composition of two male and two female members. All the members were from the Netherlands. The position and seating of the team members can be seen in Figure 7.4.

Figure 7.4: Composition of team 1




During the 'A' configuration of SA game play, all the members of team 1 focused on their individual tasks of the YCS3 game on their computer screens. At two instances the moderator had to remind the team not to talk, since it was not allowed in this SA configuration of the game play.

The second round represented the 'B' configuration of SA game play, where players of team 1 wrote down messages on the sticky notes provided to them and passed on to their team members. The flow of messages were predominantly between the Berth planner (B) and Vessel planner (V) as well between Controller(C) and Yard planner(Y). The majority of the messages were from the vessel planner aimed at the berth planner. There were only instance of message exchange from the controller to the yard planner. Although the messages were aimed at a single recipient, some of the notes were placed in the middle of the table on the common A3 sheet. The team players were often curious to look at the shared messages.

In the ’C’ configuration of the YCS3 game play, the players talked to each other about their plans. This was the third and last round of game play for team 1. Similar to the ’B’ configuration, the conversations were mainly between Berth planner (B) and Vessel planner(V) as well between Controller(C) and Yard planner(Y). Between B & V, the main topic of conversation was the order of unloading of the containers. As soon as a new ship arrived, the vessel planner would plan the priority of unloading for the containers, and would recite her plan to the berth planner. The topic of conversation between the yard planner and controller was about the positioning of containers and cranes in the yard. The conversations between Y &C were less frequent than B & V. They mostly discussed about the problems they were facing rather than their plans.

Each of the three configurations of the game play lasted about 9 minutes.

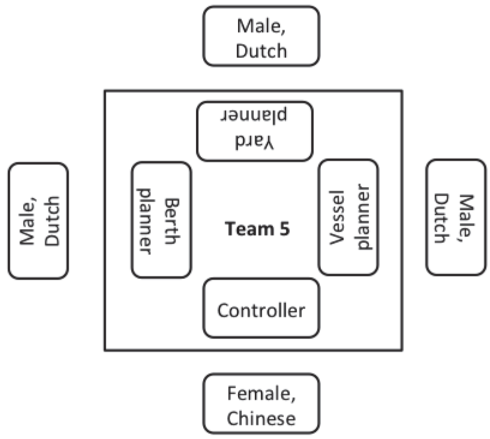
**Analysis of the transcription of the video recording of team 5 (group 2)** Team 5 had three male participants, all Dutch and one Chinese female participant. The set-up of the team during the game play can be viewed in Figure 7.5.

The ’A’ configuration of SA game play of YCS3 of team 5 was very similar to that of team 1. All the team members focussed on their individual tasks, with only one interruption by the moderator reminding the team not to talk.

The second round of game play for team 5 was set at the ’C’ configuration of SA. Even before the game began, the team members, particularly the yard planner game planned and discussed strategies with the controller, and enquired about her preferred planning methods. During the game play, the yard planner emerged as the most pro-active team member. He constantly told about his plans to controller, and constantly advised her regarding her planning. The conversation between yard planner and controller was largely one directional, with the controller following the advice of the yard planner. In addition, the yard planner also asked the berth planner two times to check if he has planned his berth cranes properly. The other prominent conversational pair was that of berth planner and vessel planner regarding the unloading plan of containers and position of berth cranes. Their conversation was two-directional. They mostly discussed their plans with each other before making a planning decision.

The third round and final round of the YCS3 game play for team 5 was that of the ’B’ configuration of SA. In this level, the most number of notes were passed

Figure 7.5: Composition of team 5




by the yard planner to the controller (uni-directional). The berth planner and vessel planner exchanged notes in an equal manner. Although the 'B' configuration of the game play had a common A3 sheet , the team members did not make use of this resource. The only shared aspect of this level for team 5, was when berth planner passed a note to vessel planner, who in turn gave it to the yard planner. The contents of the notes can be viewed in Table 7.6

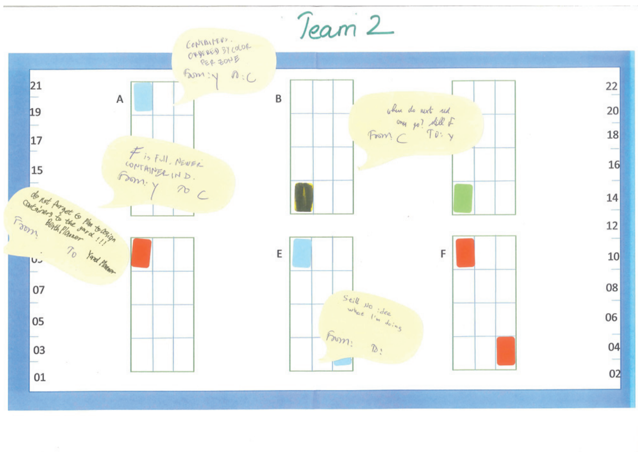
Each of the three configurations of the game play lasted about 9 minutes each.

In addition to the video analyses of the game play, we also collected the various stationary materials used by the team members to communicate during the 'B' configuration of SA game play. The contents of these materials are reported in the following sub-section.

**Qualitative data from the materials used during SSA level of the game play**

We have already explained about the various materials provided to the teams in earlier sub-sections. All teams, except team 7, made good use of the sticky

Figure 7.6: An example common sheet during the 'B' configuration of SA game play




notes, and mostly placed them on the common board. Only team 2 made use of the coloured stickers to represent container positions. Therefore, we will only report the contents of the sticky notes in Tables 7.6 and 7.7. The common A3 sheet of team 2 is represented in Figure 7.6 to show an example of how teams used their materials to create SSA.

The contents of the sticky notes of various teams showed that most of the information exchange was between the pairs of yard planner & controller regarding yard plan and allocation of yard cranes, and vessel planner & berth planner regarding the unloading plan of containers. The direction of the flow of information is explained in the Tables 7.6 and 7.7. Only team 7 did not show seriousness during the game play, and their messages did not contain any reference to their team exercise.

### 7.3.5 Overview of qualitative results and support for quantitative results

We will present the qualitative results in similar groupings (SA configurations, personality type, gender, culture, team factors) used for the quantitative results and will compare and contrast them with the quantitative results.

Table 7.6: Contents of sticky notes at 'B' SA configuration (Group 1)

| Group 1 | **From** | **To** | **Message** |
|---|---|---|---|
| **Team 1** | C | Y | Pay attention to the position of the ship |
| | Y | C | First A(yard block), then D/B, at the same time position E and then C/F |
| | B | V | Top left ship? Prioritize containers. |
| | V | B | (3 messages with drawings of container positions and priorities) |
| **Team 2** | C | Y | Where do next red (containers) ones go? F? |
| | Y | C | F (yard block) is full, new containers in D |
| | Y | C | Containers ordered by color per zone |
| | B | Y | Don't forget to plan containers to the yard |
| **Team 3** | Y | C | I'll first fill blocks A, B & C |
| | V | B | Put cranes at 04-10 |
| **Team 4** | C | Y | Only use columns where yard cranes are. |
| | Y | C | They are full |
| | Y | C | Move crane to A and D |
| | Y | V | Plan by row |
| | V | B | Move cranes left |

Table 7.7: Contents of sticky notes at 'B' SA configuration (Group 2)

| **Group 2** | **From** | **To** | **Message** |
|---|---|---|---|
| **Team 5** | V | B | (3 messages with container position numbers) |
| | Y | C | Go to D |
| | Y | C | D to A when full |
| | Y | C | D, B, C |
| **Team 6** | Y | C | Everything from top left |
| | V | B | (3 messages describing container positions) |
| **Team 7** | No meaningful exchange of messages | | |

**Team task performance at various SA configurations**

The team task performance is represented by the YCS3 score. From the quantitatively results we can observe that team members performed their best at the 'C' configuration of the game play. We will now discuss this result from a qualitative perspective. We have presented the overview of the team scores at different SA configurations of the YCS3 game play in Table 7.8

Table 7.8: Overview of YCS3 team scores at different SA levels

| Team no. | **YCS3 score team score** | | |
|---|---|---|---|
| | **A configuration** | **B configuration** | **C configuration** |
| Team 1 | 5586 | 5755 | 9692 |
| Team 2 | -1070 | 1468 | -1546 |
| Team 3 | 4165 | 7236 | 10239 |
| Team 4 | 271 | 1628 | 2934 |
| Team 5 | 3520 | 2190 | 3067 |
| Team 6 | 7839 | 6706 | 5893 |
| Team 7 | 2445 | 1087 | 4870 |

We can observe that teams 1, 3, 4, and 7 steadily improved their scores from the ’A’ to ’B’ and ’C’ configurations of the YCS3 game play.

Additionally, regardless of the order in which both teams played the YCS3 game, the ’C’ configuration scores of all the teams are higher than their ’B’ configuration scores except for teams 2 and 6. Therefore our our qualitative observations support our quantitative results on the superior performance of team members in the ’C’ configuration of SA game play.

The key differentiating variable between the ’B’ and ’C’ configurations is the information sharing approach (push vs. pull).

This means that for superior team task performance in container terminal operations sharing all the information (push) to create a common operational picture may be less efficient than seeking information from and sending information to the right person at the right time. We will now discuss the various factors and mechanisms that could play a role in this result.

Team 5 performed the best when there was no information sharing paradigm available. This could be attributed to the limited timing of the game, where the team members lost time in sharing information that did not benefit them.

Team 2 performed relatively well only in the ’B’ configuration of the SA game play and has negative scores in the other two configurations. This could be explained by their use of stationary materials to create a common operational picture of the planning situation. This could mean that the team members were better at visual communication rather than verbal communication. Additionally this could be attributed to the learning effect from earlier game play.

**Personality type, gender and culture**

Our quantitative results show that the personality trait 'emotional stability' had a significant positive influence on team task performance in the 'same goal, same location, information pull' SA configuration. We could not make any conclusions regarding the role of personality type on the team performance based on our video analysis of the performances of team 1 and team 5.

With respect to gender and culture, there was no significant difference in the distribution YCS3 scores across male and female participants, and the influence of culture could not be quantitatively assessed. From the qualitative analysis we observed that the team with balanced gender composition with the same nationalities performed better than the team with three Dutch mean and one. The performance of Team 1 was superior to that of team 5 at all SA configurations. In team 5 we noticed that the Dutch man that played the role of the yard planner constantly advised the Chinese woman who played the role of a controller. She followed the advice without much questioning. This result is less intuitive during a team activity than our qualitative analysis which focusses on the composition the teams.

**Team processes: Situation monitoring, mutual support**

From the video analysis, Team 1 appeared to have a higher grasp on the situation and the events that unfolded in the game because when we observe the contents of their messages sent through sticky notes from Table 7.6 team members exchanged information about the position and priorities of containers,and arrival and the position of vessels. From the video analysis of 'C' configuration of SA game play of Team 1 we observed that there was a constant updating between planners about priorities of containers and positions of the cranes. In comparison, the members of Team 5 exhibited limited situation monitoring when we observe their sticky note contents of the 'B' configuration in Table 7.7. Most of the messages were directing the recipient to perform an action rather than informing the status of events. The three messages with the container numbers were unclear. The same pattern repeated in the 'C' configuration, where the yard planner was instructing the controller without discussing the status of ships, resources or timing.

Our quantitative results show that mutual support had a negative but statistically insignificant effect on the team task performance. From the video analysis, comparing teams 1 and 5, we observed that mutual support between team members was exhibited most in team 5. The yard planner of team 5 constantly tried to help the controller to perform her tasks. The berth and vessel planners of team 5 spent considerable amount of time discussing potential issues for a given strategy. The members of team 1 were more independent in taking decisions and only communicated information rather than solve each other's problems. The performance of team 1 was superior to that of team 5 in all SA configurations. The qualitative results therefore support the quantitative results with respect to mutual support and team task performance.

**Team processes: Shared mental models, closed loop communication**

We evaluated the role of shared mental models and closed loop communication only through our qualitative analysis of the behaviour of teams 1 and 5.

Team 1 performed progressing better in the A, B, C configurations. In the 'B' configuration although the team members tried to create a common operational picture of container positions and ship arrivals the couldn't exchange all the required information to significantly improve their score from the baseline configuration 'A', possible due to insufficient time. In the 'C' configuration there was meaningful two-directional exchange of information between the right persons at the right time. The team was also homogeneous with two male and two female participants who were all Dutch. This could explain the effective closed loop communication between team members. Contrasting team 5's performance with team 1, team 5 performed the best at the baseline SA configuration of game play (3520) and did worse in the other two collaborative level— 'B' configuration (2190), DSA level (3067). This could be partly attributed to the communication style of the team members. During the 'B' configuration, the communication was uneven and was heavily between two players (B and V). The other players did not make use of the sticky notes to communicate and share information. In the 'C' configuration, although berth planner and vessel planner communicated a lot, they also disagreed a lot on their joint plans, which led to late decision and lower scores. The yard planner was very enthusiastic and was involved in a one-way conversation with the controller, who took orders from the yard planner without giving her opinion. This communication style might also be attributed to difference in culture between the Dutch yard planner and Chinese controller. Although shared mental models and closed loop communication seem useful for superior task performance, time pressure is a major constraint for their development and effectiveness.

## 7.4 Summary and discussion

Teams in socio technical organizations are social entities composed of members with high task interdependency and shared goals (Salas et al., 2005). Team members must integrate, synthesize, and share information; and they need to coordinate and cooperate in a dynamic environment through teamwork and task work processes to achieve their shared goal (Salas et al., 2005). Situation Awareness plays a key role in the team task performance. Based on our SA framework in Chapter 2 we tested the role of Shared SA and Distributed in team task performance. Additionally various factors (team factors, personality type, gender and culture) and mechanisms affect SA and team task work performance. (Salas et al., 2005) proposed five team factors (team leader ship, situation monitoring, mutual support, adaptability and team orientation) and three coordinating team mechanism (shared mental models, mutual trust and close loop communication). In this chapter we studied the role of personality type, gender, culture, two of the of the five team factors— situation monitoring and mutual support and two of the three coordinating mechanism— shared mental models and close loop communication. We used simulation gaming as our key research method for this study by assessing team task performance and SA using a multi-player YCS3 that represents integrated and complex planning operations in a container terminal. We used a pre-game survey the collect the demographics and personality type of the participants, and used a post-game T-TPQ questionnaire to collect the attitudes of the participants related to the team factors. We had a relatively small sample size of 26, so we used a mixed methods approach with quantitative and qualitative analysis of the data from the gaming sessions. Based on our analysis we will present the summary of our findings in the following sub-section.

### 7.4.1 Overall summary of findings

1. Team members performed best at the Distributed SA level of game play in the team task performance in container terminal planning operations represented by YCS3 score.

2. Emotional stability had a significant positive influence on team task performance. Other personality traits did not exhibit direct influence, and the sample size is relatively small to examine indirect effects.

3. The composition and diversity of team— with respect to gender and cultural background influenced team task performance of teams involved in complex planning processes.

4. Situation monitoring had a significant positive effect on team task performance, and mutual support between team members has a negative effect on the team task performance in complex planning operations.
5. Shared mental models and closed loop communication were important for the team task performance but the development of shared mental models through shared displays and the effectiveness of closed loop communication were hindered by time pressure in complex planning operations.

We will explain each of the findings in the following sub-section.

### 7.4.2 Discussion on the findings

We tested the difference between the effects of Shared SA and Distributed SA on team task performance. It emerged that the Distributed SA approach yielded the best outcomes in our study with respect to SA and team task performance in complex planning operations. We should also note that the teams performed the tasks in YCS3 under substantial time pressure. Zaccaro et al. (1995) showed that the way team members interact and exchange information to perform tasks varies a lot with varying temporal urgency. van der Kleij et al. (2009)'s study on time pressure shows that the quality of information exchange between teams operating under high time pressure was less optimal than that of teams operating at low time pressure. Under complex and time pressed situations teams that shared information in a decentralized following the DSA approach seem to preform better than teams that shared all the information (Zika-Viktorsson et al., 2003). Salmon et al. (2008a) and Chatzimichailidou et al. (2015b) support the notion that, in complex systems teams develop and maintain better SA when information is distributed rather than when it is shared. This shows that sending and seeking the right information to/from the right person at the right time is more beneficial that sharing all the information in complex planning operations in container terminals. This finding could inform the management of container terminal regarding support and train their teams to improve the quality of information exchange through DSA approach in time pressed and complex planning tasks.

The (statistically significant) positive influence of emotional stability on team task performance is consistent with its strong positive effect on individual scores in YCS1 game in Chapter 6. Among the Big-Five personality traits Mann (1959), and Heslin (1964) both found emotional stability to be one of the best predictors of team performance. Team members with low emotional ability have difficulty to adapt to stressful situations that affects their ability to cope with time pressure and high levels of task demands in a complex team environment (Costa and MacCrae, 1992). In contrast, teams with higher level of emotional stability contribute to a relaxed atmosphere and promote team cooperation in a stressful work environment (Costa and MacCrae, 1992; Reilly et al., 2002; Porter et al., 2003). This could be particularly helpful in time pressed tasks presented by the YCS3 game.

Regarding team composition with respect to gender and culture, group 1 has a balanced and homogeneous composition with 2 Dutch women and 2 dutch men while team 5 has 1 Chinese women and 3 Dutch men. The performance of Team 1 was superior to that of team 5 at all SA configurations. Nam et al. (2009) supports the notion that homogeneous teams perform better than heterogeneous teams, because their common background helps them to show agreement, give opinions, and demonstrate both positive and negative emotions with minimal inhibitions. From our study we can give an example of cultural difference— in team 5 we noticed that the Dutch man that played the role of the yard planner constantly advised the Chinese woman who played the role of a controller. She followed the advice without much questioning. This can be attributed to the fact that the likelihood of Asian team members criticising the decisions of other team members assuming leadership roles is very small (Schraagen et al., 2008). In a study conducted by Schraagen et al. (2008), a Chinese interviewee quoted saying "As a team member, you must accept and support the leader's decision even if you do not agree with it and even if it leads to a bad outcome" (Schraagen et al., 2008, p.149). This observation is also consistent with the hierarchical nature of Asian cultures that rate high on the power-distance scale of Hofstede et al. (1991). Although diversity in teams has been value as a positive performance enabler in the team due to the rich new perspectives it bring into the team, it should be noted that this positive effect has been observed only on the long term (Nam et al., 2009). Therefore team managers should be aware of the difficulties of heterogeneous teams to develop SA and work towards effective team task performance in socio technical work organizations.

Situation monitoring had shown a significant positive correlation to team task performance in study. Our finding is supported by works of McIntyre and Salas (1995) and (Salas et al., 2005) who state that team members who monitor each other's performance and are observant of possible flaws can rectify the errors in time leading to superior team task performance. Counter intuitive to our expectation, mutual support among team members had a negative effect on the team task performance. This could also be attributed to the time pressure under which the teams operated because helping another team member might boost team cohesion but is time consuming when the tasks at hand are dynamic and fast paced (Porter et al., 2003).

Although shared mental models are considered to be an important mechanism responsible for team performance, we did observe their effectiveness in the SSA level of the game play. This could be attributed to the 'ad-hoc' nature of teams who were not familiar with each other in a working environment. Ad-hoc teams don't understand each other as well as long-term teams (Klein et al., 1993). Shared mental models or team mental models rely on implicit communication that needs team cohesion and team orientation that needs time and effort to build (Klein et al., 1993).

Closed loop communication was achieved when the required information is received by the right person at the right time (Salas et al., 2005), which is close to the information pull approach. Good closed loop communication could be attributed to superior performance of most participants in the DSA level of the game play. Two teams did worse in the DSA level of game play. An explanation could be that— in a stressful, time pressed environment, closed loop communication may be hindered when members focus on individual tasks rather than think about how their tasks can affect other team members (Salas et al., 2005). Also, information overload due to excessive communication could hinder team task performance (Williges et al., 1966).

Based on our findings we can conclude that a better understanding of the team task performance under different SA configuration, team factors and mechanisms that affect SA and team task performance can help managers to better support team members by evaluating and improving their information sharing approach, paying attention to team allocation and composition and devising better ways for information exchange under time pressure in socio technical work organizations.

Although we conducted the research in rigorous manner our study has certain limitations. In addition to the limitations on the realism of a game, brief nature of the TIPI questionnaire already discussed in chapter 6, the YCS3 game was not tested as extensively as YCS1. Our sample size is relatively small and are aware that we have to cautiously interpret our results based on statistical analysis. Additionally, we set up 'ad hoc' teams where team members may or may not be familiar with each other. The participants of our study were students who had limited working experience in a socio technical work organization. In literature most works on team performance assume that team members belong to a certain organization and are involve in teamwork processes that enable team cohesion and team orientation. This common background was absent in our study. Therefore the long term effects of the information sharing approach, team factors and team coordination mechanism cannot be predicted with our study.

We will address these issues in the set-up of future studies.

We will now proceed to explain the final game of this research— the disruption board game and the related reserach associated with it in the following two chapters.

CHAPTER 8

# THE ROLE OF SSA AND DSA IN RESILIENT INTERMODAL TRANSPORT OPERATIONS: A STUDY WITH THE DISIORUPTION MANAGEMENT BOARD GAME

In this chapter we will discuss the disruptions and their effects in container terminals, the concept and importance of resilience and the role of Situation Awareness in improving resilience in intermodal transport operations in container terminals. The main contribution of this chapter is the outcome of the investigation of the role of SSA and DSA on decision making to ensure resilient operations, using a tabletop board game that simulates various disruption scenarios in a container terminal, where the performance and behaviour of the participants is analysed at various levels of SA.

## 8.1 The importance of resilience in intermodal transport operations

The performance of complex socio technical systems depends on the coordinated work of multiple individuals, that have responsibility for different subsets of goals, different access to information and different situation perspectives (Roth et al., 2006). The organizational and environmental complexity of these systems combined by human error and external factors give rise to disruptions that negatively affect the performance of these systems (Wilson et al., 2005). In the context of container terminals, unplanned and unanticipated events that affect the normal flow of goods and operations in supply and transport networks are termed as disruptions (Svensson, 2000). Container terminals, which can be characterized as complex socio technical systems, are crucial interfaces between various modes of transportation that drive global trade and economy. Seaports, which host container terminals, have been identified as critical infrastructures, which are essential elements that affect the economical and social well-being of any country (EC, 2008; Mokhtari et al., 2012). Seaport operations are influenced by the complex and dynamic interactions among multiple stakeholders, modes, industries, operating systems, liability regimes, legal frameworks, etc. (OECD, 2005). This implies that if container terminals are affected by disruptions, the negative effects like operational and collateral losses are also felt by individuals and organizations that are dependent on the businesses related to container terminal operations. This knockdown effect is known as ripple effect (Hollnagel et al., 2007). With an equivalent compounded annual growth rate of 10 %, the increasing volumes of containers exert pressure on container terminals to handle them without compromising on efficiency of operations and service quality (Kemme, 2012)). In addition to these factors, intermodal operations at seaport container terminals are managed by disparate groups of individuals and departments who are responsible for complex and time-sensitive technical operations at the terminals. This makes seaport container terminals vulnerable to both external and internal risks and disruptions (O'Reilly et al., 2004; Longo, 2012). It is very important for container terminal operations to be resilient against disruptions to avoid undesirable not only within its organization but also the ripple effects along the transportation network. Resilience is defined as the capability of a system or organization to bounce back to its normal function in spite of disruptions (Sheffi, 2005).

### 8.1.1 Disruptions in container terminal operations

Disruptions have become common phenomena in seaport container terminal operations (Loh and Thai, 2012). The main categories of disruptions are port accidents, port equipment failures, dangerous goods mishandling, port congestion, inadequacy of labour skills, hinterland inaccessibility, breach of security, and labour strikes (Loh and Thai, 2012). These disruptions not only affect the seaport operations, but also can have dire consequences on the operations and activities of the entire transportation and supply network, as well as on the economic and societal well-being of the surrounding environment (Yliskylä-Peuralahti et al., 2011). There are several examples that support this argument. For instance, Figure 8.1 indicates how the unplanned closure of ports in Finland affected the production of several Finnish industries in 2010. In our study we chose scenarios related to accidents, equipment failures and strikes to study the role of SA in preventing and mitigating the negative effects of such disruptions.

Figure 8.1: Effect of Finnish stevedore port disruption on some companies in key sectors (Yliskylä-Peuralahti et al., 2011)

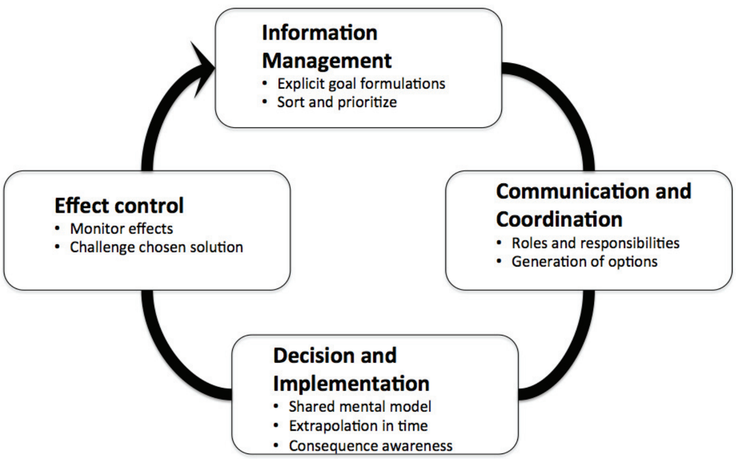
| Sector | Type of company | Time period before production stopped (lack of raw materials) after disruption at port |
|---|---|---|
| Energy | Oil | 2–3 days |
| | Coal | 3 months |
| Food supply and exports | Grain imports/exports | Several months |
| | Meat and meat products | 2–3 weeks |
| | Animal feed and malt | 2–3 weeks |
| | Wholesaler of food | 2–3 days |
| | Milk products | 2–3 days |
| Electronics | Power and automation products | 2–3 days |
| Healthcare supplies | Healthcare products | 2–8 weeks |
| Forestry | Paper and pulp | 12 h to 2 days |
| Metal | Metal products | 2–3 weeks to months |

The East Japan earthquake in 2011 heavily disrupted the operations of the northeastern Japanese seaports, which affected the activities of the warehouses and production facilities served by the port areas (Takahashi et al., 2011). Another famous example is that of the 2002 longshoreman union strike at US West Coast ports, which interrupted services to many US-based firms, with port operations and schedules not returning to normal until 6 months after the strike ended (Cavinato, 2004). A large interoperability study conducted thereafter revealed that the losses for the regional and national economy were estimated to be 1.94 billion dollars for each day the port closure continued (Cohen, 2002). In addition to the economic benefits, seaports also provide societal services in the in the form of job creation. One in 24 jobs in southern California is directly associated with the Port of Los Angeles (Jung et al., 2009), while the Port of Rotterdam employs around 86,000 people, close to 14 % of the total number of inhabitants of Rotterdam (PoR, 2009). We will now discuss the need for resilience in container terminal operations.

### 8.1.2 Principles for organizational resilience for container terminal operations

Several planning and operational departments manage seaport container terminal operations. These departments take part in addressing complex disturbances as well. The common approach to solve complex problems is to decompose them into subproblems and solve them sequentially, in this case, e.g., on a department-by-department basis. This leads to undesirable results and sub-optimal solutions. The inter-dependencies between various planning and operational departments and the need for alignment and coordination of solution strategies have been largely overlooked (Meier and Schumann, 2007). This can be translated to a lack of Situation Awareness among the various departments while dealing with disruptions.

Figure 8.2: Competencies for organizational resilience (Bergström et al., 2010)




The quick detection and management of disruptions by sharing pertinent information to the right person or department at the right time, and having a shared awareness of the effects of disruptions improves the resilience of an organization or a system (Craighead et al., 2007). Although SA has been proven to facilitate cooperative team practices that contribute to system resilience to unanticipated events (Roth et al., 2006), and even considered one of the prerequisites to organizational resilience (McManus et al., 2008), there limited studies that link SA to the principles and theory of resilience (Roth et al., 2006). Therefore in this chapter, we will study how SA affects the performance of an organization during disruption in relation to resilience principles. Before we continue about our study, we have to introduce the principles of resilience.

The resilience of a system or organization is defined by its ability to ’respond to the actual, monitor the critical, anticipate the potential, and learn from the factual’ (Hollnagel et al., 2007).

In addition to the general principles of resilience defined by (Hollnagel et al., 2007), Bergström et al. (2010) defined various competencies needed to be demonstrated by individuals in an organizational while facing escalating situations in complex and dynamic situations that can help them manage disruptions as shown in Figure 8.2. We will study these resilience principles in relation to the different levels of SA (Individual, shared and distributed).

## 8.2 Experimental design and set-up of gaming sessions

Given the undesirable ripple effects caused by disruptions in container terminal operations in the whole transport and supply network, it can be deduced that the resilience of container terminal operations is essential for the resilience and robustness of transport systems as a whole. Although not all disruptions in seaports have such grave consequences as described in the previous section, they cause delays to other parties, as well as backlogs, queues, extra traffic around the port, and chaos in operating procedures, which in turn could lead to safety issues. Therefore, it is essential to improve the resilience of container terminal operations against disruptions (Loh and Thai, 2012). In this section we will illustrate how we study the role of SA in improving resilience of intermodal transport operations using a simulation gaming study, based on the disruption bard game described in chapter 5.

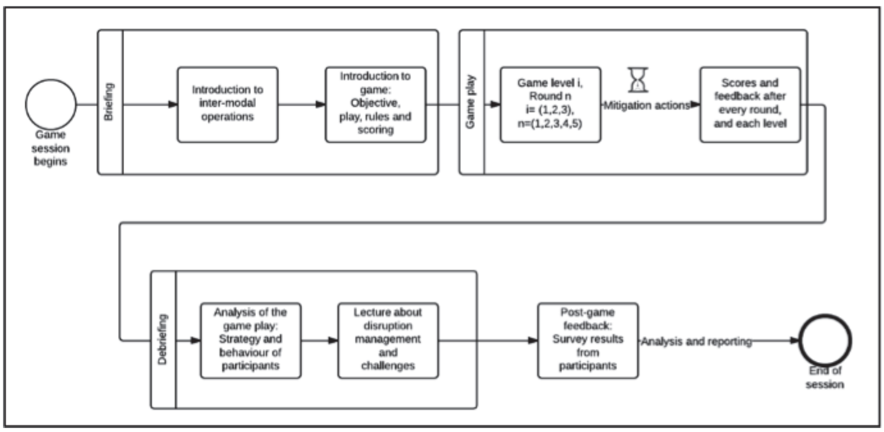
### 8.2.1 Design of the gaming sessions

A simulation game is not a stand-alone instrument. In order to deliver the full potential of the game, it is usually presented to the participants in the form of a game session. For the disruption management game, the game session adopted is described in Figure 8.3. For each of the test sessions, participants were gathered around a table in a spacious room. The room was prepared in advance for the game play, by prearranging the required game objects. Depending on the size of the group one or more game facilitators orchestrated the game play. The game facilitator was given a game manual that describes their role and the method of orchestration.

Every game session of the disruption management game began with a briefing, usually lasting 20 to 25 min. The various intermodal operations, terminal processes, roles in the container terminal, and the equipment used were described in the introduction. The disruption management game was then introduced along with the role of the game facilitator. The objectives, rules, set-up and scoring were briefly introduced. The three different levels of SA tested through this game are,

- **Individual SA: Level 1 of the game** Every player has access to information regarding his/her role. Communication and mitigation actions take place in a black-box like environment.
- **Distributed SA: Level 2 of the game** Players have means to communicate, but only on one-on-one basis. They can develop SA by seeking information from other players, but others are not privy to their communication. Their individual score boards are not visible to each other.
- **Shared SA: Level 3 of the game** All the information shared can be accessed by all players, and they have a 'common operational picture' in this level since they can view all the game boards. There no constraints about the type of communication in this round.

Figure 8.3: Game session designed for testing various levels of SA for resilient operations in container terminals




The game play began after the briefing session. Each level of the game play lasted about 1 h, which meant each round had a duration of about 12 min. After every round, the game facilitator provided individual and organizational scores to the players, along with an explanation of the effect of the decisions on KPIs. At the end of five rounds, which is the end of a level, an overview of the situation at the terminal was presented to all the participants and their decisions are briefly re-visited. This game play repeated in all three levels. Before starting each of the levels, the facilitator introduced the change of rules. The game play was observed thoroughly by the game facilitator, and after every round the decisions and scores were recorded. The game session concluded with a de-briefing session, where the game facilitator explained the principles of disruption management, the challenges faced by practitioners, the relationship of the game elements to the said challenges, the progress of the game play, a review of the scores and the reasons for obtaining these scores, potential alternative strategies, a comparison between scores of different play groups and the reasons for the differences, etc. The purpose of this part of the game session was mainly to provide a learning experience to the participants. After the de-briefing session the game facilitator encouraged the participants to provide feedback about the game and their own learning experience. Finally, an online survey was sent to the participants, to get detailed feedback about their learning experience and further suggestions. The game session is summarized in Figure 8.3.

The game sessions of the disruption board game were conducted in an exploratory setting with participants including 15 academic researchers from a technical university in the Netherlands, 30 professionals from transport and supply chain industry and 80 undergraduate and master students from a business school in the United States. The participant profiles have been already been listed in Table 5.1 in chapter 5. Figures 8.4 and8.5 give an impression of the board game session.

We will now discuss the results based on the analysis of the data generated in the game sessions with the disruption management board game.

## 8.3 Results

The two kinds of data generated in the game sessions were qualitative (observational data) and quantitative (survey data). In each session, the game facilitator observed the game play and made notes regarding the behaviour of the participants. The survey data was gathered via a post-game survey to record their experience related to the board game play. We will first present our observational results.

Figure 8.4: Board game session with professionals

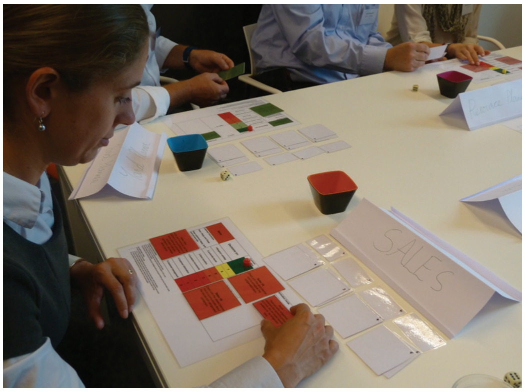



Figure 8.5: Individual player perspective

### 8.3.1 Results from observation

We observed the decision making of the participants towards mitigating the escalating situations in the game at various levels of SA. Our observations are based on how individual, SSA and DSA levels of game play influenced the resilience principles of information management, communication, coordination, effect control, decision and implementation. We have already discussed the these resilience principles are crucial for a complex system to bounce back to its original functionality and performance when disruptions occur.

#### Information management and communication

Participants were able to share information via different communication channels with varying costs and probabilities. Each of the participants was given a limited number of tokens for communication. E-mail communication costs fewer tokens but is less effective than a phone call, which costs more. In the individual SA level, participants were unable to prioritize the urgency of the information to be sent, and would send it via e-mail which sometimes got lost in spam or was not read by the recipient. The lost information could affect the mitigation choice of the intended recipient. There were instances where the information was returned to the original sender after several rounds of communication between participants. Some participants received a lot of information, while others received nothing. As the time grew near to take mitigation actions, participants stopped communicating and started making choices by intuition. In the DSA level, participants were more aware of the roles of the others in the game due to the new communication channels.

They understood the need and the importance of information exchange. For example, in a game session with undergraduate students, the yard planner contemplated whether to use a phone or e-mail to inform the control tower about an AGV break down. She realized that e-mail might be slow since safety of the terminal might be compromised so she called the control tower even though it costed her more. The situation shared SA level as participants since the participants has a common operational picture of the unfolding situation. They became more aware of the roles and objectives of others during the game, the communication patterns improved and relevant information was shared at the right time with the right participants, directly affecting the mitigation actions. This improved the resilience of the terminal, by the indication of improved KPIs that were the highest at the SSA level.

### Coordination

In general, regardless of the SA level, whenever there was time pressure participants preferred to take individualistic decisions rather than aligning their plans. For example, in a game session with professionals in the transport industry, the sales manager got several information cards regarding the strike, but he did not read some of the cards before making his choice since the game master requested to speed up the decision making. At the individual SA level, participants were unable to understand the need to align their mitigation actions, and if they did realize the need, they had excessive or inadequate information to do so. In the same example, the sales manager had most of the information cards, while the yard planner did not receive any information card. The coordination of plans did not improve at the DSA level compared to the individual SA level. However we observed that participants coordinated their plans the best at the SSA level. In a game session with researchers at TU Delft, all the planners, control tower and sales manager chipped in their communication tokens to organize conference calls to organize alternative transport options to customers while maintaining the productivity and safety of the terminal. Although aligning their plans and making joint decisions was time consuming they achieved a well balanced score between safety, productivity and customer satisfaction.

### Effect control, decision and implementation

Participants received feedback from the game master about their decision and the effect on individual and organizational score. For example, if the sales manager chose to offer free alternative transport options for clients (choice A) against charging the clients a small fee to transport their containers (choice B), the individual score of the sales manager increased together with the organization KPI of customer satisfaction, but since it costs the terminal a lot of money to organize free transport the performance of the terminal in terms of profit falls. However the choice B was a more balanced option, where although the customer satisfaction might be slightly affected, the profits won't be affected. During the game play, participants initially focused on their individual scores in the individual SA level. With each successive round, the escalation of the disruption negatively affected organizational scores. After observing these effects in a few rounds of game play, some participants sacrificed their individual scores to compensate for the organizational score of the container terminal, whereas some other participants were more strategic and increased their individual gains. The performance improved in the distributed SA level and was the best in the shared SA level.

### 8.3.2 Results from survey

The post-game survey focused on understanding the learning experiences of the student participants after the game session, regarding the concepts of communication and information sharing, coordination and interdependencies during disruption managements for resilient intermodal seaport container terminal operations. The results obtained from the survey are described in the following subsections.

#### Overall experience of the participants

The board game was designed to be a research instrument to study SA and resilience in complex systems. However, the majority (80 out of 125) of the participants were students in the field of logistics, supply chain and transportation. Since the board game session was administered as part of their regular course on port planning operations we gathered their learning experience in the post game survey. We asked them if the learning principles of the disruption management game would prepare and help them to handle real-world disruptions as future supply chain professionals.

About 37 % of the participants felt that the learning experience from the game would be helpful, 16 % responded that it would be very helpful, and 38 % felt that it would be moderately helpful, 9 % answered slightly helpful to better prepare them to handle real-world disruptions. Not even one participant responded that it would be not helpful. In addition to the rating scale as a response to the above question, there was a comment section to gather a more descriptive experience of the participants. The responses were largely positive. The synopsized comments are as follows. Most of the responses (75 %) began with 'I really enjoyed the experience of the game session'. We summarized the retailed remarks of the participants. Participants felt that the board game was a very interesting, interactive and practical simulation. They opined that it was a very good exercise to understand the importance of disruption management in transportation and supply chains. They that the game showed that it was difficult to pre-determine a perfect or optimal solution to manage disruptions. However two participants felt that the game could have been more beneficial to the participants if they had more experience in the port industry. An critical feedback against the game was about its complexity since some participants took longer than others to understand the game mechanics.

We will now present the responses from the survey related to the resilience principles.

### Information management and communication

We have already discussed earlier in this chapter that relevant information sharing and communication are essential for resilient operations during disruptions. To understand how well the participants assessed the importance of information sharing and communication for resilient operations during the SA levels of the game play we asked the participants about their thoughts on the relevance of information sharing for your decision-making during disruption management.

In response, 20 % of the participants felt that it was very relevant, while 57 % felt that it was relevant, 16 % felt that it was only slightly relevant, whereas 7 % of the participants did not think that it was relevant at all. In addition to the above rating scale, an open-ended question was asked regarding the opinions of the participants on communication and information sharing after playing the disruption management game. Most of the participants (80 %) felt that communication and information sharing were extremely important for disruption management of intermodal operations in seaport container terminal. Some of the descriptive answers of the participants mentioned that communicating the right information at the right time was very important for the right decision making during disruptions. Communication had to be done judiciously as time and resources are not unlimited during a disruption scenario. Integrating the different pieces of information was the key to make good decisions. Communication was very important because it can affect crucial decisions of other participants during disruption management for resilient operations.

### Coordination

We modelled several interdependencies between the roles and the actions they can take within the board game. Therefore participants have to coordinate and align their plans in order to make sure they have a well balanced organizational score between safety, performance and customer satisfaction. To understand the effect of coordination on their decision making we asked participants were asked an open-ended question about how much they value coordination for decision making during disruptions. The synthesized responses stated that coordination was essential for effective disruption management. It was very difficult to coordinate a good solution strategy during a disruption scenario. All participants needed to coordinate amongst themselves to mitigate disruptions through effective communication.

### Effect control, decision and implementation

One of the key features of the board game is that the game master provided the participants the effects of their decisions after every round. To assess the influence of the feedback, we asked the participants if the feedback given after each round (the announcement of scores and system status) helped them to make better decisions in the subsequent rounds. In response to the above question, 45 % of the participants replied that it was very helpful, 27 % reported that it was somewhat helpful and 28 % of the participants did not find it helpful for taking decisions on mitigation action. In the survey, the learning effect regarding decision and implementation had not been explicitly measured, but the overall decision and implementation regarding mitigations actions is the consequence of good information management, communication, coordination and effect control (Bergström et al., 2010). However, in a concluding open question of the survey, that prompted the participants to add their comments on other aspects of the game, we gathered several responses that were related to the decision and implementation. Participants felt that decision making during disruption management was more complex and interdependent than one thinks. It was important to adopt an inter-dependent view during disruption management rather than a top down approach: a big picture perspective is essential. The focus on individual score hinders the 'common good' (local optimum vs. global optimum). Participants needed to consider organizational scores before making mitigation choices.

Based on the discussed results both from the observation as well as from the survey, we drew some conclusion on the role of SA in resilient transport operations. We will provide the summary of the results together with a discussion on SA and resilience principles.

## 8.4 Summary and discussion

### 8.4.1 Summary of the results

The overall observation of the game play was based on the participants' approach to information sharing, communication, and balancing trade-offs. One of the most promising results that emerged from the analyses was the clear difference in the behavioral patterns of players at different SA levels of the game. In level 1, which represents the individual SA level of the game play, all players had limited awareness and understanding of the disruption scenario, the potential effects of their mitigation actions, and their role and objective in the game, and they made individualistic decisions. In the early rounds, there was a lot of confusion, distress among players while having to communicate and take mitigation actions in a black-box-like environment, given the time pressure. Largely, information was being requested from/sent to the wrong providers/recipients. In the distributed SA level, which is the level 2 of the game, players had relatively a higher awareness of the situation. They made good use of the available communication channels, as they understood who needed their information and who possessed the information they needed. The flow of redundant information reduced compared to level 1. Players tried to attune their plans, considering the decisions of others. In level 3, which represented the shared SA level, players had more discussions and negotiations. Players came up with innovative ways of teaming up to jointly mitigate the situation. Sometimes, players compromised their individual KPIs to boost the overall KPIs. Well-informed and rational decisions were best made in level 3.

### 8.4.2 Resilience principles and SA

We have clearly observed that the resilience principles were closely associated with SA. We will now discuss how each of these principles had been highlighted during the game play.

**Information management** was observed when the players need to process the available information they are provided with, as well as the information received from other players in the course of the play. Players needed to exchange information using information cards— the right information to the right player at the right time to make the optimal mitigation action choice. They had to be aware of their individual goals, the roles and responsibilities of other players, and situational understanding of the effects. They also have to prioritize information received and request necessary information to make the best mitigation actions.

**Communication and coordination**: If the participants did not exchange information and aligned their activities, their mitigation actions would be redundant or cancel each other out without increasing the KPIs, and thereby hurt the resilience of the terminal operations. Several channels of communication were provided in the game such as e-mail and phone. These could be utilized by spending 'communication tokens' that represent time and resources spent for communication. Coordination mechanisms in the game included aligning plans using conference calls, de-briefing sessions and teaming up.

**Effect control, decision and implementation**: After each round the effect of mitigation actions of the players was reflected on the scores. Individual mitigation actions of players not only affect individual scores but could also affect, either positively or negatively, the scores of other players. All the individual scores contribute to the organizational score of the container terminal. Therefore the effect control is modelled in terms of score, which enables players to reflect upon their choices to prepare for the next round. The decision and implementation competencies have been modelled as the various choices participants have to make to mitigate the disruption.

Resilience of intermodal transport operations is essential for the robustness of the entire transport transportation system. This chapter discusses the role of SA in improving this resilience. Based on the observational data of the simulation gaming sessions it can be observed that shared situation awareness contributes most to resilient transport operations. This also resonates with earlier research on the topic by Roth et al. (2006); McManus et al. (2008) who state that SSA is essential for effect team performance in the context of rail road repair operations. In a related field of disaster management, developing a common operational picture is a pre-requisite for decision making towards mitigation measures (Javed and Norris, 2012). Shared Situational Awareness facilitates the common operational picture. However it must be noted that creating this common operational picture is time consuming when there are many actors involved. Sometimes not all actors need to possess the same information and when time pressure is high in critical situations DSA maybe better than SSA (Mendonça et al., 2007). We will discuss the implications of SSA and DSA in socio technical systems further in detail in the following chapter.

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CHAPTER 9

# DISCUSSION

In this chapter we will consolidate all the research results from the individual chapters. We will compare and contrast these results to create a discussion that will lead us towards answering our main research questions together with testing our initial SA framework for socio technical systems. We will begin our discussion with the research process used for this study.

## 9.1 A round up and discussion on developing and using games for SA research in socio technical systems

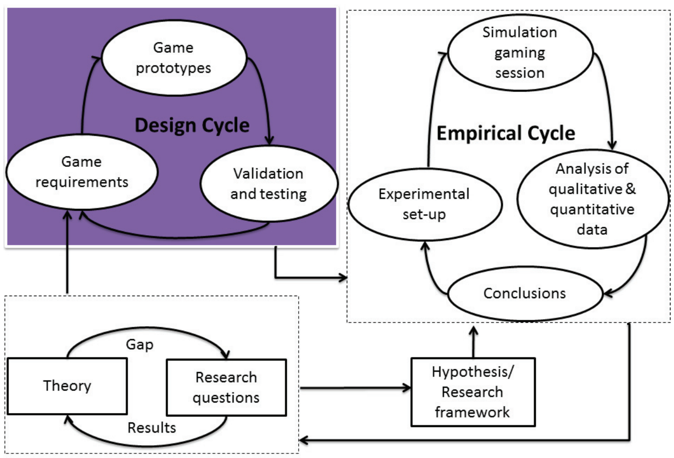
The overall objective of all the three games developed in this research was to measure SA and explore factors affecting SA in socio technical systems. We followed a research process proposed in 3.7 in chapter 3 to develop and use these games for SA research in intermodal transport operations in container terminals. We will begin our discussion with the design cycles of the three games used in this research.

### 9.1.1 Comparing and contrasting the design cycles of the games

Measurement of SA in complex systems is not an easy task. Each of the available SA measurement tools have their advantages and disadvantages (see Appendix A) and the choice of measurement is mainly affected by the objective of the researcher and the constants of the testing situation (Endsley and Garland, 2000). We chose simulation games as a performance measure of SA. Our choice is motivated by several valuable traits of simulation games: ability to engage participants, the possibility for researchers to observe their behaviour in a controlled and safe setting, and to analyse the results from the game through in-game metrics, direct observation together with the feedback from participants.

We have developed and used three games— YCS1 (Chapter 6), YCS3 (chapter 7) and disruption management board game (chapter 8) to study SA in socio technical systems in the context of container terminals. We used an iterative design process highlighted in 9.1 to design games as research instruments that are used in the empirical cycle of our research approach. We will compare the design and development of the three games as research instruments and provide our experiences and lessons learnt. This discussion will help us answer our main research questions in the final chapter.

Figure 9.1: The design cycle of our research approach




The first stage of our design cycle was meant to define the **game requirements** based on our research objective. The YCS1 game was designed to the role of SA on decision making and performance and to study factors affecting SA in individual actors in container terminal operations. Similarly, the research objectives of the YCS3 and the disruption management board game were to compare and contrast the role of shared SA and distributed SA in team and group performance respectively. YCS1 was designed to be a single player web based microgame, while YCS3 was a multi-player microgame that was designed on similar principles of YCS1. From a research perspective the main advantage of these games is that many data points can be collected due to the short time needed to administer such games. For large and varied groups of participants that are geographically distributed, scalability and portability are other key advantages. The disruption boardgame is a multi-player game but is very different to YCS1 and YCS3 because it is an analogue paper based table top game. The main reason behind the choice of developing the board game was the appeal of a low-tech, cost effective game that offered a component of social cohesion that has been known to important for developing SA in teams.

We will now describe how our game requirements were transformed into contextualized game play in the form of **prototypes** and our related experience. The prototyping of all the three games was preluded by game storming sessions together with subject matter experts, game designers and researchers. For the disruption management game the researchers were the game designers. Among the three games the YCS1 was relatively easily to prototype based on the game requirements generated in the game storm sessions. This could be attributed to the clear problem descriptions provided by the subject matter experts, the single player element of the game and the expertise of the game designer related to designing single player micro games. Although it is important to study SA in individual actors in socio technical systems, it is all the more crucial to investigate its effects on teams and groups. Therefore we had to focus our efforts on multi-player games. YCS3 was designed as an multi-player extension of the YCS1 game. Although the problem description and the conceptual idea of the game were already available, it was a challenging task to prototype the YCS3 game. Balancing the tasks allocated to the various roles and their interdependencies in the game posed a big challenge to ensure playability was not lost while accommodating realistic elements in the game. The short nature of the multi-player game was an issue for the research set-up since it needs to allow players to communicate, so we had to increase the number of tasks for all the players to extend play time. Additionally designing a multi-player game where the researcher has the control over the set-up of the game was a major technical hurdle. Although the game designer was a professional, they did not have expertise in designing short multi-player games used for research purposes. Therefore the first prototype suffered severe technical glitches due to server problems and synchronization issues. The final prototype of YCS3, although successful was not very scalable and portable since the researchers had to be present to ensure controlled experimental setting. Although YCS3 suffered sever technical hurdles during prototyping, the time required to produce an improved version was relatively short due to the easy modifiability of game with respect to the scoring system, addition of variables and to model the interdependencies without having to completely overhaul the game. In our experience, prototyping the board game was the most challenging and time consuming. Given the task interdependencies of the roles, every minor modification to the game required a reproduction of all the cards. It took us almost 8 months before the successful prototype of the boardgame emerged. Although the final prototype was met with interested and enthusiasm the participants, it was heavily dependent on the game master therefore offered poor scalability and portability.

We will conclude this sub-section by comparing the **testing and validation** process of the three games. The main purpose of all the three games was to serve as research instruments for SA research, therefore validation and testing was an important part of our design cycle. The experiences from the testing sessions helped us to improve the prototypes and the validation help us establish the reliability pf the games as research instruments. YCS1 was extensively tested since it was played 12,700 times by student participants, and over 5000 times by professionals. This level of testing was possible due to the single player nature of the game as well as the short playing time. A researcher or game master was not necessary to play the game therefore participants could also play the game in their free time on a web browser. Given the ease of play, we could also validate YCS1 quite extensively. It performed very well against psychological, structural, process and predictive validity constructs suggested by Raser (1969). Since YCS3 is an extension of the YCS1 game we extended its validity to its multi-player version. However we must admit that we could not test YCS3 extensively like that of YCS1 because for a multi-player game four players should simultaneously play the game under the guidance of the researcher. Similarly testing the game was also challenging due to the length of the game and dependence on the game master. The board game however satisfied the validity constructs except for face validity because there was no standard procedure for decision making during disruptions therefore it was not possible for experts to realism of the decision choices present in the game. Based on this discussion together with the detailed description of the design cycles of the games in chapters 4 and 5 we will now present our lesson learned and conclusions on designing game for SA research in socio technical systems.

### 9.1.2 Lessons learned on designing games for research purposes

We had rich and varied experiences with designing simulation games for SA research in socio technical systems. We gathered several lessons on the considerations that need to be made to design effective simulation games for research. Towards answering the RQ2, we will present these considerations and recommendations below:

- **Type of game—** The choice of single player or multi-player game will largely depend on the research objective, the type of research (quantitative or qualitative). Single player games are relatively easy and straightforward to design and use for research. The researcher also has a lot of control over the set-up of an experiment and data collection with single player game. Using single player micro games enables for large scale data collection for quantitative research. If a multi-player game is a requirement for a quantitative study, researchers could first explore if a quasi-multilayer game could be developed using automated players with simple Artificial Intelligence (AI). Multi-player games (both analogue and digital) are more suitable for qualitative studies since they involve communication and interaction among participants which cannot be quantified easily. Additionally given the multi-player set-up, conducting quantitative studies with groups or teams is challenging and time consuming due to the low number of data points since one data point represents a team or group and not an individual.

- **Computational and technical requirements–** Developing simulation games, especially digital games for research is an iterative, extensive and time consuming process that can also be expensive. An ideal research environment would require a professional game developer working closely with the researcher to develop simulation games. Bailey (2008) also states that one of the main constraints of employing simulation games in research is the computational cost. Digital games also require technical and electronic equipment such as computer, tablets, keyboards, mouses (mice?), earphones etc. Web based digital games also require a stable internet connection during the game session. In the absence of a professional game designer, researcher could resort to low-tech tabletop games, but we will mark recommendation with caution because, in our experience we found that designing a valid and playable analogue simulation game was more challenging and time consuming than its digital counterpart.

- **Reliability–** Simulation games for research need to be validated to ensure their purpose as a reliable research instrument. Validation of simulation games is not a standard process. The traditional validity constructs may not apply for all games. In our experience, experts could not conduct face validity in its traditional sense for disruption board game because the type of decisions made under disruptions are not pre-determined. The experts however could relate to the scenarios, time pressure, need for communication and coordination under a time pressed and critical situation, all the elements we intended to represent in the game. Our experience is consistent with the constructive approach towards validity proposed by Peters et al. (1998); Vissers et al. (2001). Reliability is not limited to the validity of the game but how when the game performs when used for a study. Data collection in digital games may be interrupted due to technical glitches in the game, unstable internet connection, faulty devices etc. One way of testing the reliability of data collection is to write down the scores manually for random participants and compare them to those in the database at different instances. We had to overcome many technical challenges to ensure reliability of our game data in the digital games. The reliability of game data is paramount to the value of the simulation game as a research instrument, therefore it is important for researchers to focus on a well designed and robust data collection regime for the game.

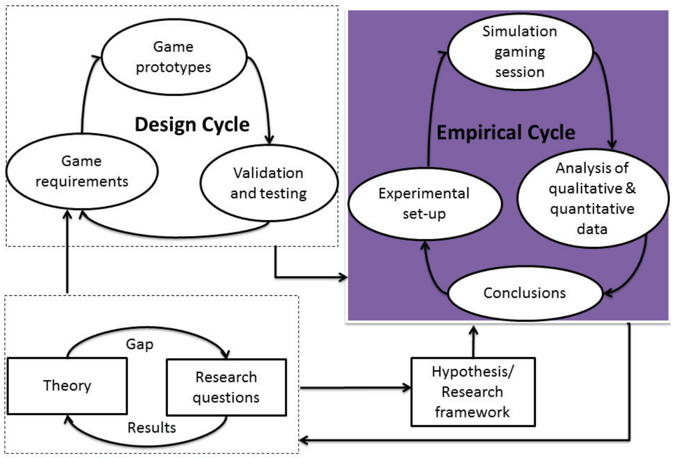
- **Scalability and portability—** For quantitative studies the ability of using the game with a large number of participants, preferably irrespective of geographical local is very important to collect as much data as possible across diverse participants. In our experience YCS1 was the most scalable while YCS3 had limited scalability due to the necessity of the researcher presence. The board game had the least scalability due to its long playing time and dependence on the game master. Therefore the results of YCS1 are quantitative, those of YCS3 are a mix of qualitative and quantitative analysis, while the results of the board game are qualitative.

- **Participant involvement and social cohesion—** In our experience the involvement of participants in the game was best noticed during the game play of the disruption management board game. The social aspect of sitting around a table in a relatively casual and relaxed environment couldn't be simulated in the digital game, YCS3. When research studies focus on social interactions between participants. tabletop board games maybe an apt choice since they prove a rich lens into the communication, coordination and negotiation patterns of participants in a relatively realistic manner.

Based on our experience and lessons learned we will conclude this section together with the following discussion.

### 9.1.3 Comparing the empirical cycles of the three studies

Figure 9.2: The empirical cycle of our research approach




The first step in our empirical cycle highlighted in Figure 9.2 is to design an **experimental set-up** using the simulation games to answer the various research questions and to test the SA framework proposed in chapters 1 and 2 respectively. The studies related to YCS1 and YCS3 were designed to be quasi-experimental and the study related to the board game was observational and subjective. The set-up of YCS1 and YCS3 was designed comprehensively with the help of a protocol and script described in Appendix E. The board game session was not scripted because the same researcher conducted all the sessions that were analysed in this book.

The set-up of the **simulation gaming sessions** of all the games was fairly similar for YCS1 and YCS3. Every session began with a briefing lecture where the researcher explained the basics of container terminal operations, the research objective and the rules of the game. In the case of YCS1 and YCS3, players were asked to fill in a pre-game survey to capture their demographics. They were allowed to try a 'tutorial' version of the game before they played the game whose results would be recorded for analysis. After the game play players answered surveys regarding their SA and general opinion about the game. The gaming session related to YCS1 also had an additional simulation exercise known as MATB-II developed by NASA to test and train multi-tasking skills. All the data related to the games was recorded in an online data base. The MATB-II data was recorded locally on participant computers. The gaming session ended with a debriefing session where the researcher discussed the game elements and related them to real life challenges and discussed the strategies to overcome them. Participants gave their vocal opinion regarding the game during the debriefing. The board game set-up also had the briefing and debriefing sessions but did not offer a tutorial. The data collection in the board game was more complicated than YCS1 and YCS3. Since all the participants had individual game boards, it was hard to keep track of how the scores progressed during the game play even if the whole session was video taped. The researcher who played the game master, not only had to steer the game play but also had to make in-game observation, therefore was subjected to significant information overload. It was partly a design flaw where the handling of the game session could not be easily delegated to another researcher. **Data analysis** for the YCS1 game was largely quantitatively due to a high number of data points (N=143) for reaching conclusion with statistical significance. For YCS3 we adopted a mix of quantitative and quantitative analysis techniques for a sample population of 26. The qualitative results based on observation of game play videos were meant to support or challenge the results generated by the quantitative analysis. We already mentioned that data collection for the board game was challenging, therefore our analysis was qualitative based on in-game observation by the researcher and the post-game survey answered by the participants referring to their experiences of the game regarding SA information sharing, disruption management, resilience etc.

Our design cycle provided simulation games as an input to our empirical cycle in our research approach discussed in the following section.

We have already discussed in detail in chapters 6, 7 and 8 on how we employed the three games for empirical research. In the following section we will compare and contrast the empirical cycles related to each of the games, present the lessons learned and end with the discussion and conclusions related to the results of the empirical cycle.

**conclusions** were drawn from the results of the data analysis to answer the research questions in teh final chapters. The results also helped us to test our initial SA framework. We have provided this discussion at the end of the chapter that led to an update SA framework.

In addition to the above results related to SA in socio technical work organizations, our empirical cycles also provides several lessons related to conducting research studies using simulation games. We will present them in the next section.

### 9.1.4 Lessons learned from the empirical cycle

The main take-away points from our research experience with simulation games can be summarized in the following three categories:

- **Preparation and planning**: We conducted our studies in the United States, Netherlands and Germany across varied participants in universities and professional organizations. Identifying and recruiting participants, scheduling time slots for gaming sessions are time consuming that require much foresight. These sessions have the potential to gather valuable and rich data from a variety of participants, and can be lengthy and expensive. Therefore the researcher should make sure that every session is successful so that reliable data can be gathered. This required extensive preparation and planning. In order to ensure consistency and reliability of simulation gaming sessions we designed a detailed protocol and script for the YCS1 and YCS3 games (see Appendix E). We had to account for technical glitches related to equipment, server connection etc. We also had to receive the approval of the ethic board of two universities to conduct our research, that took a few weeks. Therefore we recommend simulation gaming researchers to invest sufficient time and effort to carefully prepare and plan to organize successful gaming session and gather reliable data.

- **Reliable data gathering and analysis**: Simulation gaming session provide a rich amount of data— both qualitative and quantitative. In order to record the data in a reliable manner, researchers should take some precautions. In our case, the game data was recorded in an online database but in some circumstances the data was improperly recorded due to issues with the game server. As a backup measure we asked the participants to write down the score on a piece of paper right after the game play. For the YCS1 game session the MATB-II data was stored locally in the participant computers, so we had to collect data from each of the computers in a short periods time. Under such circumstances data could be easy mixed up especially since the gaming session is anonymous.

- **Participant selection**: All our studies were conducted with student participants in the field of logistics, supply chain and transportation. This is mainly due to the accessibility to student participants in home and partner universities. Although our student participants had basic knowledge of the container terminal operations, they didn't have the practitioner's knowledge of the real world operations. Recruiting experts in the study is very difficult due to their busy schedules and their expensive hourly rate. The involvement of experts in our study was limited to design and validation of the games. The validity of our results would've been further enhanced if a good portion of our participants were experts and we could've studies the role of professional experience on SA and planner task performance.

The results from the simulation cycle helped us answer the research questions and provided valuable lessons learned. We will discuss the implications for the SA framework proposed in chapter 2.

### 9.1.5 Discussion on developing and using simulation games for research

Simulation games have been traditionally used to train specific skills, transfer knowledge, or develop new strategies or policies. More recently, games are being used as a means to analyze and change complex systems in many ways. One of the main criticisms against simulation gaming as a research method is the thematic diversity and theoretical and methodological pluralism, which are considered as weak credentials in academic research (Klabbers, 2009). Paradoxically, the main criticism of gaming as a research method happen to be its key strength when applied to socio technical systems because these systems fall under multi-disciplinary research. There is a wide variety of fields in which simulation games have been employed, both in research and practice, and for a broad range of purposes, like training, teaching, performing scientific research and experiments (Peters and van de Westelaken, 2011; van Os, 2012). Simulations and games have been gaining importance in research and education both as heuristic and as data-gathering tools(Bailey, 2008). However there is no standard procedure related to designing and using simulation games for research purposes. Therefore we developed a design procedure discussed in detail in chapter 3 to develop simulation games for research purposes. We followed this procedure to develop three games during the course of this research. We used these games to conduct SA research in socio technical systems. Measuring SA in such systems in complex. Each of the available SA measurement tools have their advantages and disadvantages and the choice of measurement is mainly affected by the objective of the researcher and the constants of the testing situation (Endsley and Garland, 2000). We designed the simulation games to be a performance measure of SA. Performance measures offer an indirect measure of SA by calculating the performance of a certain task during a simulation. The assumption underlying these techniques is that the performance is mainly affected by SA (Salas and Dietz, 2011). Performance measures are very useful to assess SA by measuring participant performance during a task (Salmon et al., 2009). In many military exercises, simulation games have been used to measure SA based on the performance or score in the game (Nofi, 2000). We extended this concept to socio technical systems within the context of container terminal operations. We gathered several lessons learned during our research journey. Based on our experiences we can conclude that simulation games can be effectively designed for research purposes especially in socio technical systems. Researchers should however carefully consider the aspects of the game type, computational and technical requirements, reliability, scalability and portability and participant involvement while making their design choices.

We have established that simulation gaming is a suitable research method to study SA in socio technical systems within the context container terminal operations. We designed three simulation gaming studies to answer the research questions posed at the beginning of this book. These answers, mentioned above, helped us reflect on our initial SA framework represented in Figure 2.7. We will now pit these results against our initial ideas to verify their standing. We designed our initial framework with the premise that Shared SA is suitable for teams (members with same goals) whereas Distributed SA is more apt for groups in a system (members without a shared goal). We tested this presumption in chapters 6 and 8 and found that SSA or DSA both have a role in team task performance and their prominence in different group settings is affected by several factors. This evidence changed our outlook towards categorizing SA in socio technical and according updated our SA framework described in the following sub-section.

## 9.2 Cross case analysis of the three SA studies in intermodal transport operations

We proposed our motivation and key research gaps to study SA in socio technical system in chapters 1 and 2. We also proposed an SA framework for sociotechnical systems based on existing individual and group SA theories. We will now confront our results from the empirical cycle to test the notions represented in Figure 2.7.

### 9.2.1 SA in individual actors

In chapter 2 we introduced the three prominent schools of thought for SA in individual actors— Endsley (1995)'s three level model for decision making in Figure 2.1, Bedny and Meister (1999)'s activity theory model in 2.2, Smith and Hancock (1995)'s perpetual cycle model in Figure 2.3. In our initial research framework in Figure 2.7 we considered Endsley (1995)'s three level model depicted in to be representative of SA in individual actors in socio-technical systems. We will discuss whether this proposition still holds true based on the results of our study.

One common characteristic of all the theories of Endsley (1995), Bedny and Meister (1999), Smith and Hancock (1995) is that they all state that Situation Awareness is goal oriented. That means actors respond to a situation based on a performance objective or an indicator related to their job or situation. In our case, we asked individual participants to try to reach the maximum score possible for an integrated planning task in container terminal operations. The YCS1 game had several visual and audio cues related to the arrival and departure of ships, visual warning signs when resources are under utilized. Participants have to follow these cues and constantly modify their plans and resource allocation based on the updated information provided to them. This pattern of decision making is very closely related to naturalistic decision making proposed by Zsambok and Klein (1997). The historical top scorer of the YCS1 game was a subject matter expert with more than 15 years of experience in planning software for container terminals. This also supports the paradigm of naturalistic decision making that states that subject matter experts not surprising outperform their novice counterparts because they have 'calculated intuition' derived from their experience especially under time pressed situations (Klein, 2008; Randel et al., 1996). YCS1 is a micro game, where players are confronted with a relatively complex planning task while having to process a lot of information, understand the interdependences and constantly update their plans within a short period of time. These characteristics are typical of the nature of work in socio technical work organizations (Carayon, 2006; Vicente, 1999). Therefore our results support the notion of Zsambok and Klein (1997) and Klein (2008) that naturalistic decision making is the most suitable decision making paradigm for actors in sociotechnical systems. Zsambok and Klein (1997)'s states that the pre-decision stage for naturalistic decision making is based on the three level model of Endsley (1995) since the ability to perceive a situation, understand its significance and predict the consequences for a certain decision is very important to make quick and relatively accurate decisions in operational situations in socio technical systems. Comparing this with Bedny and Meister (1999)'s activity theory, we can observe that the activity theory model resembles a decision making model rather than a model that describes SA. In this model SA is a component that facilitates decision making, where actors evaluate the consequences of their decisions based on a performance indicator and their performance is also based on past experience. Therefore we don't recognize the value of activity theory model to describe SA in comparison to Endsley (1995)'s model. When we consider the Smith and Hancock (1995)'s perpetual cycle model we can neither confirm nor discredit the theory because although the model describes that individual actors need to constantly modify their actions based on the available information, it doesn't make a direct link to decision making and performance. The model also does not identify characteristics of an individual actor that could affect their actions like expertise and skills. We used the YCS1 game to study individual SA and factors affecting individual SA and planner task performance in intermodal transport operations in container terminals in chapter 6. We have confirmed the important role of SA on planner task performance in this chapter together with the positive significant effect of multi-tasking ability and the negative moderating effect of the personality traits, openness to experience. This could mean that, in theory, the model could be applied both to human actors and software actors/ agents. While this characteristic could be a merit of the model, which also explains why researchers like Salmon (2008) and Stanton et al. (2006) chose to use this model for individual SA for agents and human actors alike. Our study focusses on human actors and in chapter 2 we have confirmed the important role of SA on planner task performance in this chapter together with the positive significant effect of multi-tasking ability and the negative moderating effect of the personality traits, openness to experience. We have already discussed in 2 that we aren't yet in a position to assume that the behaviour and the nature of human actors and agents are the same. Therefore we can conclude that, our YCS1 study on SA in individual actors supports and reiterates our initial claim that Endsley (1995)'s three level model for decision making is the most suitable to represent SA in individual actors in sociotechnical systems

We will now discuss the implications of results with respect to SA in group settings in our initial framework.

### 9.2.2 Comparing the roles of SSA and DSA in collective settings (teams, groups, organizations)

We have discussed in 2 that SA research in sociotechnical systems is not comprehensive especially in collective settings (teams, groups etc.). We compared the existing theories on SA in collective settings— Team SA by Salas et al. (1995b), Shared SA by (Endsley and Jones, 1997) and Distributed SA by Salmon (2008) and Stanton et al. (2006) and presented our first ideas on SA for collective settings in sociotechnical systems in Figure 2.7. We proposed that Shared SA is suitable for teams and Distributed SA is most suitable for all other collecting settings (groups and organizations in the system). We will results of this research together with theory to confront these initial claims. During the course of this research we conducted two studies using the YCS3 multi-player game and disruption management board game to study SA in collective settings. We have already established in the preceding sub-section that SA is crucial for the performance and decision making for individual actors dealing with container terminal operations. We also confirmed the same for actors in team or group settings in chapters 7 and 8. However the role of SSA and DSA in team task performance differed significantly between the two studies. In chapter 7 we saw that DSA level of game play led to superior task performance compared to SSA level in the YCS3 study, while in chapter 8 the SSA level outperformed the DSA level of game play in the disruption management board game study. This directly contradict our initial notion that SSA is more suitable for teams and DSA for groups and organizations at a system level.

This difference in the studies could be attributed to several factors. The key variable was the time available for collective decision making. The short time span of YCS3 exerted a lot of time pressure on the participants and forced them to make quick decisions, while the board game gave them sufficient time to think and deliberate before making decisions.

However, the YCS3 had teams who were fully aware of their shared goal, therefore team members didn't need to spend time on working out a shared goal and there was very little room for disagreements. However in the board game study, it was in a group setting where some participants had a shared goal while some others did not have it. Even when the participants had a shared goal there were not aware of it. At the SSA levels group members had a higher awareness of their shared goal compared to the DSA level. This shows that we cannot distinguish teams and groups just by whether they have a shared goal or not. This is because in socio technical systems a shared goal might need to be established by a team or group and may not be clearly defined (de Bruijn and ten Heuvelhof, 2008). This is a contradiction to the assumption that a given team is aware of its shared goal, which is generally considered as a prerequisite to SSA by Endsley and Jones (1997) and Salas et al. (1995b). We found that under extremely time pressed situations, similar to the scenarios simulated in YCS3, DSA among team members contributes to superior performance compare to SSA. However, when participants have time to deliberate, similar to the scenarios in the board game, SSA among group members contributed to superior results compared to DSA. We noticed the negotiation and transactions in the SSA version of board game more than in the DSA version. This partially contradicts Boy (2009)'s notion that negotiations and transactions are characteristics required to develop DSA alone. We have seen that they can be used to develop SSA by developing a shared goal. We have discussed earlier that all the major SA theories consider that SA is goal oriented but the emphasis on goal orientation is not marked in SSA model of Endsley and Jones (1997) and DSA model of Salas et al. (1995b). Even our initial framework did not make this important consideration.

In both studies, we noticed that, another key aspect that influenced the differences between SSA and DSA levels of the game play was the information sharing mechanism. In the YCS3 game the SSA level of game play yielded poor results for the teams because due to the time limit sharing information and processing it to build a common operational picture within a short period of time very challenging. Therefore a distributed approach of information sharing of Salmon (2008), where information is shared only with the required person or only given when requested was more efficient in the YCS3 game play. In the board game study we noticed information asymmetry, where some participants received a lot of information and some did not receive any. There was information overload as well as insufficiency for the participants— both negatively affected the individual and overall performance. Therefore building a common operation picture by sharing all relevant information, suggested by Endsley and Jones (1997) and Nofi (2000), was more effective for decision making in the disruption management board game. Effective and efficient information sharing for decision making is a challenge in socio technical systems especially when individual actors are geographically distributed (Carayon, 2006; Vicente, 1999).

Both our studies were conducted with teams and groups located in the same area. This can be viewed as a key limitation of our study and our initial framework because geographically distributed teams are the key feature of socio technical systems and we did not represent them in our studies as well as our initial framework. Based on the above discussion we can conclude that our initial notion that SSA was more suitable for teams and DSA for organization and network levels was not valid. Both SSA and DSA play a role in SA in teams and groups within socio technical organizations under different conditions and situations based on the distinctive elements characterizing the complexity of decision making in socio technical systems— goal orientation, information sharing mechanism and geographical location. Therefore we would like to propose an updated framework to represent these conditions and situations in the form of SA configurations as a combination of the above mentioned three characteristics.

## 9.3 Updated SA framework for socio technical systems

The updated SA framework is represented in Figure 9.3 The organizational hierarchy of socio technical systems consists of individual actors, and teams and groups within an organization, and a network of organizations (Appelbaum, 1997). We have seen the importance of teams and groups within an organization, therefore we divided the different organizational levels in a socio technical system in three related categories: individual actors, teams and groups of actors within an organization, and a network of organizations. In this way all the classifications of (Trist, 1959).

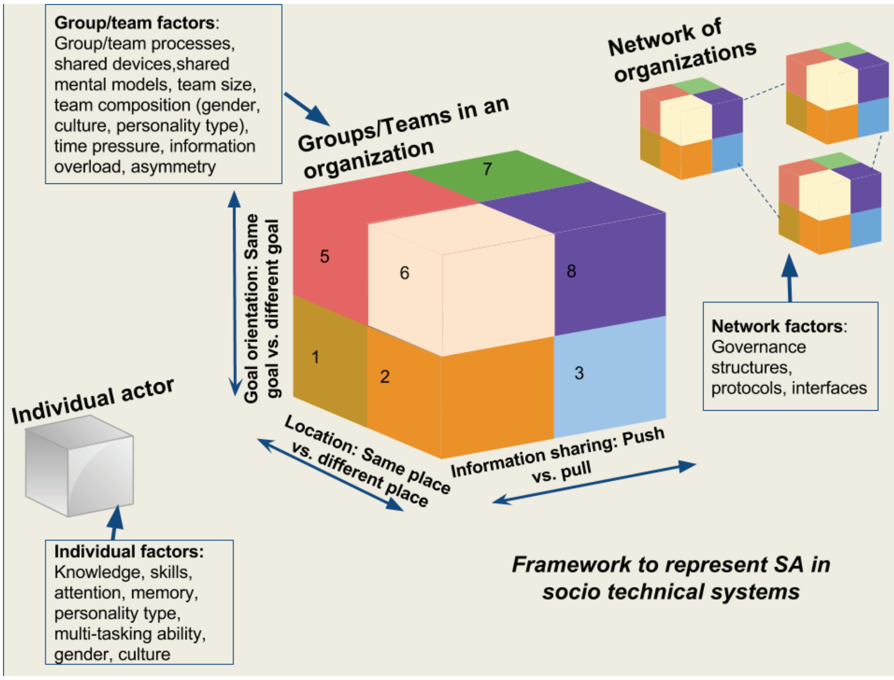
For the individual actor level, we retained the Endsley (1995)'s three level SA model to describe individual SA in socio technical systems because it is the most comprehensive as well as validated model that describes the relationship between SA and decision making and performance in complex systems (Parasuraman et al., 2008; Zsambok and Klein, 1997). In our studies we did not find any evidence to contradict the three level model. Individual SA is affected by several factors like knowledge, skills, personal attributes, background, attention and memory of individual actors (Endsley, 1995). Additionally, we found that multi-tasking ability, gender and culture can have an effect on individual SA in socio technical systems.

We will describe their influence with respect to three distinctive characteristics of socio technical systems— goal orientation, information sharing and location, each represented on a geometrical axis in a three dimensional space illustrated in Figure 9.3. We will describe each of them below.

**Goal orientation: Same goal vs. Different goal**

Situation Awareness, like decision making is goal-oriented (Endsley and Jones, 1997). SA requirements are functions of a particular goal (Endsley and

Figure 9.3: SA framework for socio technical systems




Jones, 1997). Among the prominent group SA models— Team SA, Shared SA and Distributed SA, SA in described within teams with the general assumption that all the team members work towards the same shared goal. In socio technical systems, there are teams with common goals as well as groups with different or conflicting goals (de Bruijn and ten Heuvelhof, 2008). Groups add a layer of complexity because goal conflicts may occur among the group's members (Locke and Latham, 2006). Group members often have different goals and they each view a situation differently based on their own task and goals (Salmon, 2008). When personal goals of group members are incompatible with the group's goal, the group performance is negatively affected (Locke and Latham, 2006). Information sharing among members has been proven to improve goal alignment and performance on a joint task (Locke and Latham, 2006; Endsley and Jones, 1997). Additionally when individual actors are given sufficient feedback on their performance in relation to the team performance, they are more likely to align their personal goals to the team/group goals (Locke and Latham, 2006). We noticed this aspect clearly in the board game, when the game master gave the feedback on participant actions, the awareness of shared goals and the motivation towards working towards a shared goal improved.

Goal alignment between team or group members requires common ground (Bolstad and Endsley, 2003). Common ground is the pertinent knowledge, beliefs and assumptions that are shared among the involved members (Klein et al., 2005). Not all actors need to have the same goal, but the system can have an overarching high-level goal. Therefore teams and groups need to begin with a high level system goal with a broad positioning that gives room for them to negotiate to create a common ground to align their goals. This notion is also supported by (de Bruijn and ten Heuvelhof, 2008; Boy, 2009).

**Information sharing: Push vs. Pull**

Information sharing is critical for developing and maintaining SA within teams (Salas and Dietz, 2011). Information sharing between individual actors will speed up the decision making based on shared understanding and allow operations in complex systems to be more responsive to dynamic situations (Endsley and Jones, 1997). More importantly, accurate, relevant and timely information sharing is crucial for developing SA in teams (Endsley et al., 2003; Salmon, 2008). Endsley et al. (2003) places a lot of emphasis on shared SA mechanisms, requirements and devices to enable effective information sharing. While Salmon (2008) argues that information sharing should be selective, and should happen between actors who recognize the need for the information in a particular situation (Salmon, 2008). In this respect, we recognize two types of information sharing approaches— the push and the pull approach. If information is shared pro-actively between actors, even when it has not been directly requested, then the situation is characterized as information push (Cybenko and Brewington, 1999). If an actor requests and receives specific information, it is known as information pull. Information push is similar to the information sharing approach of Salas et al. (1995a)'s Team SA model and Endsley and Jones (1997)'s SSA model, while information pull is closer to the DSA model of Salmon (2008). Our studies also supports the notion that information sharing is not straightforward in socio technical systems (de Bruijn and ten Heuvelhof, 2008). In addition to issues with information overload, reliability and availability, there could be restrictions on information sharing due to strategic interests of certain groups (de Bruijn and ten Heuvelhof, 2008). In such cases, processes like trading and negotiation becomes very important where trade-offs are discussed and agreements are reached between actors regarding information sharing (Boy, 2009).

**Location: Same location vs. Different location**

Actors in socio technical systems work across organizational, geographical and temporal boundaries (Carayon, 2006). Location of the actors in teams plays an important role in the development and maintenance of SA. Team SA and Shared SA model mainly focus on teams that are co-located (Endsley et al., 2003). Characteristics of a co-located team like a shared environment, ability to communicate non-verbally, and relationship between team members due to shared work space all contribute to an effective SA in teams (Endsley et al., 2003). In many situations co-located teams are necessary and usually have higher SA than their geographically distributed counterparts, although it is not always possible to have co-located teams (Endsley et al., 2003). SA among geographically and temporally distributed teams is described by (Endsley et al., 2003) as 'SA in teams in which members are separated by distance, time and/or obstacle'. In socio technical systems teams and groups are both co-located and geographically distributed (Appelbaum, 1997). Salmon (2008) and Stanton et al. (2006)'s Distributed SA theory intends to describe SA regardless of the actor's location. Coordination of tasks and synchronization of plans are essential for team performance, and these processes becomes more important and challenging in distributed teams (Salmon, 2008). Awareness of each other's roles, tasks and plan is essential for coordination in a team or a group (Endsley and Jones, 1997). Distributed teams rely on technology to create a shared understanding of a situation and to coordinate tasks (Endsley et al., 2003). E-mails, file-sharing, video conferencing, virtual shared work spaces (Endsley and Jones, 1997), and recent advances in virtual and augmented reality (Lukosch et al., 2015) facilitate distributed SA in teams. An entire research community (Human-Computer Interaction) has been striving to bring the feeling of co-location to distributed teams (Dix, 2009). Developing SA in distributed teams still remains very challenging despite these efforts (Chatzimichailidou et al., 2015a).

Each of these characteristics make SA development challenging, but problems situations in socio technical systems often arise due to the combination of such characteristics, that make SA development even more challenging. In addition to studying individual SA and factors affecting individual SA in socio technical systems, it is important to study SA under various configurations of socio technical systems that make SA development challenging. We would like to propose the following configurations of SA in socio technical systems at the organizational and network levels based on differences in goal orientation, information sharing and location:

1. **Same goal, same location, push approach**: Co-located teams within an organization that are free to share information with a shared platform for information sharing.

2. **Same goal, different location, push approach**: Distributed teams within an organization that are free to share information.

3. **Same goal, different location, pull approach**: Distributed teams within an organization that don't have a shared platform for information sharing.

4. **Same goal, same location, pull approach** Co-located teams within an organization without a shared platform for information sharing.

5. **Different goal, same location, push approach**: Co-located groups/departments of an organization that don't necessarily work together but have unrestricted access to a shared platform.

6. **Different goal, different location, push approach**: Geographically distributed groups/branches of an organization that don't necessarily work together but have unrestricted access to a shared platform.

7. **Different goal, same location, pull approach**: Different groups/departments within an organization with restricted access to each others' activities.

8. **Different goal, different location, pull approach**: Different organizations in a network.

Configurations 1 to 7 represents team and group levels, while 8 represents the network level of socio technical systems.

In our studies, the YCS3 study represented configurations 1 and 2, while the disruption board game represented configurations 1, 2 and to some extent 5 and 7. Therefore we also included these factors that affect SA at team, group and network level in our framework. Team and group processes such as leadership, group cohesion, motivation and synergy (Salas et al., 1995a), shared mental models, types of shared devices and the size of teams (Endsley, 1995), compatibility among team members (Salmon, 2008), affect the SA of team and group members (Bolstad and Endsley, 2003), complexity of technical interfaces affect SA (Endsley, 1995; Bolstad and Endsley, 2003). From our studies we found that time pressure, information overload and asymmetry, team composition in terms of gender, culture and personality type can have an effect on SA in team and groups within an organization. At the network level, governance structures, protocols, market demands and interfaces influence the development of SA (Salmon, 2008; Boy, 2009).

We can observe that our studies only partially cover the above framework with our empirical results, therefore the complete testing of this framework is scheduled as future work. In the following chapter we will conclude the thesis by presenting the overall research findings, practical and theoretical contributions and future work related to SA research in socio technical systems with simulation gaming as a research method.

## Chapter 10

# Conclusion

We have established in chapter 1 that Situation Awareness is an essential prerequisite to decision making and performance in socio technical systems—complex systems intertwining technology and human actors, that are an integral part of the modern society. An example of such a system is a container terminal that is a specialized critical infrastructure that facilitates global trade by handling and transferring containers at seaports across various modes. Despite the importance of SA in socio technical systems, there was a clear deficiency of theoretical models that describe and represent SA in such systems. The overall aim of this research study was to investigate the role of SA and factors affecting SA in the decision making and performance of individuals and teams in socio technical systems, within the context of container terminals. The key research question and sub-questions related to this objective posed in chapter 1 were:

**RQ1**. How can Situational Awareness (SA) influence the decision making and performance of actors involved in intermodal transport operations?

- RQ1.a. What is the role of SA in actors' decision making and performance, while handling dynamic intermodal transport operations?
- RQ1.b. What are the factors that affect the relationship between SA and decision making in intermodal transport operations?

Simulation gaming was our key research method to answer RQ1 and related sub-questions, in addition to pre and post game surveys, Multi-Attribute Test Battery (MATB-II), observation and video recording. Simulation gaming was not considered to be a mainstream research method in the container terminal research domain. This led us our second main research question shown below:

**RQ2**. How can simulation games be designed and used to study SA in individuals and teams in intermodal transport operations?

Give the lack of sufficient SA theory in socio technical systems we also proposed an initial theoretical framework (Figure 2.7, chapter 2) to describe SA in socio technical systems at the individual, team and system levels. This framework served as a theoretical lens that guided us towards answering RQ1 and related research questions. The three games designed and used to answer our research questions were YCS1 single player digital game, YCS3 multi-player digital game and disruption management board game. Our research studies were based on a research process (Figure 3.7, chapter 3) that described the design cycle for the development of the games and an empirical cycle for the execution of research experiments with the games. Chapters 4 and 5 were dedicated to describe the development of YCS1, YCS3 and the disruption management board game based on the design cycle (Figure 9.1) of our research approach. Chapters 6, 7 and 8 discussed the experimental studies related to the three games based on the empirical cycle of our research approach in order to answer the research questions and verify the initial SA theoretical framework. In this final chapter, based on the results of the preceding chapters, we will answer the research questions, discuss the value of the findings with respect to theory and practice. Finally, like all research works, we have unfinished work that needs to be carried on as future research. We will conclude this chapter and this thesis with a few thoughts on continuing this research. We will first present our research findings related to our research questions.

## 10.1 Key findings: Answers to the research questions

We will answer the first research question, **RQ1** by first providing responses to the sub-questions that complement it.

#### Research Question 1

**RQ1.a**: In all the three studies in this research we found that SA had a variable effect on the decision making and performance of individuals and teams in intermodal transport operations.

At the individual level, in chapter 6, we found that the participants with high scores on YCS1 also had higher individual Situation Awareness. We studied the role of individual SA, Shared SA and Distributed SA on team/group task performance and decision making in chapters 7 and 8. We found that co-located teams that operate under time pressure perform better in a Distributed SA setting rather than a Shared SA setting. The difference in information sharing was marked between the Distributed SA and Shared SA settings. In the Distributed SA setting participants exchanged only the information that was relevant to them and did not focus on the overall information flow within the team or group. This can be classified as information 'pull' approach. In the Shared SA setting, all the information was shared with all the team and group members. This can be described as information 'push' approach. When fast paced, interdependent decisions have to be made, exchanging relevant information between relevant participants was found to be the most effective way to make successful planning decisions. However when there was sufficient time for deliberation, Shared SA among team members contributed to superior task performance compared to Distributed SA. Teams with a shared goal required less time for decision making. When a shared goal was absent, teams and groups required time to build a common operational picture or Shared SA through information exchange, negotiations and deliberation. Our two studies on team/group SA were based on co-located teams. We argue that the shared environment and the possibility of non-verbal communication augmented the SA of the team members.

The result related to individual SA was not surprising and it merely confirmed Endsley (1995)'s theory on individual SA, decision making and performance. However the stark finding and contribution of this research is related to the role of SA in team performance in intermodal transport operations. In literature, Shared SA (Bolstad et al., 2005) was associated to co-located teams with a shared goal, while Distributed SA was associated to geographically distributed teams with or without a shared goal within a network (Salmon, 2008), which was also represented in our initial SA framework in chapter 2. Our results disproved this notion, and we proposed an updated SA framework to view SA in socio technical systems through a renewed theoretical lens shown in Figure 9.3.

Overall, we argue that SA in group settings need not be limited to SSA for teams or DSA for networks. Both SSA and DSA can be effective in decision making and performance of individuals in collective settings (teams, groups, network) based on the situation and condition of the collective setting based on three distinctive characteristics— goal orientation, information sharing and geographical location. The eight SA configurations based on these three characteristics are: 1. Same goal, same location, push approach 2. Same goal, different location, 3. Same goal, different location, pull approach 4. Same goal, same location, pull approach 5. Different goal, same location, push approach 6. Different goal, different location, push approach 7. Different goal, same location, pull approach 8. Different goal, different location, pull approach. We claim that SA in socio technical systems such as container terminals needs to be described and represented in the above mentioned eight configurations because the development and maintenance of SA in such systems is complex due to the combination of challenges related to information sharing, goal orientation and geographical distribution of individuals and teams in socio technical systems.

We will now answer the second sub-question related to RQ1.

**RQ1.b:** We have concluded from chapter 2 that although SA is an essential pre-requisite for decision making and performance in socio technical systems it doesn't guarantee them. We studied the effect of individual and team factors that affect SA in intermodal transport operations.

In chapter 6 we found that multi-tasking ability has a strong positive influence on SA, decision making and planner task performance for individual actors dealing with container terminal operations. The personality trait, emotional stability has a direct and statistically significant positive correlation with planner task performance. Another personality trait, openness to experience has a negative moderating effect on the relationship between multi-tasking ability and planner task performance. Gender and culture also have a significant influence on the planner task performance. Female participants performed significantly better than their male counterparts at planner task performance at an individual level. Dutch participants outperformed their Chinese and American colleagues significantly. Chapter 7 confirmed the positive effects of emotional stability even in group settings. Additionally, the composition and diversity of team— with respect to gender and cultural background may influence team task performance of teams involved in complex planning processes. In our experience, homogeneous teams did well at team task performance compared to mixed teams with respect to gender and culture. Situation monitoring had a significant positive effect on team task performance, and mutual support between team members had a negative effect on the team task performance in complex planning operations. Shared mental models and closed loop communication were important for the team task performance but the development of shared mental models through shared displays and the effectiveness of closed loop communication were hindered by time pressure in complex planning operations. Chapter 8 showed that communication channels, information quantity and the timing of communication are factors that affect both SSA and DSA in teams.

Overall, at individual level, multi-tasking ability, emotional stability, gender and culture of an actor directly influenced their SA, decision making and performance. Openness to experience of an individual actor negatively moderated the relationship between multi-tasking ability and planning task performance. At the team level, time pressure, situation monitoring, communication, and team composition significantly affected the way a team developed SSA and DSA in intermodal transport operations.

We will now provide the answer to the second and final research question of this research work.

**Research Question 2**

We have already discussed in chapters 3 and 9 that there is no standard method to design and use simulation games for research purposes. Therefore our research approach containing a design cycle and empirical cycle in chapter 3 was a first step towards closing that research gap. With the help of this process, we were able to design three valid games to study SA in individuals and teams in intermodal transport operations. We have already discussed the outcomes of this research process in detail in chapter 9 together with the lessons learned in the process. Based on our experiences with designing and using simulation games for SA research we can draw some important conclusions.

With respect to the design of simulation games for SA research our key conclusions are three fold. Firstly, validation and testing are the most important parts of the design process since the simulation games are designed for research. The construct validity against a specific theory (SA in our case) is very crucial to determine the usefulness of a simulation game to study it. Subject matter experts should be involved from the early stages of the design process to ensure that the 'reality' aspect of a socio technical system is not lost while a game designer translates it into a playable game. Extensive testing is crucial to increase the reliability of the game in terms of data collection and technical glitches. The design of data collection mechanism is as important as the game design itself because this ensures the researcher's control over the quality and reliability of the data generated within a gaming session. Secondly, from a pragmatic perspective, single player digital games can be designed and validated rigorously compared to their multi-player digital and analogue counterparts. Even the cost-efficient boardgames were very task intensive with respect to incorporating changes and testing and validating with experts. Finally, simulation games for research should be designed in an iterative manner using prototypes until a satisfactory balance between the realism of the game, the research objective and the playability of the game is achieved.

Regarding the usage of simulation games for SA research we also have a three fold conclusion. Firstly, single player digital games offer a superior controlled environment to conduct experimental or quasi-experimental studies compared to multi-player digital games and analogue board games. Although the environment of a multi-player game and that of a board game is conducive to facilitate team processes and inter personal communication it is very challenging to codify and record all the player decisions and team and group processes within the game. However we are very optimistic that with improvements in voice and speech recognition technologies, intelligent text and video analysis, multi-player games have a strong potential to become research methods of choice for complex systems. Secondly, from a pragmatic perspective, research studies using multi-player simulation games will benefit the most if they used a combination of qualitative and quantitative data analysis methods since it is time and labour intensive to collect large number of data points to justify the significance of quantitative data analysis results alone. Finally, a simulation game is a purposeful as well as a playable research instrument that has to be balanced between the elements of reality, meaning and play. Therefore a simulation game cannot be considered to be all encompassing and a standalone instrument to conduct research since they cannot measure all aspects related to the research problem alone. Research studies using simulation games need to be complemented with other research instruments such as surveys and video recordings to ensure comprehensive measurements and data collection.

Overall, we have shown that simulation games can be effectively developed and used for SA research in socio technical systems using our research process shown in Figure 3.7. We executed the research process according to plan, however encountered a few challenges that taught us several lessons on related to designing and using simulation game for research. The key considerations that a researcher need to make while designing a game for research are the type of game, computational and technical requirements, reliability, scalability and portability and participant involvement and social cohesion. With regards to using simulation games for research studies, researchers should focus on preparation and planning, reliable data gathering and analysis and suitable participant selection for the study.

So far we have discussed the theoretical and methodological contribution of this research. We will now briefly summarize its practical implications.

**Practical contribution to intermodal transport operations in container terminals**

We played all the three games with both students and professionals in the field of supply chain, logistics and transportation. Many of these experts validated our games and opined that they can be valuable tools to train employees in complex planning of intermodal transport operations. The game could also be used for individual employees to become more aware of each others' roles in the organization and design ways for effective communication and coordination of their plans to plan and execute complex tasks, not only in normal situations but also when unexpected disruptions occur. We can also recommend that managers in container terminals can better support the SA of team members by evaluating and improving their information sharing approach, paying attention to team allocation and composition and devising better ways for information exchange under time pressure in socio technical work organizations. Also they can benefit by considering the effects of multi-tasking ability, personality type, gender and cultural differences while design and allocation of tasks and training programs to support SA and superior task performance of individual actors and teams in their socio technical work organizations.

## 10.2 Future work

We spent over 4 years to conduct the research presented in this book. Although we designed and implemented our studies in a rigorous manner our results and conclusions have limitations and are not complete.

The level of complexity of all the three games is not as high as complexity in a real terminal. The sample population for the experiments were students although their specialization was in the field of logistics, supply chains and transportation. Although are results are significant we cannot generalize them until when we can conduct similar studies with complex and realistic planning tasks closer to the operations in real container terminals with professionals. Follow-up studies of this research should use high-fidelity simulation models of container terminals and emulated planning and control systems. Additionally the study needs to be replicated in a similar socio technical organization like an airport or a hospital to generalize our results to all socio technical work organizations. Our studies did not cover SA in geographically distributed teams and SA in a network of organizations. These missing aspects are also a part of future research.

In this work we worked on the design and development of simulation games for research purposes. Although we based our works on available theory, our contribution was more practical and applied in nature. Therefore much work is needed on the theoretical and methodological aspects of simulation gaming for research for them to be accepted as a mainstream research method.

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APPENDIX A

# SA ASSESSMENT TECHNIQUES

### A.0.1 Situation Awareness assessment techniques

The assessment of SA is used throughout the design lifecycle, either to determine the levels of SA provided by novel technology or designs or to assess SA in existing operational systems (Stanton et al., 2005). SA assessment is very crucial to the advancement of the SA theory, as it enables researchers to assess SA in individuals and teams to understand the impact of SA, as well as the effectiveness of design, procedural, technological and training interventions aimed at improving SA (Salmon et al., 2009).

Several methods and techniques are available to measure Situational Awareness based on the various theoretical models of SA. More than 25 such techniques were identified in the HFE research area (Salas and Dietz, 2011). Each of these techniques can be placed into several sub-groups— SA requirements analysis techniques, freeze probe techniques, real-time probe techniques, self-rating techniques, real-time probing techniques, observer-rating techniques, performance measures, process indices and collaborative SA measures Stanton et al. (2005); Salmon et al. (2009). We will briefly address these sub-groups in the sub-sections below.

#### SA requirements analysis

SA requirements analysis is conducted to estimate what exactly comprises SA in the environment of an individual operator. It often provides input for other SA measurement techniques to formulate the necessary queries for the operator.

The procedure consists of the definition of tasks, selection of experienced Subject Matter Experts (SMEs), interviews with the SMEs, goal oriented task analysis, development of SA requirements survey or questionnaire based on the interviews and the goal oriented task analysis, and finally the determination of the SA requirements (Stanton et al., 2005). The advantage of this method is that it is comprehensive, grounded on the experience of SMEs, and clearly outlines the knowledge required for good SA during the task. The key drawbacks of this techniques are the lack of validity, the fact that it is expensive and time consuming, and its inability to scale up to SA in complex collaborative settings.

**Freeze-probe techniques**

In freeze-probe techniques, a task is 'frozen' during a task simulation, and operators are required to answer a set of SA queries based on their knowledge and understanding of the situation at the point of the freeze. The score is based on how close the answers of the participants come to the actual state of the system at the time of the freeze. The most popular freeze-probe technique is Situation Awareness Global Assessment Technique (SAGAT), and is based on the 3 level SA model of Endsley. Other freeze-probe techniques include Situation Awareness of en-route air traffic controllers in the context of Automation (SALSA) (Hauss and Eyferth, 2003), used mainly in the aviation field, and Situation Awareness Control Room Inventory (SACRI) which is used in process control rooms of nuclear reactors (Stanton et al., 2005). These techniques offer a direct, objective and validated measurement of SA and can be tailored to all domains. The drawbacks of the freeze probe techniques are that, it is very intrusive of the primary task of study, it requires expensive computational power, and it requires substantial effort to develop the right SA queries for the task.

**Real-time probing techniques**

Real-time probe techniques require operators/ participants to answer SA related queries doing a task simulation, but without freezing the task. The score is based on the accuracy of answers and the time taken for response. Although the objective of these techniques was to reduce the intrusiveness of freeze-probe techniques , while retaining the advantages, it is not without drawbacks. The real-time methods so far have low construct validity and limited use. The widely known real-time probe technique is Situation Present Assessment Method (SPAM) (Salas and Dietz, 2011). Another example is Situation Awareness for SHAPE (SASHA), which is part of the SHAPE questionnaires

(SHAPE=Solutions for Human Automation Partnerships in European ATM) which is an European project (Stanton et al., 2005).

### Self-rating techniques

These techniques allow operators/ participants to reflect on their SA after a task is completed. The main advantages of these technique is the ease of application and non-intrusiveness, while the disadvantage is the lack of objectivity in the measurement. One of the widely used and validated self-rating techniques for SA is Situation Awareness Rating Technique (SART) (Salas and Dietz, 2011). Other examples include Mission Awareness Rating scale (MARS), Situation Awareness Rating Scales (SARS), and the Cranfield Situation Awareness Scale (C-SAS), mostly used in aviation and military applications (Stanton et al., 2005).

### Observer-rating techniques

Observe-rating techniques are based on expert assessment of SA. They are usually employed for in-field operations. The score is based on the ratings of the domain experts on pre-defined observable SA related behaviours. The Situation Awareness Behavioural Rating Scale (SABARS) is the most common observer-rating technique for SA assessment (Salas and Dietz, 2011). The key benefits of this technique are the non-intrusiveness, and the added value of expert knowledge to observe the SA related behaviours. The drawbacks are associated with the recruiting of enough SMEs for the assessment, the possibility of change of behaviour by the operator/ participant due to expert monitoring and the difficulty of access to field settings (Stanton et al., 2005).

### Performance measures

Performance measures offer an indirect measure of SA by calculating the performance of a certain task during a simulation or in a real life exercise (Stanton et al., 2005). The assumption underlying these techniques is that the performance is mainly affected by SA (Salas and Dietz, 2011).

### Process indices

Process indices include a broad range of measure aimed to capturing the various processes required to develop SA for a certain task. These techniques prove an understanding of the physiological, cognitive and complex behavioural aspects of the operators/ participants during a task. Examples include eyetracking, video and audio recording for concurrent verbal protocol analysis (Salas and Dietz, 2011).

**Collaborative SA measures**

There are very few approaches that focus solely on SA in collaborative settings. Many researchers make use of the above techniques while assessing SA in such settings. However, borrowed from psychological research, propositional networks are being used to assess SA in collaborative settings. A propositional network is used to identify knowledge objects related to a particular task or scenario, and represents the links between each of the knowledge objects identified. The technique is easy to use and is ideal to study team processes, Shared SA and Distributed SA during a particular situation. The key disadvantage is the lack of validity and reliability of the technique (Salas and Dietz, 2011).

**Discussion on different SA assessment techniques**

Despite the multitude of techniques available to assess SA, there is no consensus and clarity in the SA research community regarding the extent to which each of these techniques actually measure SA (Stanton et al., 2005). The numerous and varied research perspectives on SA imply that a unique and one-for-all measurement for SA almost impossible. Salmon et al. (2009) compared the three of the widely used SA assessment techniques— SAGAT, SART and CDM and found a lack of correlation between the measures. This suggests that different techniques measure different aspects of SA or no SA at all. Consequently, choosing the right technique for SA assessment can be complex. It is very important to not only rely on individual techniques, but choose a battery of methods that capture SA processes, factors influencing SA, information flows, individual and team behaviour etc. for a reliable and valid assessment of SA (Stanton et al., 2005). In our research we have used a performance measure (simulation gaming), SART, and video analysis for SA assessment.

Appendix B

# Game validity check-list

The following checklist for checking the validity of simulation games for research purposes has been sourced from Peters and van de Westelaken (2011).

1. Does the 'schematic' or conceptual model that will be used as a starting point for game design adequately represent existing knowledge and theoretical notions, and does it capture real-life circumstances?
2. Does the game design either include the subject(problem) to be dealt with in course of playing the simulation game, or does it allow for this subject to develop in the course of playing the game?
3. Are the number of variables, the level of abstraction, and the choice of symbols in the game design adequate, both in view of the conceptual model that is to be represented and in view of the subsequent stages of playing and the drawing of conclusions?
4. Is there reason to expect inadvertent steering by the game design, e.g. through the account system used, the amount of time available in relation to the number of tasks, the nature of tasks and roles, characteristics of the initial situation, or boundary rules?
5. Is it likely that the game design allows the processes to be studied to develop in the application stage? Is it unlikely that less complex, less time-consuming, or less laborious (e.g. already existing instead of tailor-made) games would allow such processes to develop? Is it necessary that

the game design copies some reference system in considerable detail? A second series of questions relates to intermediate stages:

6. Is the conceptual model, and the derived game design, likely to produce events and processes in the application stage that can be productively referred to in debriefing? In particular, does the design allow for an acceptable degree of dynamics?

7. Does the simulation design fit the population of participants (and is such a fit necessary): is the design offered understandable, is it fair in the eyes of participants, is it engaging, is inadvertent steering of processes a likely result of combining the design with a particular population of participants?

8. Are participants properly selected and prepared, are positions and tasks assigned to them in a way that meets the game's objectives?

9. Does deliberate or inadvertent steering of processes occur in the application stage, by participants (experimental demand) or by the experimenter/facilitator (experimenter bias)? Have preventive measures been taken?

10. Are 'environmental' circumstances likely to affect the course of processes in the application stage in an undesirable way: e.g. learning effects, maturation, 'instrumentation', sample mortality, demoralization, real-life connections between participants, 'obtrusive' observation, physical location?

11. Are, in retrospect, the events and processes that occurred in the simulation relevant with regard to the initial problem formulation? Have events, processes, or outcomes been observed or experienced that seem incompatible with the simulation game's objectives? How are these to be handled?

12. Is it possible to relate these events and processes back to some recognizable factors, by outside observers, and by participants themselves?

13. Do these factors provide clues for action?

14. Does either the nature of insights to be gained by participants in (or as a result from) the debriefing stage, or the way to help them arrive at such insights, make demands on the debriefer's own perception of (a) what went on in the simulation game, (b) how the simulation game

relates to real-life processes, (c) how people may be enabled to transfer experiences from simulation game to real life?

15. If collective learning is aimed at, in addition to individual learning: have specific measures been taken to align the debriefing process to this objective? Have measures been taken to keep all participants aboard?

Appendix C

# YCS1 EXPERT VALIDATION SURVEY AND RESULTS

The YCS expert validation survey was sent by e-mail to professionals in container terminal business. The survey was completely anonymous. We will first present the questions in the survey. The responses to the questions in terms of ratings together with the profiles of the experts are tabulated in Table C.1. Experts provided explanations to few of their ratings, and such responses are indicated by the * symbol in Table C.1. These detailed responses are further represented in Table C.2.

1. What is your age in years?
2. What is your gender (Male/Female)?
3. What is your highest level of education?
4. What is your current profession
5. How long (in years) have you working in the container terminal industry?
6. On a scale of 1-5, with 1 being poor and 5 excellent, rate your level of experience in playing computer games.
7. On a scale of 1-5, with 1 being poor and 5 excellent, rate your level of experience in playing training games related to your profession.

**Rate the following statements regarding the YCS game on a scale of 1-5 and comment if necessary. 1 is strongly disagree, 2 is disagree, 3 is neither agree nor disagree, 4 is agree, and 5 is strongly agree.**

8. The objective of the YCS game is sufficiently clear.
9. The objective of the YCS game is relevant to the challenges in Container Terminal (CT) operations.
10. The tasks in the YCS game are understandable and well formulated.
11. The YCS game is designed in an interesting and stimulating way for personnel involved in CT operations.
12. Given the objective of the YCS game and time limit, the YCS game environment is sufficiently detailed.
13. Given its objective and time limit, YCS game reflects reality of CT operations.
14. Given the time limit, the processes in CT operations are well represented in the YCS game.
15. The YCS game reflects the interdependencies among various roles in CT operations.
16. Scoring schema for ship turnaround time: +100 points for every second that a ship leaves early
17. Scoring schema for containers: +100 points for every container successfully handled before the ship leaves, -100 points for every container not handled before the ship leaves.
18. Scoring schema for resource utilization: -1 points for every second a resource (berth crane, yard crane, AGV) is inactive.
19. Scoring schema for bonus points: +100 bonus points for every yellow container handled by trucks.
20. I can relate to the challenges in the YCS game to those I encountered/observed in my professional experience.
21. I had a better insight about the importance of integrated planning after playing the YCS game.

22. The use of YCS game is worthwhile for CTs to guide their employees towards integrated planning of CT operations.
23. The use of YCS game as a training instrument can help create an integrated planning approach in CTs.
24. Please provide any other remarks/ comments/ suggestions about your overall game experience.

Table C.1: Profile and responses of experts for the YCS1 validation survey

| | Expert 1 | Expert 2 | Expert 3 | Expert 4 | Expert 5 | Expert 6 |
|---|---|---|---|---|---|---|
| Q1 | 29 | 46 | 28 | 30 | 37 | 40 |
| Q2 | Male | Male | Male | Male | Male | Male |
| Q3 | MSc. | College | BSc. | MSc. | BSc. | PhD. |
| Q4 | Consultant | General Manager | Project Engineer | Senior Manager | General Manager | Managing Direct (IT) |
| Q5 | 3 | 25 | 5 | 7 | 20 | 17 |
| Q6 | 5 | 4 | 4 | 4 | 4 | 4 |
| Q7 | 3 | 3 | 3 | 2 | 1 | 4 |
| Q8 | 4* | 4 | 4 | 4 | 4 | 4 |
| Q9 | 4 | 4 | 4 | 4 | 4 | 5 |
| Q10 | 4 | 3* | 4 | 4 | 4 | 4 |
| Q11 | 4 | 5 | 4 | 5 | 5 | 5 |
| Q12 | 1* | 5 | 5 | 4 | 4 | 5 |
| Q13 | 4 | 4 | 4* | 3 | 3* | 5 |
| Q14 | 4 | 4* | 4 | 4 | 3 | 5 |
| Q15 | 1* | 4 | 4 | 5 | 4 | 5 |
| Q16 | 3 | 3* | 4 | 4 | 4 | 5 |
| Q17 | 3 | 4 | 4 | 4 | 4 | 1 |
| Q18 | 3 | 3* | 4 | 1* | 1* | 1 |
| Q19 | 3 | 3 | 4 | 4* | 4* | 1 |
| Q20 | 4* | 5 | 4 | 4 | 4 | 5 |
| Q21 | 4 | 1* | 5 | 4 | 3 | 5 |
| Q22 | 4 | 5 | 5 | 5 | 5 | 5 |
| Q23 | 4 | 5 | 5 | 4 | 4 | 5 |
| Q24 | None | See Table C.2 | None | None | None | None |

Table C.2: Detailed responses and comments of the experts

| | |
|---|---|
| Expert 1 | **Q8**. We defined the objective as designers.<br>**Q12**. Too little control over the container flow, you don't know what's going to happen<br>**Q15**. Not in the roles, but it does reflect the inter-dependencies in the processes.<br>**Q20**. In the open yard scenario it is not very realistic yet, but there is a clear potential<br>**Q22**. The concept is great but does require some more work. I have high expectations of the game's ability to transmit the message in a nutshell. It will still be hard to communicate and convince, but with this we should be able to do a much better job than with conventional means (lectures, manuals) and it should be a great complementation to our controls trainings. |
| Expert 2 | **Q10**. Sometimes there game is a little too pixel perfect when aligning cranes and RTGs. Also, some terminal rules are broken with respect to driving patterns and crane separation.<br>**Q14**. Would be better if you could see the RTG positions when pausing. This would reflect reality where you know where RTGs are currently and you are making decisions regarding re-positioning in line with your QC deployments.<br>**Q16**. Depends on the vessel service. In reality we sometimes focus on leaving early when there is no revenue gain from doing so. In effect it is sub-optimal to the business to turn the vessel quicker. Especially if there is no other vessel berthing to realize the opportunity and you are still paying for the shift.<br>**Q17**. This could be bigger. Missing a load is a real disaster in terms of customer service.<br>**Q18**. You could increase the cranes if there is a possibility to deploy them. If there is no deployment of an RTG possible then penalizing it being inactive is counter intuitive. In the operation you would actually gain by not using the RTG if you could meet the service requirements without it.<br>**Q21**. I understood this before the game.<br>**Q24**. The approach of gaming is an excellent one. I would be interested to see the survey results. |

| | |
|---|---|
| Expert 3 | **Q13**. There are separate divisions at each terminal for yard and vessel operations and vessels arrive on a predetermined schedule within a day or two. |
| Expert 4 | **Q18**. Technical unavailability (PM/CM) is a big theme in Container Terminals. We are used to an environment where we can (and should) not always use all cranes, it would be interesting to have some Technical component in the game like breakdown or crane scheduled for PM.<br>**Q19**. Indeed, it is not only quayside operations but also gate and rail which is often a bit neglected, I would even score more points for gate or rail handled well |
| Expert 5 | **Q13**. Only covers one area and could be improved.<br>**Q18**. If all work points are covered no deduction should be made. IF a TT or STS is waiting then deductions should be made.<br>**Q19**. More road interaction is required. Rail could also be added in later stages. |
| Expert 6 | No additional comments |

Appendix D

# Expert validation of the disruption board game

## D.1 Expert validation survey for board game with responses

We gave short survey to professionals in the container terminal business for expert validation of the board the game. We will present their short responses in Table D.1 and the long responses to Q7 and Q8 below the table.

1. What is your age (in years)?
2. What is your gender?
3. Name your profession and industry.
4. How many years of professional experience do you possess?

   On a scale of 1-5, with 1 being very low and 5 very high, please respond to questions 5, 6 and 7 by rating them and comment if necessary.

5. How clearly did you understand the objective of the disruption management board game after you played it?
6. How well do you relate to the concepts in the game to real life disruptions?

7. How helpful do you think are the learning principles (if any) of the game to prepare you to handle real world disruptions?

8. Can you name three aspects that you learnt about supply chain disruption mitigation after you played the game?

9. Please provide your remarks and suggestion regarding the game

Table D.1: Expert responses to the board game validation survey

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 |
|---|---|---|---|---|---|---|---|
| **Expert 1** | 40 | Male | Researcher, Maritime logistics | 16 | 4 | 5 | 4 |
| **Expert 2** | 33 | Male | Project manager, Container terminal | 8 | 4 | 4 | 3 |
| **Expert 3** | 26 | Female | Consultant, Logistics at TNO | 3 | 4 | 4 | 4 |
| **Expert 4** | 26 | Male | Event coordinator, DINALOG | 2 | 4 | 4 | 4 |
| **Expert 5** | 23 | Female | Intern, Consultancy for container terminals | 1 | 4 | na | 4 |

Expert 1: Q7. KPIs are contradictory, communication is important, risk is identified by one actor but it needs to be tackled by another actor. Q8. It could be more transparent to understand why an actor took a certain action.

Expert 2: Q7. Don't all focus on the same aspect, don't forget about your own objectives, don't e-mail when you can call. Q8. The goals and actions were very much in line with reality.

Expert 3: Q7. Communication is key. Q8. Playing more rounds will make it more helpful.

Expert 4: Q7. who to share information with, what type of aspects are influenced by the decisions you take, typical disruptions on a terminal. Q8. I felt that the disruptions were quite real although it was not very clear what happened during the game.

Expert 5: Q7. It is hard to make choices without the necessary information, sometimes you have to choose one KPI over another and it is difficult to divide your attention especially when you don't know what others are choosing, and performance can go down unexpectedly. Q8. It is always clarifying when you see things happen.

## D.2 Post-game survey of board game with responses of supply chain students

We administered a post-game survey to a group of students pursuing their studies in supply chain and logistics at a leading university of the United States. We collected their experiences related to the game together with suggestions for improvement. the survey together with student responses (N=48) are listed below.

1. What is the highest level of school you have completed or the highest degree you have received?

   High school degree or equivalent- 33.33%; Bachelor degree- 43.75% and Graduate degree- 22.92%

2. What is your level of experience with supply chain risk management?

   Novice- 43.75% ; Beginner- 15%;Intermediate- 18.75%;Experienced- 13%;Very experienced- 0%

3. How clearly did you understand the objective of the disruption mitigation game after you played it?

   Not clear- 0%; Somewhat clear- 0%; Fairly clear- 31.82%; Clear- 49.55 %; Very clear- 4.55%

4. Can you name three aspects that you learnt about supply chain disruption mitigation after you played the game?

   The condensed list of aspects : communication, relevant information sharing, coordination, balancing KPIs (trade-off), strategy alignment, role and task interdependencies, quick paced decision making, thinking of alternatives, big-picture perspective, planning ahead, risk management, team work, user optimum vs. global optimum, optimal resource management,

5. How was your understanding of the game rules after you played the first round?

   Not clear- 0%; Somewhat clear- 13.6%; Fairly clear- 43.18%; Clear- 31.82 %; Very clear- 11.36%

6. How helpful was the feedback given after each round (the announcement of scores and system status) to make decisions in the subsequent rounds?

   Not helpful- 0%; Somewhat helpful- 20.84%; Fairly helpful- 27.27%; Helpful- 34.1%; Very helpful- 18.18%

7. How relevant was the information that you received from other players for your decision making? Not relevant- 6.82%; Somewhat relevant- 0%; Fairly relevant- 15.9%; Relevant- 56.82%; Very relevant- 20.45%

8. Excluding the joker option, what is the ideal number of decision options in each round (it is currently 2)? Please provide a short explanation for your answer.

   (consolidated)60% of the respondents opined that 2 cards are most suitable given the complexity and time limit of the game. 40% felt that 3 or 4 cards might be more suitable to make the game more realitics and provide better freedom of choice for the player.

9. As future supply chain professionals, how helpful do you think are the learning principles (if any) of the game to prepare you to handle real world disruptions?

   Not helpful- 0%; Somewhat helpful- 4%; Fairly helpful- 38.64%; Helpful- 46.36%; Very helpful- 15.91%

10. Remarks and suggestions about the game.

    Condensed list of remarks: The game was very enjoyable; the game is complex; background in container terminals is needed to excel in the game; It was very helpful with understanding supply chain; More options are needed; Very practical; Introduction and description of rules could be more clear; It is a relevant and interactive simulation; The feedback on the actions was unclear.

Appendix E

# Protocol and Script: Experiment to explore factors that affect SA in container terminal operations

## E.1 General description

Related researchers: Shalini Kurapati, Heide Lukosch, Alexander Verbraeck (TU, Delft) Stephanie Eckerd, Thomas M. Corsi (University of Maryland, College Park (MD))

The experiment is designed such that two researchers (a facilitator and an observer) are required to conduct it. 9 sessions have been conducted. Each session is given an alphabet code. The first session in Delft begins with code A, and the subsequent sessions will take the succeeding alphabet codes. Every session has a maximum of 25 participants, and each participant is assigned a workstation number (For e.g. A01- A25 in Delft) which serves as a key to match the respective data in an anonymous way. This protocol serves as a guide to conduct the experimental session, collect and match the data involved. It covers the information and materials required for the session except the MS PowerPoint slides for briefing and debriefing, as well as an MS Excel time sheet to keep track of the tasks during the session. These documents are to be found in a shared electronic folder of the researchers involved.

## E.2 Checklist for the experimental session

Table E.1: Checklist for Session Code A, Delft, 3 October 2014, Facilitator: Shalini Kurapati, Observer: Heide Lukosch

| **Materials (assigned to facilitator)** | **Quantity** | **Backup (assigned to observer)** | **Quantity** |
|---|---|---|---|
| MATB software in an USB drive | 1 | MATB software in an USB drive and in the shared Dropbox folder | 1 |
| Unity plug-in for the browser (Downloaded from web) | 1 | Executable file of the YCS game in an USB drive and in the shared Dropbox folder | 1 |
| Laptops/ computers (Windows only, XP, Vista or 7) | 25 | Laptops | 5 |
| Gamepads | 25 | Gamepads | 2 |
| Earphones | 25 | Headphones | 2 |
| Slide pack in an USB stick | 1 | Slide pack in the shared Dropbox folder | 1 |
| Time sheet for the session in MS Excel in an USB stick | 1 | Back up in the shared Dropbox folder | 1 |
| Online pre-survey (update link in the briefing slide pack) | 1 | Printed copies of pre-survey | 30 |
| Online post-survey (in the YCS game portal) | 1 | Printed copies of post-game survey | 30 |
| Login details printed and cut for each computer | 30 | A soft copy of login details in USB stick and in shared Dropbox folder | 1 |
| Pens | 30 | | |
| Printed score sheet for YCS game | 30 | Soft copy of the score sheet in shared Dropbox folder | 1 |

| | | | |
|---|---|---|---|
| Workstation numbers printouts | 30 | Soft copy in an USB drive and in the shared dropbox folder | 1 |
| Cellophane tape rolls | 2 | | |
| USB drives to collect MATB scores | 30 | | |
| Labels for the USB drives | 7 | | |
| Audio recording device | 1 | Note pad and pen | 1 |
| Gift card Û40 | 1 | | |
| Gift card Û20 | 1 | | |

The following sub-sections will present the pre and post game surveys used in the experimental sessions.

### E.2.1 YCS pre-game survey

1. Please enter your workstation number
2. What is your age, rounded to the nearest year?
3. What is your gender? (M/F)
4. What is your highest level of education? (High school/ MBO/HBO/ Bachelor/Master/ PhD/Other). If other, please specify.
5. What is your current profession?(Job title, industry)
6. How many years of professional experience do you have, rounded to the nearest year?
7. What is your nationality?
8. Approximately how many hours do you spend playing entertainment games in a week?
9. What is your preferred genre of entertainment games? (Action, Strategy, Sports, Puzzle, Rhythm, Simulation games, Role playing games, Other). If other, please specify.

10. On a scale of 1-5, 1 being poor and 5 being excellent, please indicate your level of experience with the following:

    - Entertainment games
    - Games for training or other work related issues
    - Game design
    - Port planning operations
    - Field of supply chain, logistics, and transportation

11. On a scale of 1-7, one being strongly disagree and 7 being strongly agree, for each of the pairs of adjectives below, please indicate the extent to which you agree or disagree that the pair of traits applies to you.

    a) Extraverted, enthusiastic
    b) Critical, quarrelsome
    c) Dependable, self-disciplined
    d) Anxious, easily upset
    e) Open to new experiences, complex
    f) Reserved, quiet
    g) Sympathetic, warm
    h) Disorganized, careless
    i) Calm, emotionally stable
    j) Conventional, uncreative

    ◯ Please tick this circle to confirm informed consent to participate in this study.

Thank you for your participation

### E.2.2 YCS1 post-game survey

Enter your work station number:

Please rate the following questions on a scale of 1-5 (1 is totally disagree and 5 is strongly agree), and comment if necessary

1. The objective of the YCS1 game is sufficiently clear
2. The objective of the YCS1 game is relevant to my field of study.
3. The tasks in the YCS1 game are understandable and well formulated.
4. The game is designed in an interesting and stimulating way.
5. I have a better understanding of CT operations after playing the YCS1 game.
6. The YCS1 game provided me an insight into the complexity of CT operations.
7. The YCS1 game was fun to play.
8. The feedback from the YCS1 game and the facilitator was useful.
9. Please rank the difficulty level of the game tasks.
10. The game reflects the interdependencies among various roles in CT operations.
11. The YCS1 game reflects the need for coordination of various processes in CT operations
12. I have a better insight about the importance of integrated planning after playing the YCS1 game.
13. The use of YCS1 game for education and training purposes is valuable.
14. I expect the insights gained through this YCS1 game to help me in my professional practice in future.
15. The use of YCS1 game can be worthwhile for Container Terminals towards adopting integrated planning approaches.

### E.2.3 SART survey

On a scale of 1-5, with 1 being very low and 5 being very high, rate the follow questions regarding your experience with the YCS game within the range of very low to very high.

**Instability of Situation**

How changeable is the situation? Is the situation highly unstable and likely to change suddenly (High) or is it very stable and straightforward (Low)?

**Complexity of Situation**

How complicated is the situation? Is it complex with many interrelated components (High) or is it simple and straightforward (Low)?

**Variability of Situation**

How many variables are changing within the situation? Are there a large number of factors varying (High) or focused on only one (Low)?

**Arousal**

How aroused are you in the situation? Are you alert and ready for activity (High) or do you have a low degree of alertness (Low)?

**Concentration of Attention**

How much are you concentrating on the situation? Are you concentrating on many aspects of the situation (High) or focused on only one (Low)?

**Division of Attention**

How much of your attention is divided in the situation? Are you concentrating on many aspects of the situation (High) or focused on only one (Low)?

**Spare Mental Capacity**

How much metal Capacity do you have to spare in the situation? Do you have sufficient to attend to many variables (High) or nothing to spare at all (Low)?

**Information Quantity**

How much information have you gained about the situation? Have you received and understood a great deal of knowledge (High) or very little (Low)?

**Familiarity with Situation**

How familiar are you with the situation? Do you have a great deal of relevant experience (High) or is it a new situation (Low)?

The following section explains the script used by the facilitator and observer during each session to maintain consistency among the sessions.

## E.3 Script of the experimental sessions

We created a detailed script to execute our research study to ensure consistency across several gaming sessions. This also helped us to carefully select the information that had to be given before, during and after the gaming sessions so that it would not influence how the participants fared at the YCS1 exercise. We will now describe the script.

< The facilitator and observer make sure that the room hosting the experiment is equipped with windows machines with the MATB software as well the unity plug in installed. The required game pads, ear phones, and mice are all attached to the machines. If some participants find it uncomfortable using earphones, provide the backup headset. Attach the work station numbers, using a cellophane tape. Keep 30 USB ready each labeled with the work station numbers used to collect the MATB scores. Make sure the project is connected and functional in the room. Load the slide pack containing the briefing, MATB, game play and de-briefing slides on the computer and test it. Open each of the work stations with the web browser open with the pre- game survey loaded on it >

### E.3.1 Briefing

<The facilitator opens the session>
"Hello, everyone. Welcome. We hope to provide an interesting session today. The session is completely anonymous, and you will be identified with your workstation numbers. We may also take some pictures for our records, but will not be published. If you have any reservations against participation or taking pictures, please let us know now."

<Wait for objections. Observer notes the objections, removes the data set and/or photos of the concerned participant who objects after the session >
"Thank you. We require your full engagement and attention during the entire session. We also would like to follow instructions very carefully. For your involvement in the session, you will be rewarded in the form of a weighted

lottery method. There are two prizes, a gift card worth 40 euros and another worth 20 euros. Two winners will be selected from the raffle, based on their highest scores in the second mission of the simulation game. Everyone has a chance to win, but the higher your score, the higher is your chance to win. Now, let us begin with the briefing lecture, where we will explain about the context of the research together with further instructions."

< Facilitator gives a general briefing lecture on research context >

"Do you have any questions?" <Answer the questions. Observer can help if facilitator requires it.>

We will now begin the experiment with a short online survey. As the whole study will assures anonymity it is very important that you to fill in your work station number wherever required. You will be identified by your work station number. The prizes in the end also correspond to the work station number. Also note that the first 9 workstation numbers are A01 to A09 and not A1. Please pay attention to enter them correctly as they correspond to a unique key. We now request you to fill in the online survey available on your web browser within the next 5 minutes.

<Wait for the participants to fill in the online survey. If the online version fails the facilitator provides the paper copies to the students.>

### E.3.2 MATB exercise

"Thank you. We will now proceed to the next step pf the experiment which is the MATB exercise developed by NASA for testing multi-tasking abilities. We will now present to you the instructions for the MATB exercise. We will explain how to perform different tasks in the exercise. Please feel free to ask questions regarding the instructions before you begin the exercise as it is best not to interrupt in between."

<The facilitator presents the MATB instructions>

"Do you have any questions?"

<Answer the questions >

"We will keep a slide open on the screen to summarize the tasks for your reference. Please be reminded that it will be possible to ask questions after you start you MATB exercise as it has to be finished I in a short span of about 5 minutes."

<Wait for more questions>

"Great.. Now, on you marks, get, set, and go!!!!"

<Wait for the participants to finish the MATB >

"Was that hard work? (<Smile>). You deserve a short break for all the hard work! We hope to see you back in 10 minutes to commence the exciting game session. Please don't be late and please be sure to sit in the same work station when you are back!"

< Facilitator (A01- A12) and observer(A13-A25) collect the MATB data from the work stations. My Computer> C drive > MATB> Data. Copy the entire data folder and paste in the respective USB stick. After data collection, prepare the log in page of the YCS game available on the web browsers of the work stations.>

### E.3.3 YCS game play

"Welcome back. Now let us begin with the gaming task. To get you prepared, we will give you a short introduction of the game."

<The facilitator gives a very brief introduction to the YCS game>

"It is always better to try it out than listen to the game play. You will first play a tutorial mission to get you acquainted with the game mechanics. To try the game you will first play the first level of the game known as 'Mission 1' for 2 times. You can ask questions during the tutorial mission and the 'Mission 1'. After getting acquainted with the game for a couple of times you will the play 'Mission 2' in which you are required to play uninterrupted. Therefore please clear your questions before you begin Mission 2. The prizes will depend on the scores of Mission 2 only. At any point of the time if your game is stalled, close the game and restart. Your scores won't be affected. You will now be given a sheet of paper and pen to report your scores of mission 1 and mission 2. You should report the scores of completed games only."

"Do you have any questions?"

<While the observer answers the questions, the facilitator distributes the login information and YCS game score sheets to the corresponding work stations. Facilitator activates the tutorial widget in the portal.>

"Please log onto the game play mode by using the login details available on your workstation. Please check if the log in details and score sheet correspond to your work station number. Please complete the tutorial session."

<Wait until participants finish the tutorial. If log in problem try clear browsing history, retry. If problem persists change browser. If that doesn't work, load the executable file for that participant.>

"I hope you understood the basics of the game. Now let's begin playing it in full."

<Observer deactivates tutorial and activates Mission 1>

"Please play mission 1 two times and record your scores manually on the paper on your desk with the pen provided. You can always ask questions during mission 1. This mission is for you to familiarize with the game. Now let us begin playing!"

<Game play mission 1 for two times. Observer keeps displaying high scores every 3 minutes>

"We now request you to stop playing mission 1. Please be reminded to write your work station number on your score sheet."

< Observer deactivates Mission 1 and activates mission 2 on the portal >

"You will now see mission 2 appear on your screen. You can now begin to play mission 2. Please play mission 2 for three times and write down all the three scores on the paper in front of you. The lottery prizes depend on the scores of Mission 2. The higher your score the higher is your chance of winning. You need to play the uninterrupted. Don't forget to write down your scores on the score sheet. Unless you have technical issues regarding the running of the game, you are requested not to ask questions regarding the game play. Are you ready?.......... Lets play!!!!!!!"

<Game play Mission 2 for three times for about 20 minutes.>

"We now ask you to please stop the game play."

<The observer de-activates Mission 2 and activates the post game survey on the portal. After which the observer collects all the score sheets from each of the work stations>

"You will now see a survey appear on your screen. Please fill it in while we draw the winners, who will be announced after the final debriefing session."

"We hope you had fun! Please mind that high scores need not automatically mean that you won the prizes. We have to wait till the debriefing session to decide the winners using the weighted lottery method. You will now see a survey appear on your screen. Please fill it in while we draw the winners, who will be announced after the final debriefing session."

<Facilitator runs the script to draw winners based on high scores to determine the winners>

### E.3.4 Debriefing

"Before we begin our debriefing lecture, we would like to gather your opinions regarding the game play. We would like to audio record your answers. If any of you have objections please let us know."

<If there are no objections, the observer records the answers using an audio recording device(cell phone for e.g.). If any participant objects, the observers takes note of the answers on a note pad>

Questions for debriefing:

**Game Play - Improvements**

- Did you find the game fun playing? What made it fun?
- Did you encounter any problems or difficulties while playing the game? What kind of?
- How could the game be improved?

**Strategies— Player with the highest score**

- Why do you think you got the highest score? What did you do?
- Did you apply a certain strategy? What kind of?
- What did you learn from playing the game?

**Strategies— Any Player with a Lower score**

- Why do you think you got a lower score?
- Did you apply a certain strategy? What kind of?

- What did you learn from playing the game?
- Do you think you would be able to obtain a higher score next time you would play it?

**Fidelity of the game**

- Did you clearly understand your tasks within the game? What was the game about?
- Thinking about real container terminals as introduced earlier Đ do you think that the game represents an adequate level of reality?
- If not, do you think it is necessary to change it? If yes, how?

"Thank you. We will now conclude this experiment with a debriefing lecture for reflection and of course announce the winners afterward."

<The facilitator gives a Debriefing lecture>

"Do you have any questions?"

<The observer and facilitator answer questions together >

"Thank you for participating in this study. Now it is time for the rewards. We have two winners. And they are........Congratulations!!"

<Give away prizes>

"Thank you all for your help. If you have further questions or interest regarding our research please contact us via e-mail available on the last slide. Thanks again, all the best."

<Back up all the data in the Dropbox folder as soon the session is over. Deactivate the YCS game accounts.>

## E.4 Application form

Please fill in the checklist first if you have not done so already. Please complete this form digitally and send it the Ethics Committee.

Date of Submission: 27-10-2014

Project Title: SALOMO — Predictors for Operator Performance in Sea-Port Planning Operations

Name(s) of researcher(s): Prof. Dr.Ir. Alexander Verbraeck, Dr. rer.soc. Heide Lukosch, Ir. Shalini Kurapati

Name of supervisor (if applicable): Prof. Dr.Ir. Alexander Verbraeck

Contact Information:

Department: Multi Actor Systems Systems Engineering and Simulations Section

Telephone number: 278 3211

E-mail address: h.k.lukosch@tudelft.nl

Contact information of external partners (if applicable): Enter contact information here.

**Summary**

Please provide a brief summary of the research.

In our research, we aim at understanding skills and attributes that are needed in sea-port planning operations. Such operations are complex, dynamic, and inter-dependent. An integrated planning approach is needed for smooth and cost-effective flow of cargo through a sea-port. Planners have to able to perform integrated planning, confronted with high time pressure, and a huge amount of information. In order to investigate which attributes and skills are needed for these tasks, we are going to execute a combined experiment, where the participants conduct a personality test (TIPI), a multi-tasking test (MATB, NASA), and play a simulation game (Yard Crane Scheduler Ð YCS).

**Research**

R.1. What is the research question? Please indicate what scientific contributions you expect from the research.
In this research, we investigate which skills and attributes are needed to perform complex planning tasks in seaport container terminals. The aim of the research is to contribute to the area of transport and logistics by understanding the requirements of the tasks and to provide supportive tools that answer these requirements.

R.2. What will the research conducted be a part of?

- Bachelor's thesis
- Master's thesis
- PhD thesis
- Research skills training
- Other, namely: Enter what the research is part of here.

R.3. What type of research is involved?

- Questionnaire
- Observation
- Experiment
- Other, namely: Simulation Game, Multi-Tasking Test (MATB, NASA)

R.4. Where will the research be conducted?

- Online

- At the university
- Off-campus / non-university setting: Enter which setting here.
- Other, namely: TU Delft, University of Media Design, Dusseldorf, and University of Maryland, College Park, MD, USA

R.5. On what type of variable is the research based? Give a general indication, such a questionnaire scores, performance on tasks, etc. Relationship between personality test scores, MATB scores, and high scores of the simulation game.

R.6. If the research is experimental, what is the nature of the experimental manipulation? Enter the nature of the experimental manipulation here.

R.7. Why is the research socially important? What benefits may result from the study? Planning of complex tasks within the container transportation field will be much better understood. Requirements are analysed and tools will be developed to answer the specific needs of the field in order to improve performance of container transportation.

R.8. Are any external partners involved in the experiment? If so, please name them and describe the way they are involved in the experiment. University of Media Design, Dusseldorf, and University of Maryland, College Park, MD, USA are research partners in the Salomo project, and will support the experiments with providing classrooms, equipment, and with enabling students to participate in the study.

**Participants**

Pa.1. What is the number of participants needed? Please specify a minimum and maximum. Minimum: 120 Maximum: 250

Pa.2.a. Does the study involve participants who are particularly vulnerable or unable to give informed consent? (e.g., children, people with learning difficulties, patients, people receiving counselling, people living in care or nursing homes, people recruited through self-help groups) no

Pa.2.b. If yes and unable to give informed consent, has permission been received from caretakers/parents? Enter if permission from the caretakers/parents can be received here.

Pa.3. Will the participants (or legal guardian) give written permission for the research with an ÔInformed ConsentÕ form that states the nature of the research, its duration, the risk, and any difficulties involved? If no, please explain. Yes, within the pre-test questionnaire

Pa.4. Are the participants, outside the context of the research, in a dependent or subordinate position to the investigator (such as own children or students)? If yes, please explain. One group of 26 students of TUD has a possible power relationship to one of the researchers, as these students are partly supervised by the researchers, but the results of the experiments are not related with any course or formal educational assignment. In this case, the phd researcher will facilitate the session as an intermediair, the researcher who is also teacher of this group is only observing the experiment and has no active role in it. Furthermore, we will collect some sensitive data by using the personality test, but we will collect all data anonymously, so no conclusion about the results in relation to a certain student will be possible. The workstations used are laptops that belong to the university and does not contain any personal data of the student as no login is required with a netid or other personal information. The workstation numbers are also created on the spot, and students are advised to take random seats during the sessions. There is no key or document linking a particular student to the workstation number, therefore the teacher is unable to identify the students.

Pa.5. How much time in total (maximum) will a participant have to spend on the activities of the study? 90 minutes

Pa.6. Will the participants have to take part in multiple sessions? Please specify how many and how long each session will take. no

Pa.7. What will the participants be asked to do? Participants will be asked to fill-in a pre-test questionnaire, including a short personality test, conduct the MATB, and play several rounds of the simulation game. After the game, participants are asked to join the de-briefing of the whole session.

Pa.8. Will participants be instructed to act differently than normal or be subject to certain actions which are not normal? (e.g. subject to stress inducing methods) no

Pa.9. What are the possible (reasonably foreseeable) risks for the participants? Please list the possible harms if any. We do not see any risk for the participants while participating in the experiment.

Pa.10. Will extra precautions be taken to protect the participants? If yes, please explain. All materials will be checked whether they have the CET certificate.

Pa.11. Are there any positive consequences for a participant by taking part in the research? If yes, please explain. Participation is compensated by a weighted lottery method where two winners are chosen from a raffle. The prices are a 20 Euro gift card and a 40 Euro gift card from bol.com.

Pa.12. Will the participants (or their parents/primary caretakers) be fully informed about the nature of the study? If no, please explain why and state if they will receive all information after participating. yes

Pa.13. Will it be made clear to the participants that they can withdraw their cooperation at any time? yes

Pa.14. Where can participants go with their questions about the research and how are they notified of this? Participants can reach the phd researcher at any time, they are informed about that within the presentation given at the beginning of the experiments.

Pa.15. Will the participants receive a reward?

- Travel expenses
- Compensation per hour
- Nothing

- Other, namely: see Pa.11.: Participation is compensated by a weighted lottery method where two winners are chosen from a raffle. The prices are a 20 Euro gift card and a 40 Euro gift card from bol.com.

Pa.16. How will participants be recruited? Participants are students of the project partners, recruited by their university.

**Privacy**

Pr.1. Are the research data made anonymous? If no, please explain. yes

Pr.2. Will directly identifiable data (such as name, address, telephone number, and so on) be kept longer than 6 months? If yes, will the participants give written permission to store their information for longer than 6 months? no

Pr.3. Who will have access to the data which will be collected? Prof. Dr. Ir Alexander Verbraeck, Dr.rer.soc. Heide Lukosch, Ir. Shalini Kurapati TU Delft, Dr. Stefanie Eckert, Prof. Dr. Thomas Corsi University of Maryland, Ir. Daan Groen (Developer of the simulation game used)

Pr.4. Will the participants have access to their own data? If no, please explain. Only partly, as the data is collected in the background of the MATB test and has to be analysed by a researcher. For the simulation game, all scores are visible for the particpants. Participants who like to kno about their results can be informed by the research team (see also Pa.14)

Pr.5. Will covert methods be used? (e.g. participants are filmed without them knowing) no

Pr.6. Will any human tissue and/or biological samples be collected? (e.g. urine) no

**Documents**

Please attach the following documents to the application:

- Text used for ads (to find participants);
- Text used for debriefings;
- Form of informed consent for participants;
- Form of consent for other agencies when the research is conducted at a location (such as a hospital or school).

APPENDIX F

# MULTI ATTRIBUTE TEST BATTERY: MATB-II

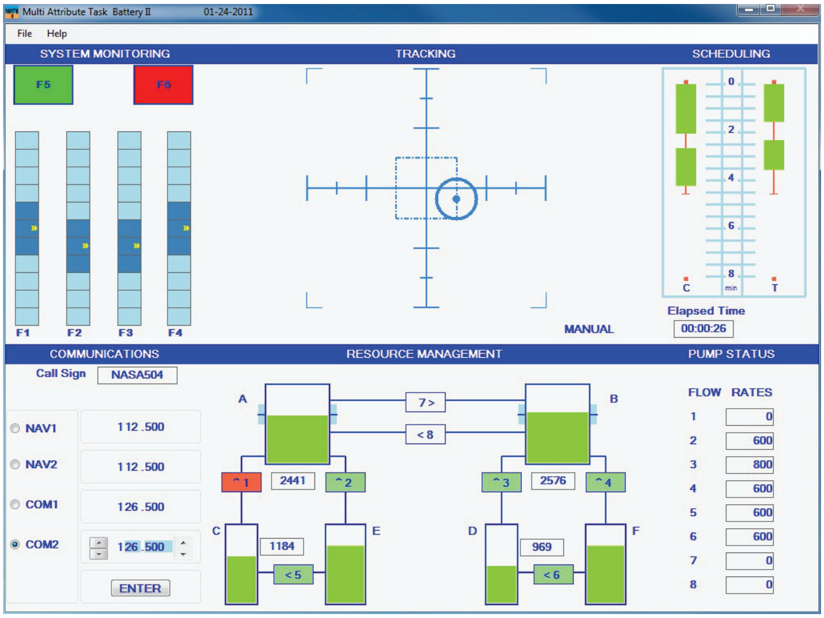
## Multi Attribute test Battery: MATB-II

### MATB-II task descriptions

The Multi Attribute Test Battery (MATB-II) was chosen as the research instrument for measuring multi-tasking ability. MATB was developed in the early 90's for performing multitask workload and human-computer interactions focussed on space and aircraft cockpit tasks. MATB was upgraded to MATB-II following a wide acceptance from research communities not limited to space and aircraft applications. MATB and MATB-II have been used in over 130 research studies on human performance related to multi-tasking and complex tasks Based on our search for a validated tool to capture multi-tasking ability we found that MATB-II is an apt tool that clearly represents computer based multi-tasking of complex tasks. The software was requested from the subsidiary website of NASA (http://matb.larc.nasa.gov/). As illustrated in Figure 2, MATB-II is a computer based multi-tasking exercise, which requires the simultaneous performance of systems monitoring, tracking, dynamic resource management and communication tasks.

**SYSMON task** The systems monitoring task or SYSMON is in the upper left corner of the MATB-II task window. SYSMON has two sub-tasks: detecting changes in the warning lights and changes in the scales of the system. The

Figure F.1: Screenshot of the various tasks in the MATB-II exercise (Santiago-Espada et al., 2011)




default colors of warning light F5 is green, and F6 is the background color of the MATB-II window. Whenever the green light in the F5 box turns off and/or a red light appears in F6, participants should click on the box that experienced a change in color using a mouse or by pressing the respective function key on the keyboard. In the second sub-task of SYSMON, each of the 4 blue scales F1, F2, F3, F4 have dark-blue indicator lights fluctuating around the middle of the scale. If participants notice that the indicator lights shift their position away from the center, they need to respond by either clicking or pressing the respective function key of the affected scale. In our study we offered the choice of using either the mouse or the keyboard. The performance of the SYSMON task is determined by the (lowest) number of errors each participant commits in terms of noticing changes in the boxes and scales and reacting correctly to them. MATB software generates an individual data file with all the changes in the system together with the participant responses.

**TRACK task** The tracking task or TRACK is in the upper central part of the MATB-II task window. This tasks has two modes: MANUAL or AUTO ON. If the MANUAL mode is on, the participants need to keep the target in the center of the inner box using a joystick. We provided gamepads that contain joysticks (Speedlink, Logitech) to the participants. By default, the software records the position of the target with respect to the center point every 15 seconds, by calculating the Root Mean Square Distance from the Center (RMSDC) of the target from the center point. The closer the participant positions the target to the center, the better they perform at the TRACK task.

**RESMAN task** Dynamic resource management or RESMAN task is in the lower center part of the MATB-II task window. RESMAN represents a fuel management system containing tanks: A, B, C, D, E and F and a set of 8 pumps: 1, 2, 3, 4, 5, 6, 7, 8. These pumps are along the fuel lines connecting all the tanks. The objective of the RESMAN task is to maintain the fuel levels in Tank A and Tank B within 2500 units of fuel throughout the exercise. To maintain this objective, participants are required to supply the fuel tanks A and B with fuel using the set of 8 pumps from the supply tanks C, D E and F. The capacity of tanks E and F is infinite. However tanks C and D have a finite capacity of 4000 units each. A pump is green when it is in the ON state and has the background color of the MATB-II task window when it is in the OFF state. If a pump is broken or malfunctioning it turns red, and reaches a FAILED state. When a pump is FAILED, participants have to look for alternative fuel routes to supply fuel to tanks A and B, by using the other functional pumps. Each of the pumps has a specific direction indicated by a small arrow head symbol. The pumps can be turned ON or OFF by clicking on them using a mouse or by pressing the respective number of a pump. The flow rate of each of the pumps is displayed in a separate column known as pump status in the bottom right part of the MATB-II task window.

**COMM task** Communications or COMM task can be found in the lower left corner of the MATB-II task window. Participants are provided with earbuds (JVC) through which they can hear auditory commands generated by the MATB-II software that requests them to choose a certain radio and change its frequency. Participants are only expected to respond to the auditory commands that have a call sign 'NASA504'. Any other command has to be ignored. An example auditory command is "NASA504 tune your com one radio to frequency one two four point eight six". Participants can either use mouse or keyboard to select the radio and change the frequency. When a COMM event occurs the software records it together with the participant response and generates an output file for analysis. The performance at the COMM task is determined by the number of appropriate and accurate responses of the participants to the

Table F.1: Correlations: MATB individual scores and YCS1 score

| Correlation with YCS1 score | | |
|---|---|---|
| | Pearson's R coefficient | p value |
| Systems monitoring (SYSMON) | .198 | .022 |
| Communication (COMM) | .226 | .009 |
| Tracking(TRCK) | .252 | .003 |
| Resource management (RESMAN) | .453 | 000 |

auditory command.

The other aspects of the MATB-II task window include a scheduling display, SCHED that indicated the communication and tracking tasks' timeline during the exercise. This display doesn't require participant intervention. During the exercise, a work load rating scale based on NASA-TLX is displayed while the run timer of the exercise freezes. After the participants fill in the rating scale, the tasks resume with previously saved states of each of the tasks.

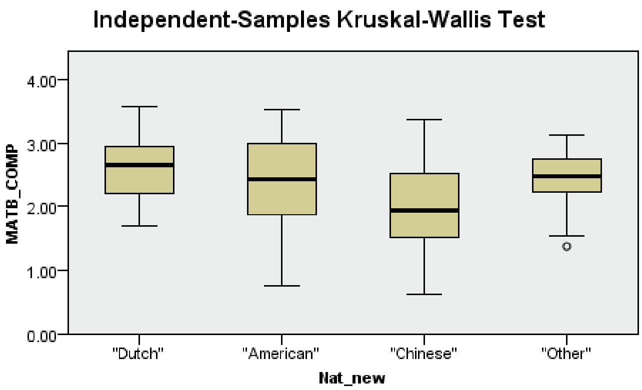
Each of the 4 tasks of MATB-II have a different output file with varying performance indicators. The following section describes our efforts to define a composite score for MATB-II.

## F.1 MATB data analysis

We will present the correlations between individual components of the MATB score and the YCS1 score in Table F.1. We can see that all the four individual components of the MATB score are strongly correlated to the YCS1 score.

We will test the role of nationality and gender on the multi-tasking ability of participants from the YCS1 study using Kuskal-Wallis and Mann-Whitney U test respectively. Figure F.3 shows that Dutch participants had super multitasking skills compared to other nationalities. Based of the pair-wise comparisons we found that the significance of difference was marked between Dutch and Chinese participants ($p<.003$).

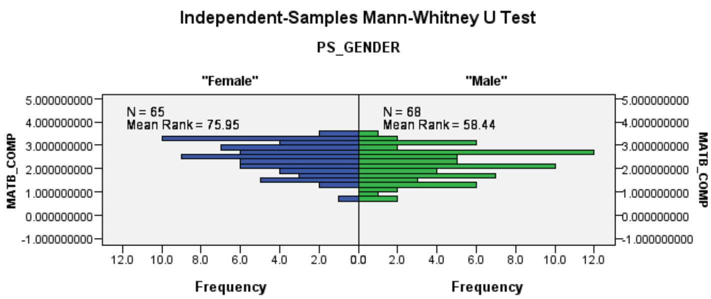
Figure F.3 shows that female participants had higher multi-tasking ability compared to their male counterparts with a superior mean rank of 75.95 and a significant test statistic ($p=.009$).




| | |
|---|---|
| **Total N** | 129 |
| **Test Statistic** | 13.582 |
| **Degrees of Freedom** | 3 |
| **Asymptotic Sig. (2-sided test)** | .004 |

1. The test statistic is adjusted for ties.

Figure F.2: MATB and Nationality: Kruskal-Wallis test




| | |
|---|---|
| **Total N** | 133 |
| **Mann-Whitney U** | 1,628.000 |
| **Wilcoxon W** | 3,974.000 |
| **Test Statistic** | 1,628.000 |
| **Standard Error** | 222.164 |
| **Standardized Test Statistic** | -2.620 |
| **Asymptotic Sig. (2-sided test)** | .009 |

Figure F.3: MATB and Gender: Mann Whitney U test

APPENDIX G

# YCS GAME DATA AND ANALYSIS

## G.1 Variables measured in the YCS games

Table G.1: Variables measured in the YCS game

| Variable name | Explanation | Mean | Std. Dev |
|---|---|---|---|
| 1. BerthCranesUsed | The number of berth cranes used during the game | 2.8 | 0.4 |
| 2. BonusEarlyVessel | Bonus points earned due to early departure of vessels | 9744.3 | 9025.9 |
| 3. BonusSeconds | The difference between the duration (in seconds) of actual departure and early departure of vessels that lead to bonus points | 97.4 | 90.3 |
| 4. BonusYellowCainer | Bonus points for handling yellow containers carried away by hinterland trucks | 168.5 | 166.1 |
| 5. PlandAftArrival | Number of containers planned before arrival of the vessel | 1.8 | 4.0 |
| 6. PlandBfArrival | Number of containers planned after the arrival of the vessel | 13.9 | 11.7 |

| | | | |
|---|---|---|---|
| 7. LongstContainerIdle | The longest idle time of a container (seconds) | 86.1 | 54.1 |
| 8. LongstInactiveBerth | The longest idle time of a berth crane (seconds) | 46.6 | 48.2 |
| 9. LongstInactiveYard | The longest idle time of a yard crane (seconds) | 107.8 | 101.7 |
| 10. LargeVesselsArrived | Number of large vessels that arrive in the game | 1.6 | 1.1 |
| 11. LeastEfficientBerthCrane | The idle time of the least efficient berth crane (seconds) | 48.9 | 46.3 |
| 12. LeastEfficientYardCrane | The idle time of the least efficient yard crane (seconds). | 106.2 | 96.5 |
| 13. MostEfficientBerthCrane | The idle time of the most efficient berth crane (seconds) | 1.9 | 8.3 |
| 14. MostEfficientVessel | The waiting time for the most efficient vessel (seconds) | 87.7 | 95.7 |
| 15. MostEfficientYardCrane | The idle time of the most efficient yard crane (seconds) | 0.7 | 0.5 |
| 16. NotPlanned | The number of unplanned containers | 2.6 | 3.8 |
| 17. PointsTotal Succes | Bonus points for successful handling of containers | 1766.0 | 1561.0 |
| 18. Score | The overall game score | 6310.8 | 7203.6 |
| 19. ScoreContainers | The points awarded for handling containers | 1107.9 | 1373.3 |
| 20. ScoreVessels | The points awarded for handling vessel | 9912.9 | 8942.8 |
| 21. SecsBerthCraneInactive | The idle time of all the berth cranes (seconds) | 88.2 | 90.8 |
| 22. SecsContainerIdle | The waiting time for all the containers to be handled (seconds) | 963.5 | 699.3 |
| 23. SecsWaitBerth | Waiting time for containers in the quay to be loaded onto the vessel (seconds) | 94.0 | 87.1 |
| 24. SecsWaitInSchip | Waiting time for containers in the vessel (seconds) | 486.6 | 394.3 |
| 25. SecsWaitInStack | Waiting time for containers in the yard (seconds) | 245.3 | 221.1 |

| | | | |
|---|---|---|---|
| 26. SecsWaitYard | Waiting time for containers to be handled by yard cranes (seconds) | 136.9 | 175.0 |
| 27. SecsYardCraneInactive | The idle time of all the berth cranes (seconds) | 390.2 | 366.7 |
| 28. SmallVesselsArrived | Number of small vessels arrived | 2.1 | 1.5 |
| 29. StarsContainers | Stars awarded for handling containers | 1.4 | 1.1 |
| 30. StarsCranes | Stars awarded for handling cranes | 3.3 | 1.7 |
| 31. StarsTotalScore | Total number of stars awarded based on total score | 3.9 | 1.4 |
| 32. StarsVessels | Stars awarded for handling the vessels | 3.1 | 1.6 |
| 33. StrafContainerIdle | Penalty points due to container idle time | -89.2 | 159.7 |
| 34. StrafCranesIdle | Penalty points due to crane idle time | -472.8 | 434.1 |
| 35. StrafTotaalUnsuccessful | Penalty points due to unsuccessful container handling | -568.9 | 553.1 |
| 36. TotalContainers | Total number of containers moved | 17.1 | 12.4 |
| 37. TotalSuccesful | Total number of containers successfully handled | 11.4 | 9.3 |
| 38. TotalUnsuccessful | Total number of containers that were not handled | 5.7 | 5.5 |
| 39. TotalVesselsArrived | Total number of vessels arrived | 3.7 | 2.4 |
| 40. TotalVesselsEarly | Total number of vessels that left earlier than scheduled | 1.8 | 1.4 |
| 41. YardCranesUsed | Number of yard cranes used | 5.0 | 1.2 |
| 42. YellowContainersCollected | The number of yellow containers picked up | 1.7 | 1.7 |
| 43. YellowContainersLeft | The number of yellow containers left behind | 0.3 | 0.7 |

## G.2 Statistical results of Chapters 5 and 6

Figure G.1: Test for normality: YCS1 score among male and female participants

**Tests of Normality**

| | PS_GENDER | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|---|
| | | Statistic | df | Sig. | Statistic | df | Sig. |
| Y_HIGH_1_2 | "Female" | .104 | 65 | .077 | .980 | 65 | .377 |
| | "Male" | .063 | 68 | .200* | .974 | 68 | .168 |

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Figure G.2: Test for normality: YCS1 score among male and female participants

**Tests of Normality**

| | Nat_new | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|---|
| | | Statistic | df | Sig. | Statistic | df | Sig. |
| Y_HIGH_1_2 | "Dutch" | .140 | 28 | .168 | .954 | 28 | .254 |
| | "American" | .154 | 37 | .026 | .913 | 37 | .007 |
| | "Chinese" | .092 | 39 | .200* | .972 | 39 | .430 |
| | "Other" | .142 | 25 | .200* | .937 | 25 | .129 |

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Figure G.3: Test for normality: YCS3 individual and team scores

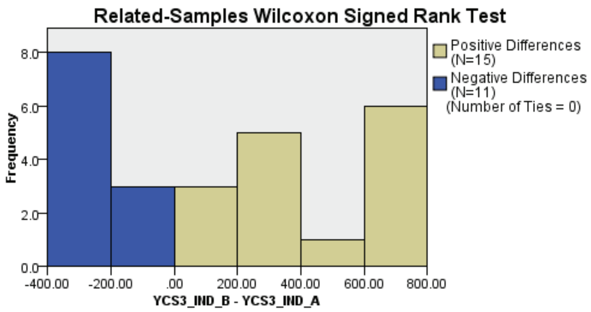
**Tests of Normality**

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| YCS3_IND_A | .131 | 26 | .200* | .942 | 26 | .153 |
| YCS3_IND_B | .227 | 26 | .001 | .841 | 26 | .001 |
| YCS3_IND_C | .171 | 26 | .049 | .914 | 26 | .033 |
| YCS3_TEAM_A | .137 | 26 | .200* | .929 | 26 | .075 |
| YCS3_TEAM_B | .288 | 26 | .000 | .782 | 26 | .000 |
| YCS3_TEAM_C | .185 | 26 | .022 | .888 | 26 | .009 |

*. This is a lower bound of the true significance.

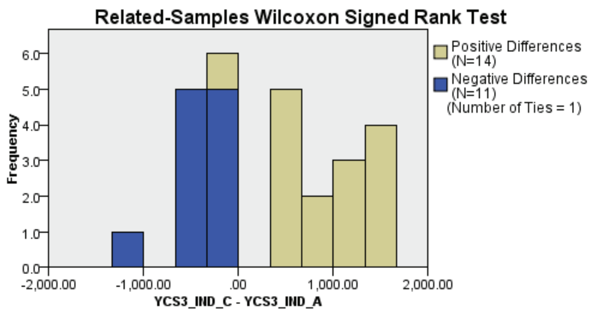
a. Lilliefors Significance Correction

Figure G.4: Comparing the YCS3 individual scores of SA configurations A and B



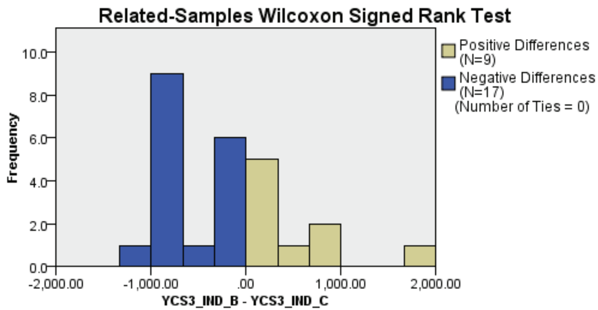

| | |
|---|---|
| **Total N** | 26 |
| **Test Statistic** | 232.500 |
| **Standard Error** | 39.372 |
| **Standardized Test Statistic** | 1.448 |
| **Asymptotic Sig. (2-sided test)** | .148 |

Figure G.5: Comparing the YCS3 individual scores of SA configurations A and C




| | |
|---|---|
| **Total N** | 26 |
| **Test Statistic** | 249.000 |
| **Standard Error** | 37.165 |
| **Standardized Test Statistic** | 2.327 |
| **Asymptotic Sig. (2-sided test)** | .020 |

Figure G.6: Comparing the YCS3 individual scores of SA configurations B and C




| | |
|---|---|
| Total N | 26 |
| Test Statistic | 94.000 |
| Standard Error | 39.372 |
| Standardized Test Statistic | -2.070 |
| Asymptotic Sig. (2-sided test) | .038 |

## APPENDIX H

# TEAMSTEPPS TEAM PERCEPTIONS QUESTIONNAIRE (T-TPQ)

On a scale of 1 to 5, rate the statements below **Situation Monitoring**

- My team members anticipate each other's needs in the game.
- My team members monitor each other's performance.
- My team members exchange relevant information during the game
- My team members seek information from others when required.
- My team members correct each other's mistake to ensure good performance in the game.

**Mutual Support**

- My team members support me while I had difficulties in the game.
- My team members request assistance when they had difficulties in the game.
- Feedback received from my team members helped me make good decisions in the game.

- My team members caution me about a difficult situation in the game
- My team members were visibly upset when one of the team members didn't perform well

**Communication**

- Team members share relevant information in a timely manner
- Team members communicate in a clear and understandable manner
- Team members constantly seek information from each other
- Team members verify the received information with each other
- Team members allow questions during communication

Appendix I

# Transcription of YCS3 game videos

## I.1 Video transcription of Team 1 (Group1)

Team 1 played the YCS 3 game in three levels in the order of individual, shared and distributed levels of SA.

The set-up if the individual level is such that participants are not allowed to interact with each other in any form— verbal, non-verbal or otherwise. Therefore during the 9 minutes of the video recording, all the participants were silent and were working on their individual computer screens. After 1:15 minutes, C asked a question about the game to the moderator, which was quickly clarified. During the game play the moderator had to remind the team twice that talking wasn't allowed. At the end of 9 minutes, the game was over with team members smiling at each other looking at their scores on the screen.

## I.2 Video transcription of Team 5 (Group2)

We have already mentioned in the transcription of Team 1 regarding the set-up of individual SA level of game play. All the team members were quite concentrated when the game began. At about 03:17 minutes into the game play, the berth planner asked the moderator a question about his task, with was solved within 10 seconds. The game was over at 07:58 minutes.

Table I.1: Transcription of the activity during the Shared SA level of YCS3 game play

| Time | Participants involved | Activity of Team 1 |
|---|---|---|
| 00:00 | All | Game starts. Players are concentrated on their tasks. |
| 01:44 | Yard planner (Y) and Controller(C) | Y passes a note to Controller(C), who reads it and places on the A3 sheet in the middle of the table |
| 02:20 | Vessel planner (V) and Berth planner(B) | V passes a note to B, who looks at the note and gets back to his task |
| 02:58 | Vessel planner (V) and Berth planner(B) | V passes another note to B |
| 03:40 | Vessel planner (V) and Berth planner(B) | B takes look at the A3 sheet at the middle of the table. |
| 04:52 | Vessel planner (V), Berth planner(B) and Yard planner (Y) | V writes a note and sticks it on the A3 sheet in the middle of the table. Y looks at it, but B takes it to his side away from Y's view (Moderator helps B to put the note back on the common sheet) |
| 08:10 | All | Game over |

Table I.2: Transcription of the activity during the Shared SA level of YCS3 game play

| Time | Participants involved | Activity of Team 1 |
|---|---|---|
| 00:00 | All | Game begins |
| 0:14 | Berth planner (B)<br>Vessel planner (V) | B asks V about the priority of containers,<br>and V recites the order of her planning |
| 0:23 | Yard planner (Y)<br>Controller (C) | Y tells C to plan cranes in various blocks in the yard |
| 00:37 | V and B | V recites the order of container unloading to B<br>for a different ship. |
| 00:49 | Controller (C) | C (inaudible murmur) |
| 01:00 | Y and C | Y to C : First in block A and the block B and<br>then the rest of the yard. |
| 01:43 | V and B | V recites the order of container unloading to B<br>for a different ship. |
| 01:45 | Y and C | Y tells C to finish B first and then go to A, C<br>agrees to the do B(yard block) first but doesn't agree<br>with proceeding to A. |
| 02:05 | Controller (C) | C shakes his head looking at the screen and<br>says out loud that, it is not what he was expecting. |
| 02:16 | V and B | V recites the order of container unloading to B. |
| 02:49 | C and Y | C discusses his problem regarding planning<br>the cranes with V. |
| 02:59 | V and B | V recites the order of container unloading to B<br>for a different ship. |
| 03:13 | C and Y | C and Y discuss about where to plan the next<br>containers and yard cranes. |
| 04:06 | V and B | V recites the order of container unloading to B<br>for a different ship. |
| 04:51 | C and Y | C discussed with Y discuss yard plan<br>and crane positions. |
| 06:31 | C and Y | C and Y discuss the problem with each other's plans. |
| 07:17 | C and Y | C and Y continue to discuss their plan. |
| 07:59 | C and Moderator | C asks the moderator if anything is wrong with his task. |
| 08:19 | Y and B | Y reflects on her tasks with B. |
| 08:47 | All | Game over. |

Table I.3: Transcription of the activity of Team 5, DSA level, round 2

| Time | Participants involved | Activity of Team 5: DSA level, round 2 |
|---|---|---|
| 00:19 | Vessel planner (V) and Berth planner (B) | V and B discuss with each other about their roles, while C and Y are finishing the SART questionnaire after round 1. |
| 01:09 | All | The game is about to begin shortly. All the team members have finished the SART survey from round 1.Y asks C about her preferred way of planning and resource allocation. They discuss what they can or cannot see on their respective screens regarding the team activity. |
| 02:54 | All | Game begins. |
| 03:11 | All | Y tells C about his yard plan. V&B discuss the order of ships and unloading plan for containers. |
| 03:23 | Yard planner(Y) and Controller(C) | Y continuously informs C of his actions. |
| 03:54 | Vessel planner (V) and Berth planner(B) | V and B discuss about the priority of containers. |
| 04:06 | Yard planner(Y) and Controller(C) | Y informs C about his yard plan. |
| 04:51 | Berth planner (B) and Yard planner(Y) | Y asks B to check a ship |
| 05:11 | All | Y tell C to move cranes in a certain order, C follows Y's instructions. B and V continue negotiating the unloading plan. |
| 06:45 & 08:17 | Vessel planner (V) and Berth planner(B) | V and B discuss unloading plan |
| 08:25 | Controller(C) and Yard planner(Y) | Y tells C what to plan, C nods. |
| 09:21 | Berth planner (B), Yard planner(Y) and Controller(C) | B and Y discuss about their respective statuses in the team activity. C asks Y a question about yard capacity for which Y responds. |
| 10:41 | All | Game over. |

Table I.4: Transcription of the activity of Team 5, SSA level, round 3

| Time | Participants involved | Activity of Team 5: SSA level, round 3 |
|---|---|---|
| 00:23 | All | Game begins |
| 00:45 | Vessel planner (V) and Berth planner(B) | V passes a note to B |
| 01:28 | Yard planner(Y) and Controller(C) | Y passes a note to C |
| 02:01 | All | V sends a note to B, and B passes this on to Y |
| 02:16 & 03:31 | Yard planner(Y) and Controller(C) | Y sends a note to C |
| 04:06 | Vessel planner (V) and Berth planner(B) | V sends a note to B |
| 04:51 | Berth planner (B) and Yard planner(Y) | B sends a note to Y |
| 04:55 & 05:23 | Yard planner(Y) and Controller(C) | Y sends a note to C |
| 07:44 | All | B sends a note to V, and<br>Y sends a note to C |
| 09:28 | All | Game over. |

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# Curriculum Vitae

Shalini Kurapati was born in Vellore (India) on the 27th of May 1988. She completed her bachelor in Mechanical Engineering at College of Engineering, Guindy, Anna University Chennai in June 2009. She was awarded a faculty scholarship to continue her master studies at the TPM faculty at TU Delft, the Netherlands. She completed her MSc. in Engineering and Policy Analysis in August 2011.

In November 2011, she started her PhD at the TPM faculty. Her PhD work was based on a collaborative research project including researchers at TU Delft, Open University of the Netherlands, University of Maryland, container terminals at the Port of Rotterdam, and several small and medium gaming and simulation companies. Her research and academic interests include conducting empirical research using simulation gaming, game data analytics, and simulation gaming for training.

# List of Publications


1. Kurapati, S., Lukosch, H., Verbraeck, A., & Brazier, F. M. (2015). Improving resilience in intermodal transport operations in seaports: a gaming approach. *EURO Journal on Decision Processes, 3*(3-4), 375-396

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3. Kurapati, S., Groen, D., Lukosch, H. & Verbraeck, A. (2014). In Kriz, W. (Ed.) Microgames in Practice: A Case Study in Container Terminal Operations *The Shift from Teaching to Learning: Individual, Collective and Organizational Learning Through Gaming Simulation*, ISAGA, 333-346

4. Kurapati, S., Lukosch, H., Eckerd, S., Verbraeck, A., & Corsi, T. Relating Planner Task Performance for Container Terminal Operations to Multi-Tasking Skills and Personality Type. *In review.*

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7. Lukosch, H. K., Groen, D., Kurapati, S., & Verbraeck, A. (2015): Using Simulation Games as Research Instruments— Lessons Learned from the Transportation Domain. In Kanegae, H., Arai, Y., & Deguchi, H. (Eds.) *Proceedings of the 46th International Simulation and Gaming Association Annual Conference*, Kyoto, Japan, 17-21.07.2015, (pp.177-190)

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Olde Keizer, M.C.A., *Condition-Based Maintenance for Complex Systems: Coordinating maintenance and logistics planning for the process industries*, T2016/26, December 2016, TRAIL Thesis Series, the Netherlands

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