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Integrated Planning for Safe and Efficient Autonomous Transport Operations

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ABSTRACT

Introducing new technology and autonomy into the supply chain are expected to result in more efficient, safe, and environmentally friendly transport operations. Autonomy is likely to change the transport operations, and especially the way of planning. There will likely come new threats, unfamiliar events, and new types of incidents, and the rapid pace of technological and societal change creates a strong need for new competence and work practices. This to exploit the benefits of the new technology, without operating at an unacceptable risk level. In this paper we elaborate on the different planning needs and what will be important for a successful implementation of Integrated Planning for Autonomous transport operations (IPA). The IPA is a suited framework when planning and addressing the resilience perspective, in addition to identify criticalities within the transport system when new technology is introduced. This knowledge forms an important basis for decisions about which measures should be implemented when introducing IPA.

Keywords: Maritime transport, Autonomous solutions, Integrated planning, Situational awareness, Operational envelopes, Safety, Resilience, Humans in the loop

INTRODUCTION

A new challenge associated with autonomous technologies is the realization of new ways of planning, working and collaborate in a transport system. This requires new routines and practices. Hence, the authors introduce Integrated Planning for Autonomous transport operations (IPA), as a framework towards successful implementation of autonomy into the transport system. The procedures for conventional planning must be changed from being a human based process, to a scenario where the collaboration between humans and technology will become stronger. IPA is based on the Integrated Planning and Logistics (IPL) that initially developed for the offshore petroleum industry in a previous Norwegian research centre (The Centre for Integrated Operations) and is based on the concept of IO (Integrated Operations), where principles of integrating people, work processes, and technology was developed for the purpose of making smarter decisions and achieve better execution. This enabled by real-time data, collaborative techniques, and sharing of expertise across disciplines, organizations, and geographical locations (Ramstad et al., 2013).

When working with autonomy it will be important to understand the threats along the value chain, to identify different barriers, and to plan for actions if something differs from plan. Increasingly, automation is being implemented in vessels and infrastructure (e.g., at ports and terminals), and it is therefore important to consider the impact of an even more widespread use of such advanced technology across the whole transport chain. Thus, resilience is of high importance for being able to prepare and plan for the unknown, what can happen, how to enter back to normal or adapt to changed premises if something deviates from a plan (Fjørtoft et al. 2021). This also requires an integration of plans across the value chain, also covering different planning stages and geographical areas. However, increased digital transformation and exchange of real-time data may lead to increased brittleness. For example, studies of cyber resilience of ship information systems, indicate that the increasing use of remote-controlled autonomous technology used on ships today will likely leads to an increase in worldwide new types of cyberattacks (Onishchenko et al., 2022). Zhou et al. (2019) examined sea transport from a resilience perspective. They tried to improve safety based on comprehensive risk assessment at the theoretical and operational levels concerning the specificities of water transport (Stene et al. 2021).

Moreover, the current transport domain experiences a lack of coordination between different organisations, technologies, and transport operations. Execution of activities are often sub-optimal, in addition to difficult to prioritise in case of conflicts of interests. One main challenge in this context is that changes to plan often results in a *win - lose* situation, where the consequences of a change are not addressed to all involved stakeholders. Weak planning may affect inefficient utilization of means as example.

RESILIENT SYSTEMS

Numerous definitions of resilience have been postulated the last two decades, where the concept is used in several disciplines, for quite different professions, and for deviant scopes and target groups. The popularity has led to rather broad and diffuse definitions that are sometimes difficult to operationalize (Huber & Kuhn, 2017). Despite the lack of an agreed definition; resilience perspectives emphasise aspects as collective, multifactorial, multilevel and multidimensional; associated with four key principles; anticipation, response, learning and monitoring, and successful outcomes (Pillary, 2017). Further, the gap between work as imagined and work as performed is an important aspect.

One main characteristic of a resilient system is adaptability. Woods (2019) definition is: Adaptive capacity "*is the potential for adjusting patterns of activities to handle future changes in the kinds of events, opportunities and disruptions experienced, therefore, adaptive capacities exist before changes and disruptions call upon those capacities.*". Woods argues that adaptation is not always about changing the plan, model or previous approaches, but the potential to modify plans to continue to fit changing situations. Adaptation can mean continuing to work to plan, but with the continuing ability to reassess whether the plan fits the situation confronted. A central term used to explain the resilience concept is brittleness. A resilient system is described as the opposite of brittleness, referred to as "*graceful extensibility*", the ability of a system to extend its capacity and to adapt when surprise events challenge its boundaries. Boundary refers to the transition zone where systems shift regimes of performance. Brittle systems experience rapid performance collapses, or failures, when events challenge boundaries. Brittleness and graceful extensibility refer to the behaviour of the system as it transitions across this boundary area. All systems have an envelope of performance, or a range of adaptive behaviour, questioning how systems will perform when events push the system near the edge of its envelope. Systems with low graceful extensibility risk a collapse in performance. On the other hand, systems with high graceful extensibility may be able to continue to meet critical goals and even recognize new opportunities. These systems have capabilities to anticipate bottlenecks ahead, to learn about the changing shape of disturbances or challenges prior to acute events and possess the readiness-to-respond to meet new challenges. Sustained adaptability is the ability to continue to adapt to changing environments, stakeholders, demands, contexts and constrains. In socio-technical systems, sustained ability addresses a system's dynamics over life cycles or multiple cycles of change. Central to resilience is identifying what basic architectural principles provide the needed flexibility to continue to adapt over long scales. Hollnagel (2009) characterised four abilities regards resilient organisations:

1. *Ability to respond* refers to the ability of an organisation to detect that something has happened, to recognise that it is relevant, and finally to respond to it. This implies that the organisation defines, a set of events to which it should be capable of responding, and then allocates appropriate resources (e.g. technology, competences, etc.) to actually respond in case they actually occur.
2. *Ability to monitor* refers to the ability to understand when a situation, in the short term, is going to become critical, and therefore to start preparing for it. This implies that the organisation defines and updates a set of valid and meaningful indicators, and it performs sound measurements of significant changes.
3. *Ability to anticipate* refers to the ability of an organisation to look far ahead in time to identify events that need to be prevented from occurring. This implies that the organisation looks at the future with appropriate imagination and performs safety assessment with methods able to account for emergent phenomena.
4. *Ability to learn* refers to the ability of an organisation to analyse and understand both successful and unsuccessful past events. This implies that the organisation adopts a plan for continuous learning which includes the analysis, communication and sharing of the reasons of its (successful/ unsuccessful) performance.

A completely non-adaptive system may show a typical resilient response behaviour, while, on the other hand, a truly adaptive system may show a degrading performance that has nothing in common with a typical resilience performance curve (Huber & Kuhn, 2017). In transport operations there will be many interdependencies to consider in the execution of a transport, also when talking about an autonomous transport. In IPL there are three types of interdependencies that are of relevance:

- *Activity interdependencies* exist when actions in one discipline affect important outcomes in another, e.g. quality, delivery time, cost, customer satisfaction, etc.
- *Resource interdependencies* arise when units share resources or transact with each other, such as personnel on-board, storage, use of loading equipment, etc.
- *Commitment interdependencies* refers to the existence of or need for an agreement/promise between actors or sub-units involved in a work process to produce certain actions which have high impact on key work outcomes.

THE PLAN HIERARCHY

Integrated planning (IPL) and the planning hierarchy must be designed from a holistic perspective. Illustrated by the plan hierarchy, both horizontal and vertical integration must be accounted for. Different companies define levels of planning in various ways, but they all define the boundaries of long, medium- and short-term planning, each involving different levels of the organization and different planning horizons. This tells that one planning level will be input to another. Planning across one level means that there will be several plans within the same time horizon, which will be beneficial to share across systems and companies.

Strategic planning has a long-time perspective. This is normally CAPEX intensive costs planning. Important factors to be considered are market and financial issues, infrastructure and governmental decisions, and laws and enforcement that must be followed. Typical stakeholders involved in this planning process will be infrastructure owners/managers, strategically planners, transport service providers and owners, regulators and government (financial issues, funding, needs for new means/technology/infrastructure etc.). Examples of plans that will be of importance for IPA are technological investments, operational management, safety and security, CONOPS (Concept of Operation), risk assessment, resilience, standards, and emergency preparedness.

The *tactical planning* has a shorter time-horizon than the strategic. It includes a more detailing and updated planning quality with reference to strategic

plans. It will also be important to include more human oriented planning, such as training and competence building at this level.

Operational planning has an even shorter time-horizon, where the plans include detailed instructions for the transport and how the execution should be done. It is a continuation from tactic planning, but where the planning quality is more accurate with more detailed information and instruction regards operations of means and handling of the cargo to be transported. For IPA this planning data will be used when designing the operational envelopes (Fjørtoft et al. 2020). For an autonomous ship system this includes the definition of what conditions the ship can operate under, with operational boarder and constraints as examples.

In an IPA framework a new fourth level is likely to be included, called the *executional planning* level, which is a definition set by the authors. The planning focus will be on a short time horizon, more digital driven, where normally real-time data is used for decisions making. It focuses on technological operations, such as to provide commands/instructions for how the autonomous execution of the technology should be done. In some cases the technology is capable to do their own decisions based on sensor data (i.e. traffic, weather, positioning). It is still important that it has a high explainable degree such that humans can understand the reason for a decision taken by the technology, at the same time as the humans should be better prepared to take control of technology if needed, i.e. from a Remote Operation Centre (ROC). The hand-over processes between technology and ROC must be planned for, for example by use of operational envelopes where the state and activity diagrams are designed.

CAPABILITIES FOR AUTONOMOUS AND RESILIENT SYSTEMS

From the IPL project a Capability Model was defined. The main objective was to support design and implementation of IPL best practices by focusing on key capabilities. The Model proposes a focus on two main groups of capabilities: (1) enabling capabilities and (2) human and cultural capabilities. This is in accordance with Duffield & Whitty (2015), which categorize the knowledge sharing and management factors into two major categories: (1) structural factors (systems) and (2) cultural factors (people). The structural approach typically focuses on knowledge-as-data, i.e., technology, processes and infrastructure created for access by users. The cultural approach focuses on human interaction, communication, reflection, sense-making (knowledge-as-meaning), and practice-based issues (knowledge-as-practice). The (1) enabling capabilities are structural and can be designed according to the specific needs of the organization or system: Roles and Processes, Information and Communication Technologies (ICT) and Arenas for Coordination. The (2) human and cultural capabilities are features that need to be cultivated and stimulated through continuous attention and focused leadership.

In this paper the emphasis is on the human and cultural capabilities, and less focus on the enabling capabilities. Central questions are related to autonomy and resilience: How will the capabilities change with implementation of more automated vessels, Maritime Autonomous Surface Ships (MASS)? What capabilities are needed for the system to be resiling?

To elaborate on the 4C's defined in IPL (Ramstad, 2013), we have addressed this to autonomous planning framework (IPA) and have also elaborated further on the resilient needs within each of the categories below:

Competence – The ability to do something well, effectively, following professional standards. Competence will require different skills when comparing autonomous operations with traditional transport. Competence is here defined as to know how to do certain things. This involves both knowledge and skills to perform work tasks and operations in practice. Several aspects are found to be crucial when it comes to IPL and competence as a holistic and shared understanding of IPL among the involved parties. Examples are competence in utilizing ICT tools sufficiently, and competence in cross-domain collaboration and communication. In addition, competence in terms of learning and change has also been emphasized by the industry professionals when it comes to IPL.

If we focus further on this to ***autonomous competence***, there are some new issues to be considered. The competence skills must be on the technology (enabler) and its capabilities. Some technologies are designed to take decisions by itself, without human interaction, but the humans should understand the reason for the decisions. The systems can be designed to learn by examples, for example by using artificial intelligence where the systems are adding more and more knowledge that will be used in a decision process. But it is likely that the technology will have limitations, where it calls for human decision support in case the technology cannot take decision itself. The competence for the staff at a control room is another issue. Since the humans are moving from a present location at sea where it is locally involved in the operation, to be located remotely from the operation, it will be important to understand what kind of awareness and information the operator needs for an adequate decision. This requires a clear understanding of the time windows that must be calculated for in case of a hand-over process from the technology to the ROC operator. As example, the minimum time available for an action to be taken by the ROC operator before the technology goes to a fall-back state. When it comes to the planning competence, it will be important to understand where to build enough awareness to a plan, how to exchange plans with the technology and other organisations, and not at least how to plan for resilience.

Linking this to ***resilient competences***, all plans have a bounded competence envelope, i.e., limited resources in a world of continuous change (Woods, 2019). Because boundaries of plans will be challenged by surprise over cycles of change, and competence-based systems will be brittle and may collapse as result, graceful extensibility is a required fundamental capacity for adaptive systems at all scales. The resilient ability most associated to competence is the "*ability to learn*". Relevant organisational aspects – mentioned in Macchi et al. (2011) – are competence management (training and recruitment to reduce knowledge gaps), change management (complementary mechanisms in the place to correct unintended effects of change), and operator management (feedback from contractors to be used in developing the organisation).

Further, due to increasing complexity and changes of work in safety critical systems, organizational resilience is strongly influenced by the resilient cooperation in teams consisting of several experts (Huber & Kuhn, 2017, Hoem et al. 2021). A lack of systematic cultivation of collective tacit knowledge may cause disruptions in cooperation, and thereby reduce team resilience. Team resilience may be improved regarding disruption cooperation, including sharing and joint handling of collective tacit knowledge. "*Ideal*" resilient teams (Herrera, Lay & Cardiff, 2017) are e.g., prepared to be surprised; Flexible, adaptable and gracefully extensible; Learn on a routine basis from everyday activities, threats as well as opportunities; and Understand the distance between work as imagined (WAI) and work as done (WAD). In addition to the learning ability, Macchi et al (2011) also mention Competence management as an aspect related to the. "*ability to anticipate*" (Identification of future knowledge requirements and development of competences to meet them) and the "ability to respond" (Personnel with a variety of skills for dealing with different situations). Due to increasing complexity and changes of work in safety critical systems, organizational resilience is strongly influenced by the resilient cooperation in teams consisting of several experts (Huber & Kuhn, 2017).

Commitment – A strong belief in an idea or system and the ability to act on that belief. Commitment is a central theme in IPL and can prove particularly challenging in the planning of transport operations, where changes in activities and prioritizations occur frequently and often unexpected. This challenges critical aspects such as quality of input and ownership. Commitment in this context is therefore more than commitment to the given plan, it is also commitment to the planning process and to the overall business model in which the operations take place. Commitment in planning means responsible action that acknowledges the interdependencies between one's own work and that of others. It means taking responsibility for one's own workload, but also for communicating issues or problems to others who are dependent on it. Commitment is further intimately linked to ownership and trust between different actors and technologies. Therefore, efforts for establishing trust within and across disciplines, companies, and organisations are essential. In essence, trust is a strong belief that others will do as agreed and promised. In the context of planning logistics operations, trust can be that the activities listed in a plan will be performed as scheduled, and that the necessary resources to do so are readily available.

Commitment on ***autonomous technology*** is a new and unproven issue. It will be important to understand the technological capabilities, to understand how to give instruction to be followed by the technology, as well as to understand the reasons for a decision made by the technology. It is also important to understand how to exchange information with the autonomous technology, either directly with the technology or through a ROC, and not at least understand how to exchange information with other external systems or operators, for example ICT at another vessel. In autonomous operations it will most likely be harder to do changes to plans than for conventional. The technology is planned to deliver according to pre-defined agreements. The commitment will be to other technologies, to people or groups of people involved in the operation, to external stakeholders, and between technologies. The interdependencies between the activities and plans must be emphasized. Commitment is also about communicating issues or problems/deviations to others who are dependent on it, which is very important when talking about autonomy.

Resilient and commitment aspects are linked to the gap between work-as-imagined and work-as-practiced. Three of the four resilience abilities are relevant; the abilities to learn, to monitor and to respond. Examples based on Macchi et al. (2011) are Work conditions and Supervisory support for safety activity. Work conditions related to the "*ability to learn*" (Preparedness exist for reflecting on outcomes of work), to "*ability to monitor*" (Prerequisites exist for identifying critical situations), and "ability to respond" (Enough resources to respond to various events). Resilience implies to plan for future normal variations because of innovations or changes, in addition to foreseen and unforeseen challenges. Initiatives require the ability to see or recognize that the plan is not making progress or that the plan does not fit the situation (Woods, 2019). Woods argues that initiatives are almost synonymous with an ability to adapt, especially the role of anticipation.

Collaboration is the act of working together to achieve the desired goals and objectives. Collaboration is a process in which different entities share information, resources, and responsibilities to jointly plan, implement, and evaluate a program of activities to achieve a common goal. However, there are several challenges associated with collaboration across boundaries (organizations, disciplines, and locations), involving advanced collaboration technologies and limited face-to-face interaction. Especially IPL at operational level is characterized by collaboration between participants located at different locations, often representing challenges related to different local cultures and lack of commitment to common goals. Nevertheless, commitment and trust in both colleagues and technologies are needed because collaborative work rests on shared understanding of objectives, each other's position and contributions. Collaboration for early coordination and prioritizations should be supported by methods for structured collaboration, facilitation of interdisciplinary communication involving the relevant stakeholders and expertise. In addition is it crucial to motivate people to collaborate and remove barriers to employee participation in virtual knowledge-sharing communities of practices.

Regarding ***autonomous collaboration*** there will be new elements to be included. The technology will to a larger extent be managed from someone located far away from the operation, for example from a ROC. The technology should collaborate with other technologies, and with conventional systems. Sometimes an autonomous vessel will meet another autonomous vessel, that means two technologies must collaborate to avoid conflicts. Other times the MASS will meet another vessel that have a captain physically operating the vessel. In both cases it is important to understand each other's decisions such that unwanted situations do not occur. It is about increasing performance, safety, and efficiency. It is also about how to solve deviations and conflicts such that the consequences become as low as possible. In the future where many autonomous technologies are working together, it will be important to understand the way of collaborating in the digital transmission of information, as well as to understand where humans must take part in the process in case the challenges cannot be solved by the systems themselves.

Resilient collaboration in social sciences, network sciences and computational social sciences have all identified that reciprocity across roles, units and layers is essential in human adaptive systems (Woods, 2019). "*Ideal*" resilient teams (Herrera, Lay & Cardiff, 2017) are e.g. characterized by: Value different points of view and are collaborative, cooperative; Are empowered at local level with humble leadership; and Pay attention to the system within its boundary and its environment. Of the resilient abilities mentioned by Hollnagel (2009), collaboration may be linked to Work process management. Work process is related to the "*ability to learn*" (Relevant information flows to sustain learning), to "*ability to monitor*" (Communication and cooperation to provide a shared understanding), and "*ability to respond*" (Communication and cooperation to allow adequate response to various events).

Continuous Learning is an ongoing learning process that seeks to incorporate lessons learnt into a continuous improvement process. In this context we promote continuous learning as an important capability regarded as one fundamental requirement for all organizational changes, sustained existence, and continuous improvement of practices. Continuous learning is both related to developing and implementation of IPL practices in general but also learnings for improving the plan quality based on feedback and sharing of experience. According to the practice-based learning theories learning must be connected to practice and the people involved in practice if the ambition is to change the way people and organizations work. In the context of integrated planning this includes people involved in IPL where key roles are planners, planning managers, discipline leaders, project leaders and project controllers.

Continues learning regarding autonomous technology and operation will address new elements. The technology in use is often developed as a self-learning system, where artificial intelligence and machine learning is used. It is designed to learn by examples and to achieve more-and-more knowledge to be used for decisions. From a human operator's point of view it will be important to understand the decisions made by the technology, which is called explainable AI. From a ROC perspective it will require skills to manage the technology, to understand the decisions made, to learn the capabilities and to understand the interaction with the technology and with the stakeholders involved. It will be different needs for expertise's compared with traditional knowledge for operations.

Resilience and continuous learning in addition to learning from past events and experiences, resilience perspectives emphasise even more future scenarios. It is important to note that experiences from successful handling and outcomes are as much important to learn from, as failures and things that went wrong. All four abilities of resilient organisations (Hollnagel, 2009) are related to continuous learning.

CONCLUSION

When addressing IPA there are some criticalities to be considered. First, we should understand if one action affects the outcomes of another, and if so in what way? This is of high importance when the technology should do the operations with a low influence from humans. As such, it is also necessary to understand the levels of dependability and ambiguity between the input and output, where it is important to understand the uncertainty vs criticality. The criticality for activity interdependency can be evaluated by considering the effect of removing interdependency between tasks, this by removing the ability of another operation to perform its function. In the same way, uncertainty can be evaluated by considering the likelihood that the other will perform the operation. Resource interdependencies arises when resources, equipment or infrastructure will be shared. If so, this must be coordinated between business units and technologies, and be part of the planning process. The criticality depends on the relative share of the resource, uncertainty is when the unit is subject to competitive pressures from others, which will be decreased if it lacks the ability to switch or swap unit. Commitment interdependence refers to the ability to collaborate between organisations and units that are involved in a transport. In order to cope with the interdependencies, it is necessary to ensure that relevant mechanisms for coordination and integration are in place (e.g. interaction, information sharing, collaboration, standardization) also at the different planning levels, which are important both for IPL and IPA. In IPA we have addressed the autonomous 4C's perspective and have introduced new elements compared with the IPL. These focuses are building new competence, commitment, collaboration and continuous learning on operation of autonomous technology. The studies have compared IPA with the traditionally IPL approaches. It addresses that the planning elements also can be done between technologies and not only between humans. It also describes the needs of understanding the shift between technology in control to human controlled operations. Resilience planning should be part of the planning process at every four stages which is mentioned in the planning hierarchy, where threats and possible barriers to be implemented should be identified. The main objective with IPA is to improve the understanding of the complexity of efficient planning practices, and thereby how to increase the awareness towards supporting overall performance of autonomous transport operations. It is about the integration of technology and humans. The main idea with IPA is to get an overview on influencing aspects, to understand the objectives, involved stakeholders and technologies, and to identify different capabilities (human, technological and organizational). The outcome will be to understand how these aspects interplay.

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