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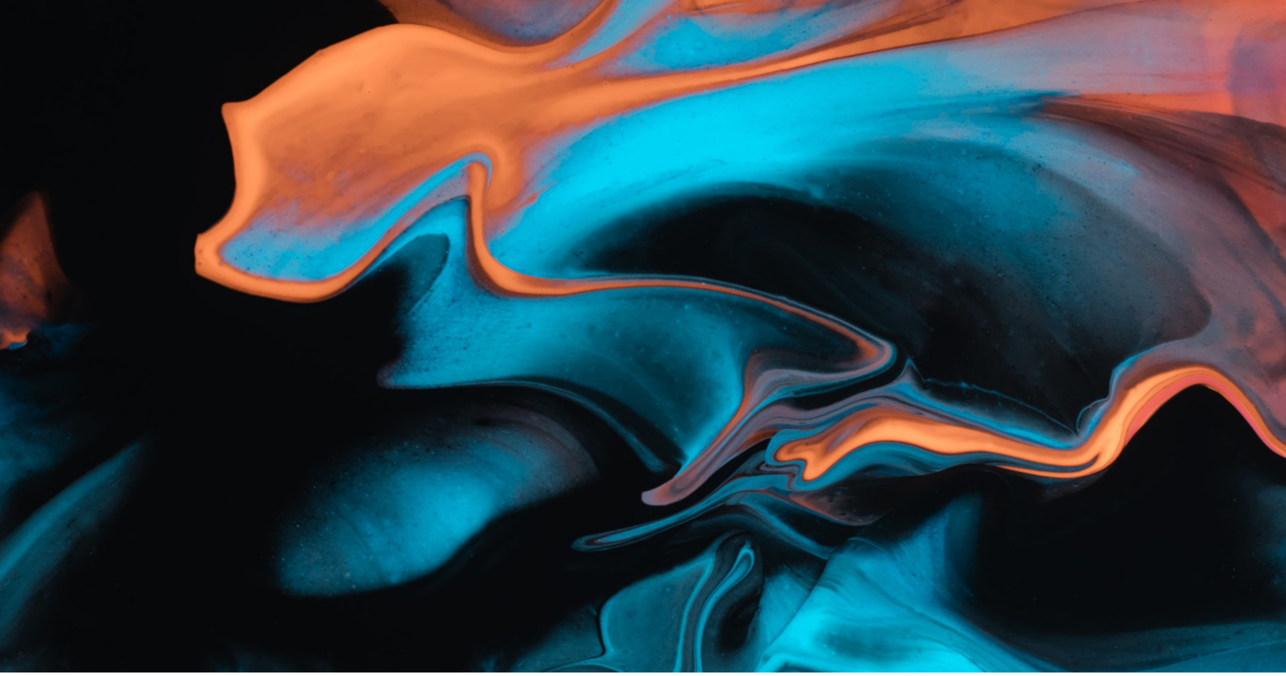
Understanding the Shift Toward More Digital Industry

Tsiulin, Sergey

DOI (link to publication from Publisher):
10.54337/aau517403831

Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record



MARITIME PORTS AND BLOCKCHAIN

UNDERSTANDING THE SHIFT TOWARD
MORE DIGITAL INDUSTRY

BY
SERGEY TSIULIN

DISSERTATION SUBMITTED 2022

AALBORG UNIVERSITY
DENMARK

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Dissertation submitted: October 2022

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Department: Department of the Build Environment

ISSN (online): 2446-1636
ISBN (online): 978-87-7573-805-2

Published by:
Aalborg University Press
Kroghstræde 3
DK – 9220 Aalborg Ø
Phone: +45 99407140
aauf@forlag.aau.dk
forlag.aau.dk

Printed in Denmark by Stibo Complete, 2022

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Sergey Tsiulin obtained his M.Sc degree in Supply Chain Management from South Ural State University (SUSU), Russia, in 2014. He then continued in academia and worked as a Research Assistant at SUSU, where he had a chance of visiting foreign universities, spending three semesters at Polytechnical University of Catalonia (UPC) and Lappeenranta University of Technology (LUT) as a granted scholarship Erasmus Mundus. He worked on several projects, including the topics of urban logistics and green mobility TEN-T.

In 2017, Sergey joined SAP – German software company associated with ERP system. He worked on a financial module of the ERP, collaborating on the creation of data workspace, transferring, and automating financial reporting for a large air company in East Europe.

Since 2018 Sergey works at Aalborg University, first as Research Assistant, and since June 2019 – as a Ph.D. student. During his stay at AAU, he participated in three research projects: City Logistics (last-mile delivery), Block-kraft, and BLING (both regarding blockchain in the maritime sector) both as a researcher and project manager.

ENGLISH SUMMARY

Digitalization has become an important concern in the maritime industry due to increasing complexity of overseas shipping. The volume of seaborne trade is growing annually, especially for e-commerce, finished goods, and container cargo. Lack of stability in the global agenda contributed to greater fluctuations in demand, which resulted in congested seaports, shortages in containers, and limited operating capacity. This led to delays in delivery time, freight traffic congestion both on sea and landside, increased freight rates, and reduced level of service and reliability. These factors motivate maritime actors to not only adjust to increasing freight volumes, but to optimize infrastructure and ongoing business processes. The scattered nature of supply chain actors and general lag in the use of modern IT technologies complicate the innovations.

Fluctuations in demand and uncertainty with short-term planning have intensified the request for transparency and trackability. In this case, digitalization can enable the supply chain to have more reliable service and a higher level of shipment security. That can contribute to automation of correspondence, provide better coordination with actors, and increase time-efficiency.

The emergence of blockchain technology, a decentralized and distributed peer-to-peer database, followed by discussions on the relevance for the maritime industry, opened the door to digitalization in the field. The main priority is to boost efficiency along the shipment i.e., to speed up, simplify, and unify correspondence and tracking possibilities. The existing literature focuses greatly on the potential of blockchain across different industries, yet promotes ideas for use in ideal conditions, neglecting industry specifics and limitations other than generally discussed.

The aim of this thesis is to analyze the feasibility of blockchain technology in the maritime industry, including port logistics. That is, to define the current trends in development of blockchain applications and outline scenarios of potential adoption. Also, to provide knowledge on what preceded the technology in the sector and what innovates cargo handling equipment currently. To analyze whether the proposed decentralization meets the port development in Denmark, to clarify the challenges of adoption, and to reflect on future progress. The thesis investigates the explication of blockchain and broaden the knowledge on existing issues with adoption in the field.

The contributions of the thesis are organized into three parts, combining different methods: qualitative study, literature review and hackathon. The first part analyzes blockchain applications in the maritime industry through a systematic literature review and a hackathon. In the second part, the scale is on port area, investigating previous attempts of port digitalization to find interconnections with other developments. In the third part, we study practical explications of blockchain through qualitative research with an emphasis

on port strategic development of the largest Danish cargo ports, summarizing challenges that complicate blockchain adoption.

The results showed exponential growth of blockchain projects within the years 2017-2019. Three scenarios of usage were distinguished: document workflow management, financial processes, and device connectivity. The conceptual framework summarizes the found scenarios along with the held hackathon. Moreover, the study showed a close similarity between the blockchain scenarios and Port Community System (PCS). The configuration of certain blockchain projects tends to semi-replicate PCS, which indicates that both systems can bring a larger impact if they complement each other.

The qualitative study within Danish cargo ports revealed the trend of expanding port services by providing more space for bulk and container cargo, as well as improving connectivity with the hinterland. Thus, the development relies on increasing infrastructure capacity, rather than investing in digital solutions. Nevertheless, global terminals are undergoing changes toward energy transition and better cost efficiency, gradually embedding electrified equipment, opening avenues for partial automation of port facilities and joint operation, leaving a room for decentralization if needed.

The summary of challenges revealed 18 barriers, having the main lying within the complexity of integrating supply chain actors into one network. The problem points to a variety of software used across organizations, their level of advancement, which in turn challenges the integration. This is compounded by local corporate cultures across organizations and the technological limitations of the blockchain itself.

Therefore, with respect to the maritime industry, the technology has shown a low level of feasibility and adoption despite a series of conceptually valuable solutions. Regardless of many potential applications, the industry has not seen decentralization fully used in practice. Also, a considerable number of barriers slow it to become an integrated system. It also demonstrates that either decentralization is not demanded by industry actors or the importance and benefits of such a system are not yet evident. While blockchain projects have been widely discussed in academia and mass media, maritime ports (being one of the target users) are prioritizing other improvements.

Thus, blockchain is still poorly adopted and is likely to become an intermediate stage for port digitalization or a driver for upcoming digital products. Therefore, the study opens the possibility for further analysis on the topic. It indicates an overlap of blockchain and PCS that can transform the industry and combine the best from both approaches. Hence, a more in-depth analysis of port network structure is necessary with respect to the combination of PCS and blockchain.

DANSK RESUME

Digitalisering er blevet et vigtigt anliggende i søfartsindustrien på grund af den stigende kompleksitet i skibsfarten i udlandet. Mængderne af søtransport vokser årligt, især for e-handel, færdigvarer og containerfragt. Manglende stabilitet i den globale dagsorden bidrog til større udsving i efterspørgslen, hvilket resulterede i overbelastede havne, mangel på containere og begrænset driftskapacitet. Dette førte til forsinkelser i leveringstiden, overbelastning af godstrafikken både til vands og til lands, øgede fragtrater og et lavere serviceniveau og lavere pålidelighed. Disse faktorer motiverede søfartsaktørerne til ikke blot at tilpasse sig de stigende fragtmængder, men også til at optimere infrastrukturen og de løbende forretningsprocesser. Forsyningskædens spredte aktører og den generelle forsinkelse i brugen af moderne it-teknologier komplicerer innovationen.

Udsving i efterspørgslen og usikkerhed i forbindelse med kortsigtet planlægning har forstærket kravet om gennemsigtighed og sporbarhed. Digitalisering kan i dette tilfælde tilvejebringe, at forsyningskæden får en mere pålidelig service og et højere niveau af sikkerhed for forsendelser. Det kan bidrage til automatisering af korrespondance, forbedre koordinering med aktørerne og forøge tidseffektiviteten.

Fremkomsten af blockchain-teknologien, en decentraliseret og distribueret peer-to-peer database, efterfulgt af diskussioner om relevans for søfartsindustrien, åbnede døren for digitalisering på området. Hovedprioriteten er at øge effektiviteten langs forsyningskæden, dvs. at fremskynde, forenkle og ensrette korrespondancen og sporingsmulighederne inden for transport. Litteraturen fokuserer i høj grad på potentialet i blockchain på tværs af forskellige brancher, men den promoverer ideer om anvendelse under ideelle forhold og negligerer branchespecifikke forhold og andre begrænsninger end de generelt diskuterede.

Formålet med denne afhandling er at analysere gennemførligheden af blockchain-teknologien i søfartsindustrien, herunder havnelogistik. Det vil sige, at formålet er at definere de nuværende tendenser i udviklingen af blockchain-applikationer og skitsere scenarier for potentiel indførelse, og give viden om, hvad der gik forud for teknologien i sektoren, og hvad der innoverer lasthåndteringsudstyr i øjeblikket. At analysere, om den foreslåede decentralisering imødekommer havneudviklingen i Danmark, afklare udfordringerne ved vedtagelsen og reflektere over den fremtidige udvikling. Afhandlingen undersøger anvendelse af blockchain og søger at udvide kendskabet til teknologiens eksisterende problemer med indførelse på området.

Afhandlingens bidrag er organiseret i tre dele, der kombinerer forskellige metoder: kvalitativ undersøgelse, litteraturgennemgang og hackathon. Den første del er dedikeret til analyse af blockchain-applikationer for den maritime sektor gennem en systematisk litteraturgennemgang og et hackathon. I den anden del er skalaen på et havneområde hvor tidligere forsøg på havnedigitalisering undersøges, idet man søger at finde

sammenkoblinger med den seneste udvikling. I tredje del undersøger vi gennem kvalitativ forskning praktiske forklaringer af blockchain med fokus på havnens organisatoriske struktur og den strategiske udvikling af de største danske godshavne og opsummerer udfordringer, der komplicerer vedtagelsen af teknologien.

Resultaterne viste en eksponentiel vækst af blockchain-projekter i årene 2017-2019. Der blev skelnet mellem tre forskellige brugsscenarier: document workflow management, financial processes og device connectivity. Det konceptuelle framework opsummerer de fundne scenarier sammen med det afholdte hackathon. Desuden blev der fundet en tæt lighed mellem blockchain-scenarierne og Port Community System (PCS), hvilket tyder på at begge systemer kan få en større virkning hvis de supplerer hinanden.

Den kvalitative undersøgelse i danske godshavne afslørede tendensen til at udvide havnetjenesterne ved at give mere plads til bulk- og containerlast samt forbedre forbindelserne til baglandet. Udviklingen er således baseret på en forøgelse af infrastrukturkapaciteten snarere end på investeringer i digitale løsninger. Ikke desto mindre gennemgår globale terminaler ændringer i retning af energiomlægning og bedre omkostningseffektivitet, idet der gradvist indlejres elektrificeret udstyr, hvilket åbner muligheder for delvis automatisering af havnefaciliteterne og deres fælles drift, hvilket giver plads til decentralisering om nødvendigt.

Sammenfatningen af udfordringerne viste 18 barrierer, hvoraf den største lå i kompleksiteten i at integrere forsyningskædens aktører i ét netværk. Problemet peger på en række forskelligt software, der anvendes på tværs af organisationerne, samt deres udviklingsniveau, hvilket igen udfordrer integrationen. Dette forværres af lokale virksomhedskulturer på tværs af organisationer og de teknologiske begrænsninger i selve blockchainen.

Med hensyn til søfartsindustrien har teknologien derfor vist et lavt niveau af gennemførlighed og vedtagelse på trods af en række konceptuelt værdifulde løsninger. Uanset de mange potentielle anvendelsesmuligheder har branchen ikke set decentralisering fuldt ud anvendt i praksis. Der er også en lang række hindringer, der bremser det for at blive et integreret system. Det viser også, at enten efterspørger industriens aktører ikke decentralisering eller også er betydningen og fordelene ved et sådant system endnu ikke indlysende. Mens blockchain-projekter er blevet drøftet i vid udstrækning i den akademiske verden og i massemedierne, prioriterer søhavne (som er en af målbrugerne) andre forbedringer.

Blockchain er således stadig dårligt undersøgt og vil sandsynligvis blive et mellemstadium for havnenes digitalisering eller en drivkraft for kommende digitale produkter. Derfor åbner undersøgelsen muligheden for yderligere analyser af emnet. Den peger på overlapningen mellem blockchain og PCS, der kan transformere industrien og kombinere det bedste fra begge tilgange. Det er derfor nødvendigt med en mere dybtgående analyse af havnenetværkets struktur med hensyn til kombinationen af PCS og blockchain.

РЕЗЮМЕ НА РУССКОМ

Цифровизация стала важной задачей в морском секторе из-за растущей сложности морских перевозок. Объемы морской торговли ежегодно растут, особенно в интернет-коммерции и контейнерных грузах. Нестабильная глобальная обстановка лишь увеличивает колебания спроса, что приводит к перегруженности морских портов, нехватке контейнеров и операционных мощностей. Это приводит к задержкам сроков доставки, перегруженности грузового транспорта, повышению фрахтовых ставок, снижению уровня сервиса и общей надежности между поставщиком и субподрядчиками. Это побуждает участников приспосабливаться к растущим объемам грузов, оптимизировать инфраструктуру и бизнес-процессы. Разрозненность логистических участников и общее отставание сектора в использовании современных IT технологий усложняет внедрение инноваций.

Колебания спроса и неопределенность в краткосрочном планировании усиливают запрос на отслеживание в транспортировке. Цифровизация способна обеспечить логистику большей надежностью услуг и безопасностью груза. Это может способствовать автоматизации корреспонденции, обеспечить координацию между компаниями, повысить эффективность и передачу информации.

Появление технологии блокчейн, распределенной базы данных, за которой последовали дискуссии об ее актуальности для морского сектора, открыли возможности для цифровизации в этой сфере. Основным приоритетом стало повышение эффективности, т.е. ускорение, упрощение и унификация коммуникации и отслеживания груза. Научная литература уделяет внимание потенциалу блокчейна в различных отраслях, но проецирует сценарии на идеальные условия, пренебрегая отраслевой спецификой и её проблемами.

Целью данной диссертации является анализ целесообразности применения технологии блокчейн в морском секторе и портовой логистике. То есть, определить тенденции развития блокчейн проектов и сценарии потенциального внедрения. Расширить представление о том, что предшествовало появлению технологии и какие инновации происходят с портовым оборудованием сегодня. Проанализировать, релевантна ли децентрализация для портов в Дании, прояснить проблемы её внедрения и спроецировать будущее развитие. В диссертации исследуется применение блокчейна для морского сектора и портов, расширяя знания о технологии, а также о существующих проблемах с её внедрением.

Диссертация состоит из трёх частей и сочетает различные методы: качественное исследование, обзор литературы и хакатон. Первая часть описывает и анализирует применение блокчейна в морском секторе. Для этого был проведен систематический обзор литературы, а также организован хакатон. Во второй части исследуются предпосылки цифровизации портов, с целью найти взаимосвязь с последними разработками. В третьей части мы изучаем практическое применение блокчейна с акцентом на стратегическое развитие датских грузовых портов. Исследование заключает обзор проблем, усложняющих внедрение технологии.

Результаты показали экспоненциальный рост блокчейн-проектов в течение 2017-2019 годов. Были найдены три сценария использования технологии: для корреспонденции, отслеживания грузов и работы с финансами. Концептуальная схема обобщает найденные сценарии вместе с проведенным хакатоном. Более того, было обнаружено близкое сходство между сценариями блокчейна и системой портового сообщества (PCS). Конфигурация некоторых блокчейн-проектов имеет тенденцию к повторению PCS, что указывает на потенциал при взаимосвязи двух систем.

Исследование датских грузовых портов выявило тенденцию портов развивать свои услуги за счет расширения пространства для навалочных и контейнерных грузов, а также улучшения мультимодальности. Таким образом, развитие опирается на увеличение мощности инфраструктуры, и меньше на инвестиции в цифровые решения. Тем не менее, портовые терминалы претерпевают изменения в сторону энергетического перехода и повышения экономической эффективности, внедряя электродвигатели, открывая возможности для автоматизации портовой техники и продвигая потенциал для цифровой децентрализации.

Обобщение проблем показало 18 барьеров, которые лежат в организационной плоскости, т.е. в интеграции участников цепи поставок в единую сеть. Проблема указывает на разнообразие ПО, используемого в разных организациях, на уровень их продвинутости, что, в свою очередь, затрудняет интеграцию. Это усугубляется корпоративной культурой среди организаций и технологическими ограничениями самого блокчейна.

Поэтому, несмотря на ряд концептуально ценных решений, технология показала низкий уровень внедрения. Несмотря на потенциальные варианты использования, отрасль не увидела применения децентрализации на практике. Блокчейну препятствуют значительные организационные сложности для интегрирования в цепочки поставок. Это также говорит, что либо децентрализация не востребована участниками отрасли, либо важность и преимущества такой системы еще не очевидны. Хотя проекты блокчейн широко обсуждаются в научных кругах и СМИ, морские порты, будучи целевой аудиторией, отдают предпочтение другим улучшениям.

Таким образом, блокчейн все еще слабо адаптироан и, скорее всего, станет промежуточным этапом цифровизации портов или драйвером для будущих цифровых продуктов. Данное исследование открывает возможности для дальнейшего анализа этой темы. Для будущей работы необходим более глубокий анализ структуры портовой сети в отношении комбинации PCS и блокчейна, которые могут преобразовать отрасль, объединив лучшее из обоих подходов.

ACKNOWLEDGMENTS

I am writing this section last, looking at the whole thesis done and perfectly aligned, juicy and ready for submission.

It was a long (maybe a bit too long), but interesting journey. A journey where I learned a lot about the industry which attracted me with its complexity, challenges, and lag of changes.

Of course, I am grateful to everybody who helped and supported me. I thank my supervisors Peter Frigaard and Kristian Reinau. I was very independent in choosing the ways to structure my study and which topics to dig into – so I thank Kristian for providing me with freedom of exploration. I am very grateful to Peter who carried me at the end of my studies with support and positive vibes. Also, much obliged Jesper Raakjær who accepted to be the chairman of the defense.

I am proud of working with Ahmed Karam and Olli-Pekka Hilmola, who gave me numerous academic advice and inspired me with productivity and high research quality. It was truly the spirit of full-scale, constructive collaboration.

Another luck of mine was to participate in BLING project (Blockchain in Government), an Interreg North Sea Program by which my position was covered. I loved the cooperation with partners during these years. It gave me an opportunity to grow and take on much more responsibilities than just of a PhD student. So, my biggest thanks go to Renske Stumpel, the project leader. Bedankt Renske!

I appreciate all the practical help and support that I received at my cozy faculty of Civil Engineering (or Built Environment). Some times were not easy, so Dalia, Tanja, Linda, Pelle, Anja, Vivi – thank you all for your assistance along the way!

Now you have reached the most important part. As I left my home country, things have never been simple. And so lucky am I to have my family close, even when it was physically not. Nevertheless, I was always able to get support from my mom, Natalia Tsiulina, and my father, Sergey Tsiulin Sr. (yes, we share the same name). Finally, I want to express how important my girlfriend, Émilie Aimé, played during this time, being the biggest supporter and friend.

Thank you! Tusind tak! Spasibo!

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LIST OF PUBLICATIONS

The following publications are part of this PhD thesis:

i. Tsiulin, S., Reinau, K. H., Hilmola, O-P., Goryaev, N.K., Mostafa, A. K. A. (2020) Blockchain in Maritime Port Management: Defining Key Conceptual Framework. Review of International Business and Strategy. Special issue: "Blockchain and the Multinational Enterprise", Volume 30, Issue 2, pp 201-224; **Published**

ii. Tsiulin, S., Reinau, K.H., N. Goryaev (2020) Conceptual Comparison of Port Community System and Blockchain Scenario for Maritime Document Handling. Proceedings - 2020 Global Smart Industry Conference, GloSIC 2020, South Ural State University, pp 66-71; **Published**

iii. Tsiulin, S., Reinau, K.H. (2021) The Role of Port Authority in New Blockchain Scenarios for Maritime Port Management: The Case of Denmark. Transportation Research Procedia. Proceedings of 23rd EURO Working Group on Transportation Meeting, EWGT 2020, Paphos, Cyprus, Volume 52, pp 388-395; **Published**

iv. Tsiulin, S., Reinau, K.H. (2022) How to reduce emissions in maritime ports? An overview of cargo handling innovations and port services. Proceedings - IntelliSys 2022, Lecture Notes in Networks and Systems series vol 542; **Published**

v. Tsiulin, S., Reinau, K.H. (2023) Blockchain for Trailer Pick-up Error in Maritime Ports. Using Hackathon to Prototype Potential Solutions: The Case Study. Proceedings ICICT: Lecture Notes in Networks and Systems, 2023, 465, pp. 593–606; **Published**

vi. Tsiulin, S., Hilmola, O-P., Reinau, K. H. (2023) The key challenges of blockchain implementation in maritime sector: summary from literature and previous research findings. Proceedings of ISM – International Conference on Industry 4.0 and Smart Manufacturing; **Accepted/In Press**

DISSEMINATION

A full overview of dissemination activities and academic papers is accessible through the link: https://vbn.aau.dk/en/persons/142239

Projects:

- BLING – Blockchain in Government; 2019 – 2023
- Maritimt Block-kraft, 2019 – 2022
- Collaborative logistics in Aalborg, 2018 – 2020

Publications not included in the thesis:

- Project report "Blockchain in Maritime Industries", *Maritimt Block-kraft, 2021*
- Tsiulin, S., Jensen, A., Reinau, K-H. (2019) Urban freight logistics: influence of delivery companies on policy regulation. *NOFOMA 2019 conference, Oslo; May 2019*
- Dryga, A., Tsiulin, S., Valiavko, M., Yang, Q., Reinau, K.H. (2019) Blockchain-based wildlife data-management framework for the WWF bison rewilding project. *ACM International Conference Proceeding Series, Jinan, August 2019, pp 62-66*

Conference presentations and panel discussions:

- Presenting thesis findings and work-in-progress paper "Port Governance in Denmark: a retrospective and prospective view on maritime port reforms"; NOFOMA 2022 conference, *Iceland; June 2022*
- Presenting research findings for Interreg project CONNECT; *Brussels, March 2022*
- Presenting research findings "Blockchain for maritime ports in Denmark" for BLING online conference organized as the project mid-term event; *online, March 2021*
- Presenting research findings at the workshop "Blockchain Technology to Address Social and Environmental Issues"; *Aalborg University, Copenhagen, November 2020*
- Presenting research findings at BLING kick-off workshop, *Aalborg, April 2019*

Hackathons:

- Participating in online blockchain hackathon "DAH (Decentralized Autonomous Hackathon)" as a jury; *online, April 2022*
- Participating in online blockchain hackathon "BLINGathon" as a tutor; *online, November 2021*
- Participating in offline blockchain hackathon "Blockchain Summer School 2018", presenting prototype "Blockchain as a tracking database tool: case of WWF"; *Copenhagen Business School, July 2018*

PREFACE

The topic of this PhD was hugely inspired by the situation in 2018. The public interest in blockchain was at its peak. The price of alternative currencies reached historical heights, and the whole internet was discussing and projecting new ideas of how blockchain can change the state of things in the world.

Blockchain seemed the panacea to any disease. The solution to any industry problem.

Even after the famous fall of alternative currencies later in 2018, the public interest did not fade away. Instead, it continued, seeing the technology as a future trailblazer. That year, I was able to participate in Blockchain Summer School hosted by CBS in Copenhagen. I saw more than 200 young talents, with full creativity, worked on blockchain prototypes and solutions.

Among blockchain use cases, the most interesting was the one the Danish company Maersk, the largest freight carrier in the world, was working on.

Maersk's idea was to digitize the entire supply chain. That is, to connect producers, consumers, and carriers by sea and by land - through one digital system that everyone would have access to. It means connecting more than 1000 completely different companies into a platform that would work in real-time, automating forwarding of information and securing corporate data.

All that to happen in the maritime industry that is not famous for innovations.

The idea seemed utopian. And seems so even today.

The project idea received a lot of interest from the mass media. At the same time, without revealing much of details, competitors and startups started to come up with their proposals. So, the question was — would such an ambitious project work in practice? Is it feasible? Is the industry ready for such innovations? For example, on the scale of maritime ports.

The case study arose at the right timing – our Freight Transport Research Group became a part of an Interreg project called BLING – “Blockchain in Government”, during which partners from 13 institutions helped to shape critical perspectives on blockchain possibilities across different industries. A lot of factors came together to give birth to the topic of this dissertation.

I wish you a good reading.

CHAPTER 1. INTRODUCTION

This chapter briefly introduces the background and industry specifics that are necessary for understanding prior to analyzing blockchain opportunities. Since the thesis is built at the intersection of two disciplines, it is important to illustrate exactly how the maritime sector is established, what are the challenges and what leads to retrospect the moves toward the adoption of new IT solutions such as blockchain.

The chapter will explain the current challenges in the supply chain industry. Next, the role of port as an infrastructural unit and service provider will be revealed. Thereafter, the chapter will explain blockchain on the fundamental level as well as its spread across different industries, case studies and how exactly blockchain has been attracted to the supply chain and shipping industries.

1.1 Ports in the global supply chain

1.1.1 Problems in the global supply chains

Maritime transportation plays a crucial role in today's global economy as more than 90% of trade is carried out by sea (Francisconi, 2017). The volume of international seaborne trade keeps increasing throughout the years, showing steady and continuous growth (Figure 1). For example, the volume of seaborne trade accounted for 4 billion tonnes in 1990. The number had reached 6 billion in 2000, yet by 2010 it was already exceeding 8 billion tonnes. Container and bulk trade recorded significant growth within the last decades. In 2020, containerized cargo accounts for 1.85 billion tons, while overall volumes of cargo reached 10 billion tonnes (Statista, 2022a; UNCTAD, 2021).

Within the years 2020-21, the industry was expected to the effect of the COVID-19 pandemic, yet the volumes fell less dramatically than projected initially. Having a shock in the first half of 2020, maritime trade fell by 3.8%, yet had recovered by the end of the year, when containerized cargo and dry bulk nearly returned to pre-covid levels. Shipments of crude oil fell by 7.7%, dry bulk by 1.5%, and containerized cargo only by 1.1%. Regarding, for example, container cargo, industry experts claimed it as a positive sign for further growth – especially in comparison with the 2008 crisis, when container shipments fell by 8.4%. Moreover, the growth of global GDP for 2021 has been forecasted at 5.3% (UNCTAD, 2021).

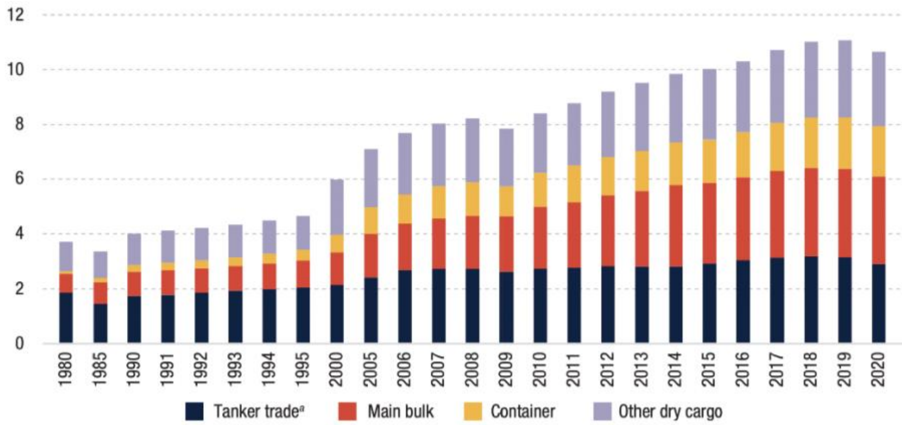

Figure 1. International maritime trade throughout the years by cargo type, in billion tones (Statista, 2022a; UNCTAD, 2021)

Besides COVID-19 and blockage of the Suez Canal route that had caused problems in timely goods delivery, there are, however, other issues that arose in 2020 and 2021. That is shortages in containers, equipment and shipping capacity that shippers and ports have experienced. Combined with time delays, port congestion, increasing freight rates and reduced level of service and reliability – it all created major challenges for the shipping industry to adapt to (UNCTAD, 2021; Clarksons Research, 2021).

Carriers experienced recent fluctuations in demand as well as surges in trade flows. Consequently, that affected delays in returning containers, hence goes the reduction of available capacity which forced carriers to readjust existing networking and avoid going to certain ports (Mongelluzo, 2021; UNCTAD, 2021). Ports, accordingly, faced uncertainties with carriers, mentioning 'double-sailings', i.e. arriving at the same port several times within a short time period. That caused unexpected peaks and vessel congestion (Waters, 2021). Also, the empty containers left behind at port yards resulted in higher dwell time and complexity in storing and managing the space (UNCTAD, 2021).

Within constantly growing demand and earnings, carriers are left with a choice. Whether they extend the range of services, direct seaborne connections and deploy more vessels, or simply build vessels of a large size instead. With large vessels, ships could remain fully loaded while generally operating on fewer services (UNCTAD, 2021). Since the 2010s, the difference in proportion between regular container ships and mega-container ships has been growing strongly. The proportion of vessels able to carry 10,000 twenty-foot equivalent units (TEU) and above has increased from a share of 6% to almost 40% between 2011 and 2021 (Sanchez, 2021). Moreover, the capacities grew significantly, splitting large vessels into categories of 1) 10,000 – 15,000 TEU, 2) 15,000 – 20,000 TEU and 3) 20,000 TEU and above (UNCTAD, 2021). Hence, the ratio of 'over-tonnaging' has increased which leaves great pressure on ports to accommodate such vessels and forces them to quickly adapt their infrastructure.

1.1.2 Rise of e-commerce

E-commerce represents another challenge for the maritime industry. The spread of internet connectivity and simplicity of mobile access significantly contributed to the development of digital retail services. Eventually, the growth was particularly strong for consumer products and finished goods, and considerably less for raw materials (de Langen, 2019).

According to Statista (2022b), sales from the global retail e-commerce sector amounted to approximately 4.9 trillion US dollars in 2021, showing annual growth rates of 10-15%. For comparison, in 2015 internet-based sales were estimated at 1.5 trillion dollars, and by 2018 this figure has almost doubled to 3 trillion. In 2021, having a market size of 4.9 trillion dollars, the number of e-commerce sales is forecasted to grow by 50 percent over the next four years.

Moreover, the growth rate of e-commerce is increasing significantly compared to the rest of the retail. The share of e-commerce was estimated at 7.4% in 2015. In 2018, the number has reached 12.2% share. The trend is expected to continue. For 2021, global e-commerce was estimated at 19.6% with forecasts to become a quarter of total global retail sales by 2025 (Statista, 2022c).

Within the rapid increase of volumes and considerable extension of e-commerce, it sets according to expectations for logistics facilities. Thus, the demand is foreseen to be boosted towards better port infrastructure i.e., storage capacities, and warehouses that can fulfill and provide space for modern logistics (UNCTAD, 2021). This also implies handling data in a more efficient and resilient way (Drewry, 2021a). Embedding digitalization for information exchange with customers, partners and suppliers potentially can open opportunities for new value-added services (Logmore, 2019). Also, the integration into e-commerce can be boosted for ports by establishing a better connection with the hinterlands – establishing an information hub for multimodality and facilitating partnership along the supply chain (UNCTAD, 2021).

1.1.3 Need for digitalization in maritime sector

Having swings in demand and uncertainty with short-term planning, requests for more transparency and trackability have intensified in the industry. Moreover, the COVID-19 pandemic and the closure of international borders emphasized the need for cross-border trade facilitation (UNCTAD, 2021).

Importantly, as experts state, the situation will hardly be improved using regulation (Baker, 2021; UNCTAD, 2021). Instead, it requires a proactive position from carriers and other actors towards taking more risks and implementing technologies for more accurate and predictable supply chains. As experts claim, it will likely be more beneficial than the anticipation of delays and adoption to lower capacity shipments (Drewry, 2021b). Digitalization, in this case, can provide a supply chain network with more reliability of services and achievement of a higher level of shipment security.

In recent years, the introduction and promotion of new technologies imply several benefits to the industry. The main priority has always been to reduce costs and boost efficiency along the supply chain i.e. to speed up, simplify, and unify administrative processes in transportation (Kshetri, 2018; Baalen et al, 2008). That can potentially automate correspondence between supply chain parties, provide better coordination with custom authorities, monitoring with terminal operators and transform transportation into a less paperwork process (Tsiulin et al, 2020). It, as well, could extend market access and make the logistic network more interlinked.

As standard vessel shipping involves a variety of parties such as shippers, carriers, shipping agents, banks, port authorities, terminals, customs, and forwarders – the shipping process commonly goes through a round of confirmations and approvals between these parties (Groenfeld, 2017; T-Mining, 2022). And the challenge lies in the lack of awareness of upcoming transportation. The current workflow does not allow fast data processing and real-time communication, which is usually completed by e-mail, telephone, fax, or relevant module of an ERP system (Kshetri, 2018; Tsiulin et al, 2020). Most likely, every actor processes information differently, varying in the degree of software they use. Therefore, within each step of forwarding cargo information along the supply chain, the risks of delays, uncertainties, and disputes increase (Tsiulin et al, 2020).

Thus, the industry's lag in dealing with digital information is pushing the shipping industry to look toward *end-to-end*, single-window solutions – meaning systems where parties can be provided with cargo status along the supply chain embedded into existing software or working fully independently (UNCTAD, 2021). For example, shippers will be provided with access to warehousing, customs clearance, and the ability to track cargo transportation along the supply chain (Knowler, 2021). This way, the shipper is secured with space on vessels on a long-term scale. Similarly it can work ports, knowing status of upcoming cargo in advance. It also brings advantages to freight forwarders, terminal operators, customs, etc., by facilitating security and the ability to know where cargo is and what is condition of it (Tsiulin et al, 2020).

Besides the reasoning to use end-to-end solutions for visibility, the purpose is also to reduce unpredictability in shipping. That is, knowing precise information about location, customs clearance, the status of bank payments, etc. According to industry reports (UNCTAD, 2021; Olesen, 2015), the current situation when 'supply not keeping pace with demand' challenges ports with uncertainty and blank sailings. For example, blank sailings happen when vessels skip ports or cancel part of the route, due to prioritizing higher-paying customers over lower-paying shippers (Waters, 2021c). Such uncertainty quickly affects export in ports and their overall financial wellbeing.

1.1.4 Initiatives towards digitalization

The initiatives with digitalization did not take long to come as industry leaders such as Maersk recently announced their pilot to digitalize supply chain workflow back in 2018 (Safety4sea, 2018; Tsiulin et al, 2020). Later in 2021, a framework for smart port development was launched by COSCO Shipping Ports (Greenport, 2021), and the Port of Rotterdam has run a series of pilot projects emphasizing sustainability and a smart port environment (PortStrategy, 2021; UNCTAD, 2021). The mentioned projects highly contribute to the so-called “economy of connection” – a trend toward process coordination through digital connectivity (Francisconi, 2017; Lee et al, 2015)

Apart from the newly emerged attempts towards transforming the global supply chain to digital space and enabling end-to-end solutions, the industry has been establishing similar initiatives yet on a local, port site level. Rewinding to the time prior introduction of blockchain, Port Community System (PCS) has been known as among the first attempts to transform communication, document management and cooperation into a digital platform (Tsiulin et al, 2020b). PCS implies an information hub that establishes a connection between the main port actors, enabling digital coordination of documents and information (Tsiulin et al, 2020a; Baalen et al, 2008; EPCSA 2011). Even though PCSs differ in functionality and network coverage, the goal has been to automate correspondence, reduce the number of errors, minimize human factors, and optimize costs and time delays (Tsiulin et al, 2020b).

The relevance for such systems increases exponentially depending on the port size. The importance is especially great for large ports as those are required to have more advanced coordination and information exchange with port site partners (shippers, carriers, banks, freight forwarders, customs) and enhance the port throughput rate (Francisconi, 2017).

On the other hand, shifts toward digital solutions imply high risks in terms of cyber security (Meland et al, 2021; Rødseth et al, 2020). Generally, no actor in maritime supply chains is secured from ransonware and data leakage both at sea and at ports. The problem is common for vessels, ports, terminals, authorities and private companies. Moreover, even short-time outages bring significant financial risks, including data manipulation that is used for smuggling operations (Meland et al, 2021). The problem takes great importance as shown by Meland et al (2021) – as more and more literature are dedicated to the topic with time. It all seeks to find a proper solution to secure data not only from malicious attacks, but also keep practical use of generated corporate data, without fully subcontracting it to third parties i.e., giving it to a centralized actor.

1.1.5 Issues with digital port systems

An interesting illustration can be discovered by Marek (2017), following the case of an electronic cargo coordinating system created by the Polish Customs Office to simplify and speed up customs duties. The system is supposed to receive import declarations from customs agencies and refer with calculated import duties based on the submitted cargo information.

The system is meant to be based on a Bill of Lading, submitted either by the ship’s agent or container terminal (on behalf of the shipping line) that sends the cargo manifest to the Customs. However, due to occasional mistakes or failures to correctly declare the consignment – the incoterms identification has been missing regarding who is directly responsible for loading the cargo aboard a vessel. Hence, it results in Customs Office being unaware of cargo loaded, and consequently has not been declared (Marek, 2017). The lack of information results in penalties, time delays and an increased number of cargo units for the customs check – which is especially crucial for dangerous goods. Also, it complicates the job for terminal operators who need to move such containers to a dedicated facility quickly.

Therefore, the uncertainty of such data input, even having the system in electronic format, leads to problems with developing better-targeted customs controls. The situation is worsened for grouped/consolidated cargo i.e., shipments that take only a portion of the container (LCL). In conclusion, Marek (2017) refers to the lack of standardization across transport documentation as the main problem – that such standardization is done only to a certain extent.

Thus, the cases of PCS vary across ports globally and within the EU, having organizational problems and lack of unification as the main obstacles. Having small number of alternatives, ports were left to develop their individual systems. Consequently, the systems differed in the success of their implementation. Some PCSs however, implemented in Valencia, Singapore and Busan, still work successfully (Carlan, 2019). While other systems, such as Rotterdam, due to the large network of planned participants (more than 2,400 parties), faced challenges not being able to unite all into a single electronic system (Francisconi, 2017). The complexity lay in processing transactions across members from different locations, which led to redundancy and inaccurate data. Data security concerns became and additional factor that complicated finalizing the pilots – that is, reaching a consensus on data ownership and protecting it from leakage and unwanted use by other parties (Tsiulin et al, 2017; Nordtømme et al., 2015; Van Rooijen and Quak, 2010).

Nevertheless, the cases around PCS showed the obstacles to port efficiency and that further development of smart technologies can solve barriers faced by the industry, also contributing to the environmental agenda (Schewerdtfeger, 2021). COVID-19 pandemic, even though being a great disruptor to the current state of supply chains, had nevertheless created opportunities for the maritime sector to make a great step towards digitalization (UNCTAD, 2021).

1.2 Blockchain

Blockchain got significant media coverage starting from 2017, being associated with bitcoin as a platform for digital currency. Shortly after, the workflow of blockchain started being applied to financial markets and banking (Haferkorn and Quintana Diaz, 2015; Nguyen, 2016; Fanning and Centers, 2016; Swan, 2015) by reimagining traditional payment mechanisms.

The payments would exclusively be established between the money sender and the receiver, exempting banks as mediators and third parties. Hence, in the absence of centralized authority, the owner of the money is also being its holder e.g., the custody of funds. Moreover, to prove that these means exist, the records of previous financial payments are stored decentralized across all nodes i.e. parties who volunteered to be part of the system. This way, transactions only happen between users, while referring to the global database that keeps all transactions recorded and immutable once they are approved.

Afterward, the technology was projected to a wide range of other industries: healthcare (Swan, 2015), supply chain (O'Leary, 2017; Casino et al, 2019), public governance (Hou et al, 2018; Moura and Gomes, 2017), warehousing (Casino et al, 2019) data management (Swan, 2015; Casino et al, 2019; Antonopoulos 2015), connectivity with the Internet of Things (Tsiulin et al, 2020a; Casino et al, 2019) and even wildlife monitoring (Dryga et al, 2019).

Even though blockchain seems as a newly emerged technology, its origins refer to the 1990's (Chaum 1993) and dot-com era (Wright 1997; Hwang et al. 2001), having a range of similarities with current cryptocurrencies such as "Ecash", a digital-based system to anonymize the transfer of funds emerged in the early 90s, was partially implemented in USA and Europe, but did not survive through the rise of credit cards and large banks.

The concept of blockchain was initially introduced by Satoshi Nakamoto in 2008 (Nakamoto et al, 2008), outlining how the workflow would benefit electronic payments. The distinctive feature of blockchain is emphasized through its ability to sync the three already existing technologies, namely 1) peer-to-peer network, 2) cryptography and 3) predefined algorithms (smart contracts) (Holbrook, 2020).

As of today, blockchain is considered the key element of Web 3.0 – the third generation of internet services, focused on shifting websites and applications to more device interconnected, data-driven, and machine-learning web internet services (Holbrook, 2020; Gillis, 2022). Moreover, blockchain is seen as a part of Industry 4.0 – the concept of automated and digitally integrated manufacturing (Tsiulin et al, 2020a; Casino, 2019)

1.2.1 What is blockchain?

Blockchain is commonly abstracted as a decentralized and distributed database, whose data is stored in blocks and interlinked between each other (Seebacher and Schüritz, 2017). Seebacher and Schüritz define it as a user-to-user network (also called "peer-to-peer") that "*consists of a linked sequence of blocks, holding timestamped transactions that are secured by cryptography and verified by the network community. Once an element is appended to the blockchain, it cannot be altered, turning a blockchain into an immutable record of past activity*" (Seebacher and Schüritz, 2017, p.14; Tsiulin et al, 2020a).

Holbrook (2020) argues that there is no correct definition of blockchain, yet rather several, depending on the audience and the environment blockchain is managed in. To simplify the understanding of technology, he splits the definition into technical, business, and legal:

Technical. Blockchain is *a globally shared and secured data structure that maintains a transactional backend database that is immutable*.

Business. Blockchain is *a business network that is used between peers to exchange value. Value can be currencies, tracking information, or anything that interested parties require to be maintained on the blockchain ledger*.

Legal. Blockchain is *a corruption-resistant string of ledger entries shared over a network by multiple parties not requiring a centralized intermediary to present and validate transactions* (Holbrook, 2020, p.5).

In contrast to centralized databases, the history of previous records is kept among all participants who can either be anyone (open database, also called public blockchain) or certain users who have access (permissioned database, also called private blockchain). Common study cases for open blockchains are electronic voting, finance, or e-government services where citizens and public audiences are expected to participate (Swan, 2015). Examples of permissioned databases are represented by the maritime industry (Kshetri, 2018; Tsiulin et al, 2020), healthcare, land registry, etc (Casino et al, 2019) with a specified number of different actors, contributing according to their role.

In the database, the information is stored in interlinked blocks, keeping the data history of previous records. Users with access are allowed to verify the state of the database i.e., to ensure that new information satisfies the predefined agreement (Reyna et al, 2018; Antonopoulos, 2015). Agreements are widely known as 'consensus' – a set of rules to store new information that meets the conditions set by stakeholders and, importantly, can be automated using mathematical algorithms (Tsiulin et al, 2020a). This way, all network actors maintain a copy of the database. In other words, the network agrees on how to save new files, and once it is saved – it becomes immutable for changes (yet still accessible to view).

Blockchain's immutability and its access to data history provide clarity on when, how, and by whom certain actions were made or approved. It represents a timestamp with information details on a particular transaction, which might be important for dispute resolution or when clarifying the area of responsibility for a particular action. For other actors in the network, it can play the role of trust, showing that the designated actions indeed occur according to a given consensus algorithm (Narayanan, 2016; Tsiulin et al, 2020).

1.2.2 Data security and hash algorithm

In terms of security, blockchain relies on its decentralized network. Security is achieved through the constant synchronization of data across the network. Originality of stored information is confirmed by the hash algorithm – each new block always refers to the hash of the previous one (Antonopoulos, 2015; Qureshi 2018; Wüst and Gervais 2017; Tsiulin et al, 2020a). Inputting false information into any recorded block will trigger the change to the hash algorithm – hence the hash of the whole database. Such a system is called Merkle Tree verification.

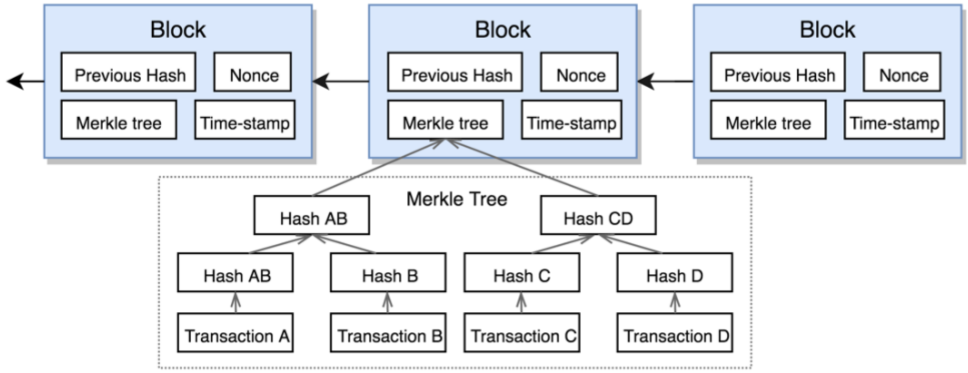

Figure 2. View on Merkle Tree approach (modified from Buterin 2015; Narayanan et al. 2016, Nakamoto, 2008)

Merkle Tree verification helps to check transactions' originality by connecting data with hashing groups that are synchronized independently (Buterin 2015; Tsiulin et al, 2020a). Each data record has its hash, which is combined in groups. Having a hierarchy, each group is split equally along with the hash. If the block had any unauthorized changes – in this case, the algorithm does not verify the transaction in the block, but each group's top-level hash until it finds a discrepancy. If it finds a mismatch, then the algorithm tracks it further down (Figure 2) in the hash groups to find a particular unauthorized recording (Buterin 2015; Narayanan et al. 2016).

1.2.3 Smart contracts

To extend the functionality of just a distributed database, certain blockchain platforms support smart contracts. A smart contract is a system of self-verifying, executing, and response algorithms. The roots of smart contracts refer to computer protocols and legal disciplines (Danzi, 2019). Such algorithms are set up by the network stakeholders, and while running the algorithm – once the predefined conditions are met, the smart contract activates an appropriate action (Narayanan et al. 2016; Tsiulin et al, 2020a).

To put it differently, the blockchain network decides on the number of instructions to be executed by the database. If a new potential record fulfills the set of rules defined for the smart contract, then its state is modified and the transaction is accepted (Danzi, 2019).

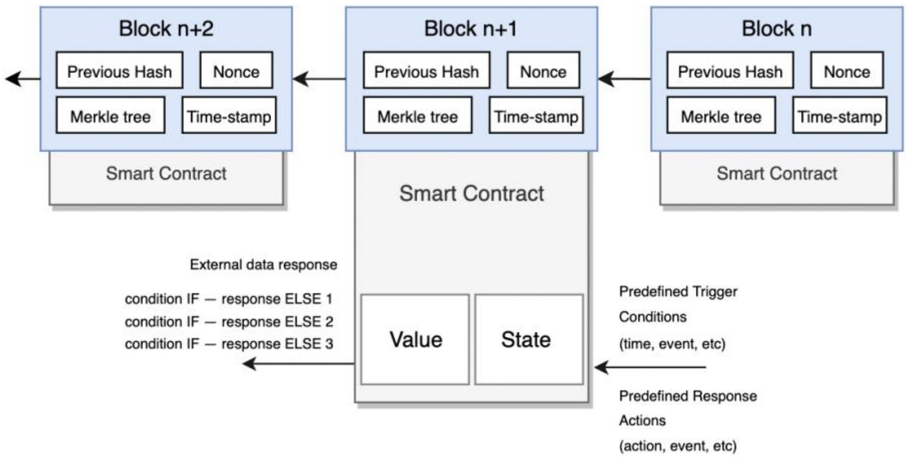

Figure 3. An overview of blockchain architecture (Tsiulin etl a, 2020a)

Smart contracts act based on "IF-THEN" logic (Figure 3). If the algorithm detects several conditions that are met (e.g. receiving approval, a document, or spotting a record from an open registry), then it responds according to the agreement in the network (e.g. confirmation, further forwarding; approving, rejecting, archiving, etc). Thus, for every new entry to the database, there is a sequence of conditions to be checked by the algorithm (Tsiulin et al, 2020a). Thereafter, depending on the check result, the record is either completed or declined. If completed, the information is then stored in the database (Yuan and Wang 2016; Tsiulin et al, 2020a).

In order words, a smart contract is a computer code that can execute a task by itself within predefined rules set by a network.

1.2.4 The competitive advantage of blockchain

Some of the key features provided by having decentralized and distributed databases are transparency and auditability of data flows. Decentralization implies provides functionality without a central authority i.e. a gatekeeper that keeps data, verifies and authenticates transactions. Consequently, it allows direct cross-party communication, as well as payments, reporting, information forwarding and accessibility of stored data. The technology is considered one of the contemporary tools that could shift out-of-date document management and decision-making processes to a fully electronic format and thus create a greater level of trackability (Hawlitschek et al, 2018; Seebacher and Schüritz, 2017; Groenfeldt, 2017).

Compared to a centralized system, all permissioned actors of the network are allowed to verify the state of the database and use it as a source of trust when approving cross-party agreements (Reyna et al, 2018). Confirmed data records represent timestamps, showing information about when, how, and by whom a particular transaction was completed (Antonopoulos, 2015). Data is protected from falsifications by decentralization and overall block dependency on each other. Usage of hash algorithms helps to constantly verify the state of the database in real-time (Tsiulin et al, 2020a).

In addition, the functionality of distributed databases is extended significantly when using smart contract algorithms – to allow automation of data management when searching, registering, storing, extracting, and forwarding information either within the database or outside of the network.

1.3 Prospects of blockchain for maritime industry

1.3.1 Blockchain applications in various industries

Since media attention given to blockchain emerged in 2018, during the next years the technology has been projected to a wide range of industries and business cases. The most frequently discussed fields have been healthcare (Swan, 2015), finance, Internet of Things (Kshetri, 2018; Groenfeldt, 2017), public governance (Hou et al, 2018; Moura and Gomes, 2017), data management (Antonopoulos 2015), and supply chains (O'Leary, 2017; Casino et al, 2019). Figure 4 illustrates an abstracted mapping of blockchain applications within different fields.

Figure 4. Abstraction mapping of different types of blockchain applications (modified from Casino et al, 2019)

However, besides finance sector which was one of the major focuses of blockchain since its early adoption, current running applications represent, for the most part, distributed e-voting platforms, tracking possibilities and identity management, extending the usability of such scenarios to other domains, especially healthcare, public governance, and supply chain (Kringelum et al, 2021; Tsiulin et al, 2020). Importantly, these three areas match the fundamental requirements of a blockchain: a high number of scattered, diverse actors with a lack of trust between each other, low level of co-integration, and the significance of third parties i.e. mediators in data processing (Casino 2019; Swans 2015; Tsiulin et al, 2020a; Groenfeldt, 2017).

Moreover, considerable attention to the technology was given in academia, dedicated to literature reviews, technical analysis (Seebacher and Schüritz, 2017), and an overview of a possible architecture for studied solutions (Karafiloski and Mishev, 2017), including potential connectivity of blockchain with Internet of Things, data sharing, etc (Hald and Kinra, 2019). While other academic literature explored to what extent the role of trust is important within specific industries and whether blockchain is necessary (Hawlitschek et al, 2018).

1.3.2 Case studies in healthcare and public governance

For healthcare, certain scenarios have been to create a database of electronic healthcare records, allowing patients to access their records regardless of the treatment center they were inputted through (Hald and Kinra, 2019; Swan, 2015). In this case, the patient has not only access to his health records but also a right to decide where the record information can travel. The control over data shifts from health institutions to a patient, who can use it accordingly to his/her needs e.g., delegating, moving it to other organizations, etc (Tsiulin et al, 2020).

Another example is public governance. A platform has been developed for the Federal Tax Service in the country of Eastern Europe, which includes all country's national banks (with the rare exception of foreign banks), tax authorities, auditors, and regulators (Waves, 2022). Each actor of the network (including banks, tax authorities, auditors, etc) allocates 1-3 blockchain nodes (depending on the load of the network segment), having over 200 nodes in the network in total.

The original goal was to give soft loans to small- and medium- enterprises during the COVID-19 pandemic. There is a requirement that the loan must be made only once to one legal entity. In addition, lists of borrowers must be stored in a database for the government to pay the bank's interest for these legal entities. Before this project started, no system would allow the banks to reliably negotiate and protect themselves from the fact of fraud, if a legal person filed 10 applications to different banks in parallel.

In this situation, blockchain proved to solve the problem with the algorithm that implements the business process. Blockchain acts as a single source of truth and based on the results of a smart contract, the application on the side of each participant can give an unambiguous answer (Waves, 2022).

1.3.3 Blockchain in maritime industry

As for the maritime industry, establishing digital connectivity between supply chain parties has been seen as the next move toward time-efficient and secured deliveries.

The public interest has risen to start with Danish shipping company Maersk announcing their blockchain solution to digitalize document paper flow, offering an end-to-end supply chain solution (Groenfeldt, 2017). The connectivity across supply chain actors is meant to ensure transparency and auditability of information flows, which is relevant within such a widely distributed network as shipping (Tsiulin et al, 2020; Kingelum et al, 2021).

Subsequently, the idea spread to a large number of startups projecting blockchain into the shipping industry. The technology was promoted as a solution to issues with cross-party communication in supply chains, data security, and elimination of central gatekeepers e.g. shipping brokers. Also, establishing point-to-point coordination with visibility of transactions and providing access to cargo tracking (Tsiulin et al, 2020a; Kshetri, 2018; Casino et al, 2020).

The majority of commercial projects, startups, and academic reviews, according to their proposals, suggested to use of blockchain for goods tracking, including time, location, and border checks, starting from the place of its origin until the final destination (Casino, 2019; Groenfeldt 2017; Kshetri 2018; Provenance 2018). Blockchain is implied to undertake the role of a global database, making it available to track the transportation process from start to end by connecting all necessary parties throughout (Tsiulin et al, 2020a).

The scenario can then be spread further to full cargo tracking of, for example, containers. That implies overall connectivity and inclusion of IoT sensors, providing information on the manufacturer, transportation time, time spent in the warehouse, and temperature requirements (Provenance, 2018). Having such connectivity, according to literature (Tsiulin et al, 2020a, Huang, 2018, and Higgins, 2017), will help to get credibility from the final customer as well as other relevant stakeholders (customs, freight forwarder, etc).

For instance, projects such as Provenance (2018) aimed at the fishing industry to allow customers to see the approximate place and date of fish catching, its further transportation, storage duration, and conditions; hence providing the customer with information about the product quality and its freshness. Other projects and applications emphasize the general direction toward digitalization and connectivity of devices (Kshetri 2018; Skwarek, 2017; Bahga and Madisetti, 2016).

1.3.4 Issues with the technology

The complexity of interconnections between different supply chain actors as well as poor monitoring of the process throughout has fueled the industry with awareness of blockchain technology (Kingelum, 2021) and the necessity to shift it towards better digitalization, data management and cross-border cooperation (Tsiulin et al, 2020a).

Technically, unlike open blockchain, which does not require authorization to use the platform, for supply chain operations and maritime industry the permissioned (close access) type of blockchain has been considered. The reason for that is having visibility of data in a *special order* (Holbrook, 2020). For example, having a network connected to blockchain starting from a manufacturer, port of origin, and then to the port of destination and further forwarding until the last mile. In this case, the data on cargo movement, as well as its documentation, will consistently move from one actor to another along the supply chain - notifying the next party in advance and putting the whole process on the blockchain.

On the fundamental level, both academic and grey literature indicate that the shipping industry, due to its complexity with the relationship of the parties with little trust in each other, and the decentralization of data, in theory, could improve the transportation process by making it more flexible, transparent and time-efficient (Kshetri, 2018; Casino 2019; Swans 2015; Tsiulin et al, 2020a).

Nevertheless, the available knowledge of blockchain applications in the maritime industry and the existing literature lacks clarity. The vast majority of projects, as they started in 2018, had not revealed the clear scheme/architecture of the proposed solutions i.e. an explanation of how blockchain transforms the supply chain from the network perspective. Other projects, commonly, were tied to the financial aspect of transportation (payments using cryptocurrency). Projects' documentation often included White Papers, press releases, and case study descriptions, yet not the scheme of how such a project could, practically, cover either document or cargo tracking within the supply chain and be implemented.

A considerable share of such projects has been supported by large IT, maritime, and e-commerce companies such as Amazon, Alibaba, Maersk, IBM, and SAP (Safety4sea, 2018; Tsiulin et al, 2020). Some, such as Maersk and IBM, have joined forces to develop a collaborative solution. Among their goals, following the ideas proposed by smaller commercial projects, were also cargo tracking and document workflow simplification. One of the studies from the current thesis analyzed the main scenarios among applications – i.e. grouping existing projects available by the end of 2019, and analyzing projects' goals and business proposals (Tsiulin et al, 2020).

Within the next four years until the middle of 2022, the situation around commercial projects and the clarity of their solutions have not become more evident. While still being considered an immature technology, practical and organizational aspects of blockchain scenarios are not yet revealed. Also, several commercial projects were absorbed or affiliated with the industry majors, e.g. T-Mining as a project of Port of Antwerp; TradeLens as a side project of Mærsk (Safety4sea, 2018; Groenfeldt, 2017). In addition, certain of these projects (Blockshipping, 2022; TradeLens, 2022) got rid of the "blockchain" tag and started developing solutions either in a related field or without mentioning blockchain at all (Tsiulin et al, 2020a).

1.4 Objective of the thesis

The overall aim of this Ph.D. thesis is to analyze the feasibility of blockchain technology in the maritime sector, including, in particular, port logistics. That is, to define the current trends in development of blockchain applications and outline scenarios of potential adoption. Also, to provide knowledge on what preceded the technology in the sector and what innovates cargo handling equipment currently. Moreover, to analyze whether the proposed decentralized approaches meet the ports' long-term priorities in Denmark, clarify the challenges of implementation and practical drawbacks and reflect on future developments

In line with the objective of the Interreg BLING project (BLockchain IN Government, extending the knowledge of blockchain possibilities for governmental services), in which this project was made, the thesis, therefore, investigates the practical explication of blockchain for maritime sector and ports, seeking to broaden the knowledge on the potential of the technology as well as existing issues with adoption in the field.

The academic objectives will be achieved by answering the main research question:

- *RQ: What is the feasibility of blockchain technology in maritime sector and port development in particular?*

The main research question will be analyzed through the following sub-questions:

- *How can blockchain technology affect maritime industry and port logistics, and what are the possible scenarios for its implementation?*

The first question addresses existing academic and grey literature on the topic, including commercial projects, white papers, public reports, etc, seeking to find the main areas of ongoing blockchain adoption. The work is the first to identify conceptual intersections between existing blockchain applications and map the ongoing trends of application development. Based on the selection, the found projects will be categorized to find similarities among their objective on the conceptual level.

Moreover, to investigate possibilities for blockchain technology on the local, port terminal level, the study organized a hackathon for several student groups to prototype pilots based on the case study of trailer pick-up error at the terminal. As a newly emerged study approach, hackathon proved as an efficient and effective assessment of the requirements for potential IT solutions, providing a guidance for future directions in development. Eventually, it will broaden the understanding of how blockchain can be used not only in international supply chains, but also on the local scale.

Having existing applications categorized, the next step is to reveal the background, i.e. to find previous initiatives to digitalize port communication. The second research question will address a closer look at existing blockchain concepts that tend to shift document flow to digital format namely port community systems. Thus, the research question is the following:

- *Prior introduction of blockchain, what have been the concept to digitalize port communication or workflow between port actors?*

The next goal is to analyze the practicalities across found scenarios. The third question addresses the prospects of found blockchain scenarios being implemented. For that, a series of interviews were conducted within port authorities in Denmark. Namely, how the projects from the literature align with Danish ports, including their development strategies and cooperation with other port actors. Therefore, the question is as follows:

- *To what extent do blockchain have practical explication from the perspective of maritime ports in Denmark?*

The next question broads an understanding of the port area as well other port innovations within the scope of cargo handling e.g., container reshuffling, mooring operations, usage of alternative fuels, etc.

Moreover, understanding the port area, and also blockchain scenarios on various industry levels, having an overview of the background and previous attempts to digitalize port communication, the research question addresses the summary of challenges that prevent blockchain from implementation:

- *What are the challenges of blockchain technology in the industry that prevent the technology from implementation?*

In order to answer the questions above, the PhD project consists of six studies, which are presented as six papers of this thesis. In the following chapters, the conducted studies as well as used methods are introduced briefly. Further information is provided in the attached papers.

CHAPTER 2. UNDERSTANDING MARITIME PORT

This chapter continues to introduce the background, acting as a gradual introduction to the state of the maritime sector and the knowledge necessary to understand this dissertation. The chapter will explain the prerequisites of port development followed by the role of ports and the actors within. Furthermore, ports will also be covered from the global perspective of sustainability and emission reduction. This way, the reader can get an understanding of port development through the time, as well as grasp the idea of port structures, port network and shifts toward sustainability.

2.1 How port is organized

The following subsections will serve as a brief introduction to a maritime port. Throughout, the main components of a port will be covered to give an understanding of how the port area is organized, including terminal area for cargo handling, and what are the main actors in terms of organization. Also, how ports, as service providers, have been changing historically with their roles and the range of available tools and services. Eventually, the chapter will introduce the discussion of how ports and their development has transformed into partially or fully interlinked industries (clusters).

2.1.1 Port development

Port development can be abstracted as a range of activities to support the continuation and creation of value for port users and society (de Langen, 2019). Such activities typically include investments in port infrastructure, making strategic land-use decisions and providing support for port activities to stakeholders. According to de Langen (2019), port development is fully related to the development of the port as an ecosystem with multiple organizations, businesses and workflows based within.

The mapping of port development commonly refers to United Nations Conference for Trade and Development (UNCTAD), a conference in 1992 where port development was introduced through a three-generation model. The model described the historical progression of ports, showing its distinctive features throughout the time as well as cargo priorities, strategic development and dependency on local factors. Moreover, the model played a role of guidance to evaluate the maturity level of a particular port (Olesen, 2015; Beresford, 2004). In 1999, the model was updated by UNCTAD with the inclusion of the fourth generation.

	First generation (Before 1960s)	Second generation (1960s to 1980s)	Third generation (1980s to 2000s)	Fourth generation (since 2000s)
External environment				
Development factors	Steamships; Rise of nations; Rise of trade	Petrochemistry; Trucks and pipelines; Structural prosperity; Industrialization	Multinational corporations; Containerization; Environmentalism; Globalization	Global economy; Information systems; Sustainability; Digitalization
Port functions	Transshipment (1); Storage (2); Trade (3)	(1) to (3) + Industry (4)	(1) to (4) + Distribution (5)	(1) to (5) + Logistics (6)
Nature of production	Cargo flow; Simple services; Low added value	Cargo flow; Cargo transformation; Combined services; Improved value-added	Cargo/information flow; Cargo distribution; Multiple service package; High value-added	Cargo/information flow; Cargo/information distribution; Multiple service package; High value-added; Chain management
Type of cargo	General cargo and bulk	General cargo, bulk and liquid bulk	Bulk and unitized/containerized cargo	General/containerized cargo; information
Spatial organization				
Port spatial scale	Port city	Port area	Port region	Port network
Port spatial expansion	Quay and waterfront area	Enlarged port area	Terminals and inland corridors	Network-related functional expansion
Location factors	Labor and market access	Access to raw materials; Access to sales market; Availability of capital	Availability of transshipment facilities; Access to sales market; Space; Flexibility; and labor costs	Availability of transshipment facilities; Access to sales market; Space; Flexibility; and labor costs
Strategy				
Organization	Independent activities within port; Informal relationship between port and port users	Close port/users relationships; Loose port/activities relationships; Causal port/city relationship	Port community; Port/transport chain integration; Close relation between port and municipality; Enlarged port organization	Port network community; Close relation between port network and public authorities on different levels
Role of port authority	Nautical services (1)	(1) + land and infrastructure development (2)	(1), (2) + Port marketing (3)	(1) to (3) + Network management (4)
Port strategy	Port as changing point of transport	Transport, industrial and commercial center	Integrated transport and logistic center	Integrated transport, logistic and information complex and network

Table 1 – UNCTAD four-generation port model (1992; 1999), Notteboom et al (2022), Van Klink (2003); Beresford et al (2004)

As seen in Table 1, through time and globalization, ports made a significant shift from a simple service operator e.g. loading/unloading and storing, to a step of becoming a fully-integrated community system with close relationships between port actors and public authorities (Notteboom et al, 2022; Olesen, 2015; Beresford et al, 2004).

The fourth-generation port implies the development of containerization and logistics, including a wide range of value-added services to generate better income. It also extends activity towards landside logistics and emphasizes the work with data. Thus, new generation ports prioritize the collection and management of data. Through data analysis, the port can optimize and strengthen the existing business processes.

Moreover, some literature (Molavi et al, 2019; McKinsey, 2018) introduced the concept of a fifth-generation port also known as 'Smart Port' – a concept of fully automated operations, digitalized network and sustainable cargo handling. The concept of a Smart Port is centered around the customer and lies within urban sprawl, where the port is one of the integral parts of the local urban environment.

An interesting insight into the comparison between different port models is that one port could go through different stages of development across its areas simultaneously (Olesen, 2015). Nevertheless, one of the key conclusions made (Olesen, 2015; Pettit and Beresford, 2009) by elaborating on UNCTAD port development (Figure 5) is a tendency of maritime ports to go toward the integration of logistics services across the port services as well as the supply chain.

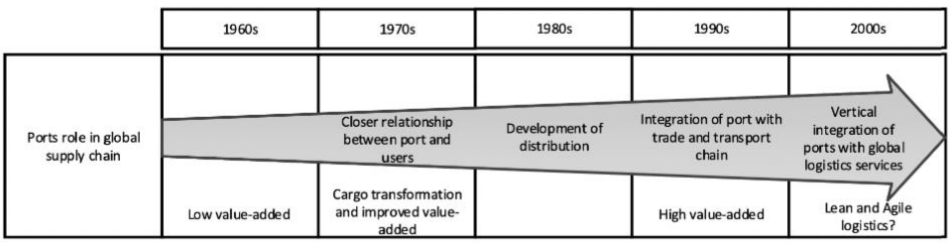

Figure 5. Historic perspective on ports integrating into the supply chain (Pettit and Beresford, 2009; Olesen, 2015)

Generally, seaports tend to develop in several directions. Ports increase their functional capabilities in terms of cargo types they can handle and accommodate. At the same time, ports increase spatially with infrastructure upgrades, spreading to landside operations, and extending the operational network (Notteboom et al, 2022). Finally, digitalization and data management allow saving costs by optimizing existing infrastructure and processes.

2.1.2 Port actors

To illustrate a port from the perspective of organizations and businesses based within, the following section describes port actors as well as how different tasks are executed accordingly to each actor, shaping a simplified scheme of communication between actors at the port site – also referred to as "port community".

Port description commonly starts with the type of its ownership. Governments have been closely involved in the port industry throughout history, mostly being the owners of the port infrastructure or port assets (for instance, cargo handling equipment). Therefore, the ways of managing the port vary significantly per country. For example, in the UK ports are represented by private companies. While in South Africa ports are run by large governmental institutions with full responsibility for site development and terminal operations (de Langen, 2019). In Brazil, the majority of ports are governmentally owned, leasing the land to both private and state-owned terminal operators based on long-term rental agreements (concession). Or, for Scandinavian countries, ports are managed by individual companies owned by the local municipality (de Langen, 2019).

In this way, due to historical prerequisites, local and social conditions, port management considerably varies across the countries hence having no ideal, global model for port development. It is also complicated to unify the definition of port actors because they could vary per country. Nevertheless, in terms of port actors, a port is generally represented by port authorities, terminal operators, customs, freight forwarders, etc:

Port authority, even though its role changes over time, is seen today mostly as a development company (Damman and Steen, 2021), and, being centered among port actors, has a focus on profit maximization. Port authority could also be defined as an entity, whether in conjunction with other activities, follows an objective to administrate and manage the port's infrastructure, coordinating and controlling the activities of different operators in the port, also following national law or regulation (Verhoeven, 2010; European Comission, 2001).

Port Authority, by managing a particular port site on behalf of national and local government, is usually associated with three functions: landlord, regulator and operator (Verhoeven, 2010; Baltazar and Brooks, 2001). The landlord function is considered the principal function of the port authority and implies management over the port site, monitoring and maintenance of the land, including the search for funding and partnerships since the direct financial support from the government could be limited. Regulation relates to policy-making, controlling and monitoring port tenants, ensuring the security of operations with cargo. Lastly, the operator function is tied to port services whether it is services related to cargo handling (mooring, provision of power, loading/unloading, etc) or to passenger and cruise vessels – then the function is similar to airport or railway (Verhoeven, 2010).

Terminal operator is usually represented by private companies which lease the land from the port authority to provide operations with cargo. It is also common to have several terminal operators competing within the territory of the same port. The terminal operator handles cargo across the quay, including transit to the port yard and warehouses, receiving remuneration in accordance with port tariffs (Martin and Thomas, 2001).

Freight forwarder is a company (also known as Hinterland carrier) that represents shippers and provides transportation on their behalf (Roslyng Olesen, 2015). The forwarder is engaged with assembling, collecting, consolidating and distributing cargo from the port of destination further to the distribution center and likely to the last mile. A freight forwarder is usually called for the shipper who does not possess a transport of their own at the time of the shipping (Hinkelman, 2015; Martin and Thomas, 2001).

Customs is generally known as a government authority designed to regulate the cargo flow to/from a country and collect duties levied by a country on imports and exports (Hinkelman, 2015). Among the objectives of customs are controlling import and export of goods, illicit trade e.g. contraband or smuggling, monitoring over restrictions regarding certain types of cargo as well as direct and indirect taxation (Marek, 2017).

Shipping broker is a coordinating party providing transportation to the customer by facilitating the booking of the transportation means and coordinating it throughout the delivery, also responsible for meeting delivery deadlines. A shipping broker is usually represented by a related agency (Olesen, 2014).

Port agent provides a service for the vessel once it arrives at the port. Responsibilities of port agents include: 1) arranging pilotage and berthing, 2) arranging maintenance and purchase of spare parts, 3) assisting the crew and taking care of the paperwork (Roslyng Olesen, 2015). Port agents are generally seen as mediators, ensuring the necessary communication between the vessel crew, the ship, operator, customs, authorities, etc. Figure 6 summarizes of port actors and their involvement in the port community

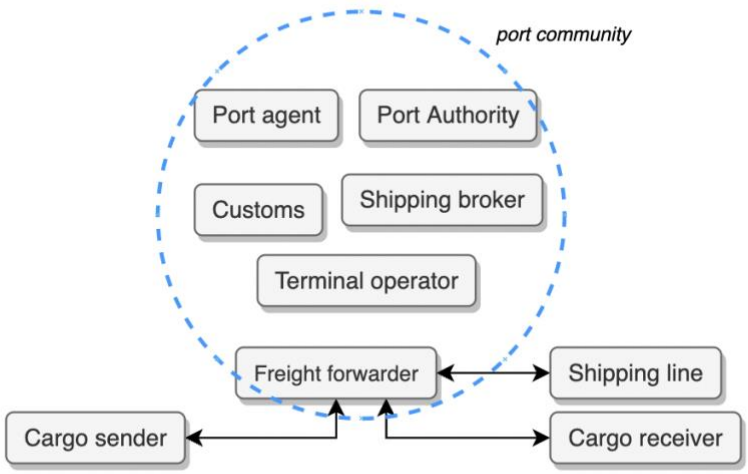

Figure 6. Simplified map of port actors and a circle representing the port system (modified from Olesen, 2015)

2.1.3 Port terminal area and operation flow

The current sub-section will shortly introduce the map of a port terminal, the areas allocated within and how it corresponds with cargo flow.

Maritime ports, even though are expanding in terms of available services and industries, are still generally associated with cargo-related operations: loading/unloading, storing, customs checks, cargo redistribution, etc. Different facilities in ports continue to grow e.g., warehousing, production line, offices, and areas of co-working, yet cargo operations remain the largest part of port business activity.

Academic literature (Iris and Lam, 2019; Carlo et al, 2014) tends to split a terminal into five areas in accordance with the operational flow: *berth, quay, transport, yard and gate* as shown in Figure 7. These are considered the operational areas of a terminal.

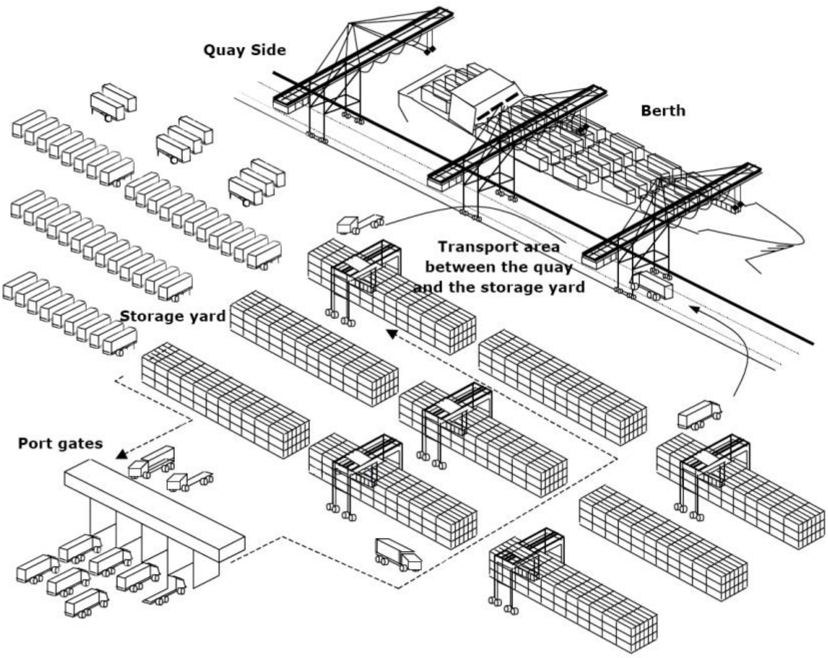

Figure 7. Illustration of port terminal areas (modified from Sharif, 2013)

Generally, operations with cargo happen as follows. When a vessel arrives at the port, it is assigned to a position at the berth. Once the vessel approached the berth and is within its proximity – it is being moored, meaning that it is fixed and secured to the berth (Tsiulin and Reinau, 2022). Then happens the unloading or loading process, quay cranes either one or in conjunction unload cargo following a particular plan and a schedule. After that, containers are picked up by port trucks and transported to the storage yard. At the storage yard, containers are usually stacked upon each other depending on the duration of stay and destination. If further delivery is on the landside, then the container is picked up by a freight forwarder. Otherwise, in case of transshipment to another port, containers go through the loading process to the further vessel (Carlo et al, 2014; Tsiulin and Reinau, 2022). Accordingly, loading of the vessel represents a similar procedure but in reverse.

2.1.4 Port clusters

Another way to look at a maritime port is through port clusters – a site of spatially concentrated and related economic activities (de Langen, 2019).

Ports, as complex organizational structures, historically have been a hub not only for cargo operations but also for a variety of activities e.g. warehousing, rail terminals, container depots, production lines, ships and equipment maintenance, etc. A big part of these activities is run by small- to medium- enterprises who intentionally chose to locate their business at the port due to location advantages. Eventually, having the synergy of co-existing within one site and proximity, such businesses form clusters (de Langen, 2019; Zhang and Lam, 2017).

The perspective of looking at the port through clusters development has been applied within the local ports of different countries. To generalize the types of the frequently met cluster, Othman (2011) suggested, based on the maritime industry in Malaysia, the clusters of shipping services, ship industry and terminals. In Norway, the fishery was included as one of the clusters (Porter, 1998), while in Canada, six clusters were identified just for Quebec's region (Doloreux and Melancon, 2008). Other studies discussed that the specifics of the local area help to define the unique formations of port clusters (Porter, 1998; Zhang and Lam, 2017). Further, the promotion and further research on port and logistics clusters were supported by United Nations publications (de Langen, 2019).

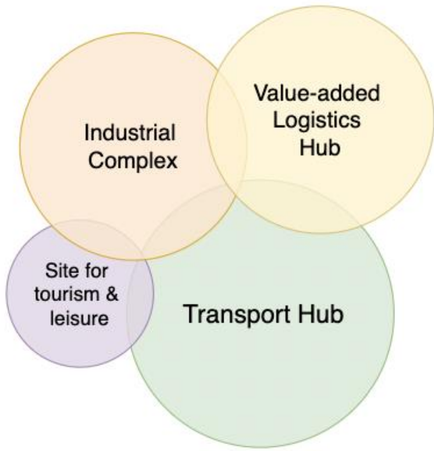

Figure 8. Clusters of a port (de Langen, 2019)

As seen in Figure 8, a port is commonly generalized into four clusters (de Langen, 2019). That is conventional and historically the main role of the port *the transport hub*, providing operations with cargo at a terminal. This way, it is a part of the supply chain, also attracting vessel and cargo-related enterprises such as vessel maintenance, storage, or management.

Furthermore, ports represent a high value for *logistic activities* e.g. storing, repacking, and redistributing. De Langen (2019) emphasized two factors on why logistic services are allocated within port sites. The first is due to the *temporal nature* of cargo storage in ports, and the second is that port services, fundamentally, are *deconsolidation* points in the supply chains. Thus, value-added logistic services are essentially connecting goods delivery to the final customer.

Because ports typically operate with high volumes of commodities, production or *industrial complexes* are a common part of the port area, represented by energy production, metal processing, oil refining, etc.

The last cluster is represented by *tourism and leisure* activities. Besides the fact that certain ports accommodate cruise ships, and also provide tourism such as hotels, restaurants, and shops, there is a long-term possibility for ports to be involved in local urban life (de Langen, 2019; Kwak et al, 2005;). Due to proximity to the waterfront and local residential areas, certain ports are undergoing the development of becoming an urban-friendly environment and a place for local tourism and co-working.

According to de Langen (2019), the look at the port area through the existence of clusters provides a new perspective on port competitiveness and 'intra-cluster competition'. Also, clusters hold a possibility for additional performance indicators, measuring the success of a particular port as the whole complex of production, storing and operating with cargo. Lastly, another perspective to look at the port is not through the complex of *in*dependent enterprises, yet rather *inter*dependent firms that can cooperate within and hence generate greater benefits (de Langen, 2019).

The development of port clusters including the research in academia emphasized the importance of collective, cross-clusters decisions when governing the port (de Langen and Visser, 2005), the likelihood of port authorities changing their functions through the time (Verhoeven, 2010), and the significance of coordinating cooperation between the clusters (Bai and Lam, 2015). Having such, the literature indicates the changing role of the port as the clusters evolve (Zhang and Lam, 2017), highlighting that the share of the currently-dominant, conventional cluster of cargo operations will be reduced compared to the roles of the others three (de Langen, 2019).

2.2 Emission problem

The following section will introduce the problem of maritime ports shifting towards greener port activities. The potential reduction of emissions from the shipping industry by 2050 is required with annual investments from 40 to 60 billion US dollars between 2030 and 2050 (UNCTAD, 2022). This includes policy regulation, and investments into alternative energy and infrastructure. To understand the significance of emissions control across the supply chain industry, it is important to see the retrospective of how climate agreements have intensified over time.

2.2.1 Global initiatives and regulation

The first actions on global climate change refer to 1992 with United Nations (UN) developed a framework on Climate Change (UNFCCC) to stabilize GHG levels and air quality (UNFCC, 1992). The initiative then was developed into the Kyoto Protocol in 1997 (United Nations, 1998), setting a goal to limit GHG emissions by 5% from 1990 levels by 2012. The next landmark in global agreement development was in 1998 with World Resources Institute (WRI) spreading knowledge on how cities worldwide can monitor progress in reaching their climate objectives (Azarkamand et al, 2020). The contribution of World Wide Fund for Nature (WWF) is also worth mentioning, whose establishment and further support of the Gold Standard emission allowance in 2003 and 2017 revealed indicators, certifications, and control to reach sustainability goals (Ecofys, 2006; Azarkamand et al, 2020).

Within time, the repercussions of global warming and an overall increase in CO2 emissions became evident to the scientific community. So did happen in the commercial industry, where the business started to consider the potential benefits of "green growth" in daily business and marketing campaigns (Fouquet and Pearson, 2011). Most important milestones were set by United Nations, the organization that remains active until now, with a successor to Kyoto Protocol. The Paris Agreement in 2015 emphasized the importance of immediate actions to limit the increase of global temperature from 2 to 1.5 °C (United Nations, 2015). Respectively, Kyoto and Paris agreements were followed by the conference in Madrid in 2019 to increase awareness and speed-up activity toward goals set in Paris (Azarkamand et al, 2020).

2.2.2 Energy transition in the maritime industry

Regarding the maritime industry, even though it is considered the least polluting means of transport and is not directly mentioned in climate agreements, the total emissions from shipping are substantial. It represents approximately 2-3% of the total level of global CO2 emissions, being equivalent to the total emissions of certain countries, for instance, Germany (Global Carbon Project, 2021).

International discussions regarding vessel-source pollution and green ports started in 2005 with the International Maritime Organization (IMO, 2019). In 2008, a set of tools has been spread to ports by the International Association of Ports and Harbors (IAPH), assisting them with measurements and raising awareness, and then later, in 2010, developed into Port Climate Initiative (Azarkamand et al, 2020). In 2011, IMO set up energy targets and proposed regulation through short-, medium- and long-term measures that later included data collection on fuel oil consumption in 2016. For instance, the carbon intensity of international shipping was targeted for a reduction by a minimum of 40% by 2030 and 70% by 2050 (IMO, 2019; Global Carbon Project, 2021). The focus was dedicated to on-shore power supply, alternative, and zero-carbon fuels as well as to data collection and port incentive schemes. Further on, the scope of IMO's goals were spread toward cooperation with ports under the IMO Ports Resolution in 2019 (Global Carbon Project, 2021).

In 2020, European Sea Ports Organization (ESPO) with maritime ports in the EU jointly initiated a list of long-term environmental priorities. Priorities differ and change with time, yet commonly focus on air and water quality, energy efficiency, waste, and port area development (Figure 9-a). These collective priorities represent the general trend for port sustainability and vary over time depending on the global agenda and the success of ongoing regulation (ESPO Environmental Report 2020). As seen from Figure 9-b, the main priorities for 2020 have been air quality and energy consumption which remain first from 2013 onwards.

Figure 9. (a) Ten environmental priorities for European ports for 2020;
(b) Tendency of the main priorities from 2016-to 2020
(modified from ESPO, 2020).

World Ports Sustainability Program (2021) stated that during the last 25 years the attention has moved greatly from generalized environmental and incident-oriented issues toward sustainable priorities. Mainly *reactive* response to incidents from the 1980s had been replaced with legislation and *increasing awareness of local initiatives and particular actors along the supply chain*, e.g., shipowners, ports and terminal operators. According to the program, the policy-making process was built around "direct control" over the waterfront. One of the success criteria is that within 2010-2015 becoming a "green port" started to be an important part of ports development strategies.

Seeing a gradual trend towards sustainability and within maritime ports, certain studies, however, highlight the problem of scattered usage of tools and methodologies for emission monitoring and calculations. Thus, according to Azarkamand et al (2020), each association, port authority, or operator uses its own method to calculate the emissions. Hence it becomes a challenge. Due to the lack of unification across the use cases, it is complicated to compare results and make a tangible conclusion on success criteria. Other studies follow the similar statement (Zhen et al, 2019), evaluation systems for emissions footprint analysis of handling activities are lacking, but also the availability of optimization models to control the emissions and machinery efficiency.

By 2014, 27% of world energy consumption goes upon obligatory standards. Certain standards such as the ISO 5001 influence organizations to have better monitoring over emissions and gradually move towards energy measurement and consumption. Within maritime ports in Europe, only ports of Hamburg, Antwerp, Felixstowe, Baltic Container Port in Poland, and Valencia port have passed certification with ISO5001 (Iris and Lam, 2019).

Having the overview of current regulations and the gradual rise of attention given to CO2 regulation, in particular to the port site, it is important to investigate how the port area is organized and what are the changing patterns towards in-port pollution reduction.

2.2.3 Energy transition in ports

Having the regulation shifts on energy transition, the main criteria for designing terminal space and handling equipment have always been operational costs and performance. Besides that, the other considerations included flexibility i.e. ability of equipment for minor adjustments and modifications, and eco-friendliness – to upgrade machinery so it produces GHG emissions as less as possible. Additionally, criteria included the capability of handling machinery to recover in short time periods – being better protected and monitored from unexpected breakdowns, and easier to maintain (Kim et al, 2012).

The trend toward lower emissions standards is closely intertwined with the concept of the energy transition, ports' energy management and related costs. Within the context of the maritime industry, energy transition is abstracted *as a pathway toward the transformation of the global energy sector from fossil-based to zero-carbon with the goal to reduce energy-related CO2 emissions and limit climate change* (International Renewable Energy Agency, 2021). Timely management of energy usage can result in a considerable reduction in port overheads (Iris and Lam, 2019).

Speaking of modern container terminals, literature typically splits the port area into five stages: *the berth*, *quay*, *transport*, *storage yard*, and *port gates* (Carlo et al, 2014; Iris and Lam, 2019). The berth and quay are the parts of the port's *seaside*, storage yard and gates are parts of the *landside*, while *transportation* (*yard moves*) is the connector between the two.

Only 2.6% of global emissions are regarded to the maritime industry and vessel movements. As for maritime ports, only 26% of emissions are related to terminal operations, while the rest comes from the vessel and follow-up freight forwarding (Merk, 2014; Hirvonen et al, 2017). From an energy consumption perspective, however, the picture is different. Several studies (Michele and Gordon, 2015; Iris and Lam, 2019) revealed that fuel is mainly consumed by quay cranes (up to 70% of all consumption) and vehicles within the yard (30%). As for electricity, reefer containers (43%) and quay cranes (37%) consume most of the port's electric energy, leaving the rest 20% to administrative buildings and yard equipment (Greencranes, 2012; Iris and Lam, 2019). The rates of consumption always fluctuate and usually depend on the type of operation with the cargo (import, export, reefer), cargo volumes and vessel scheduling, time of the year, and weather conditions (Gordon, 2016; Iris and Lam, 2019).

According to literature, the main improvements in ports emerge within the following: electrification and automation of equipment; reduction of time spent on cargo operations (ship handling time, transporting between port areas); yard design layout to achieve efficient container stacking; optimization with containers reshuffling; selection and routing of cargo handling equipment to minimize idle time; flexibility in managing storage space (Carlo et al, 2014). Reducing the average time spent in a port potentially allows for reducing sailing speed at sea, where energy savings are estimated as up to 25.4% (Iris and Lam, 2019).

CHAPTER 3. CONTRIBUTIONS

The contributions of the thesis are organized into three parts. The first part is dedicated to the outline of blockchain applications for the maritime industry and ports as well as their definition and analysis. In the second part, the scale is narrowed down to the port area, investigating previous attempts of port digitalization and current cargo handling innovations, seeking to find interconnections and possibilities for blockchain to work in conjunction with the recent port developments. In the third part, we study practical explications of blockchain technology with an emphasis on port organizational structure in Denmark and strategic development of the largest Danish ports.

The current chapter has the following structure. Each article is presented in turn, briefly revealing the motivation and purpose of the study, content, methodology, and results. The structure seeks to introduce the dissertation's content and emphasize the main findings, so a reader has a grasp of the thesis flow. For more detail, readers can navigate to the full articles that are attached at the end of the thesis.

3.1 Revealing scenarios of blockchain usage

The first part introduces the overview of conceptual scenarios of using blockchain in maritime sector, based on literature findings and an organized hackathon for students. With the scattered nature of existing applications and commercial projects, the part aims to build a conceptual framework for better understanding the industry's technology development directions.

Paper A. Blockchain-based applications in shipping and port management: a literature review towards defining key conceptual frameworks

Tsiulin, S., Reinau, K. H., Hilmola, O. P., Goryaev, N. & Mostafa, A., (2020) Review of International Business and Strategy. 30, 2, p. 201-222, 2020

Motivation. By the end of 2019, there is an extensive range of blockchain applications within many disciplines and fields, including the supply chain and maritime industry. However, academic literature is overly presented with general topics (healthcare, e-voting, identity management) and lacks reviews that reveal the state-of-the-art applications in specific areas, for example, supply chain and maritime industry. Nevertheless, the industry majors e.g. Maersk, Amazon, and Alibaba continue the support their blockchain-related projects, while the technology itself was claimed as part of Industry 4.0.

Considering the early stages of technology development, lack of implementation within the area and emerging interest from academia, it is important to investigate the trends of development of blockchain technology for the supply chain and maritime industry. Also, it brings the following questions: what are the similarities across projects, and if they could be combined by conceptual proposals? Moreover, how do found concepts relate or intersect with each other?

Thus, the purpose of the paper is to define and categorize main blockchain concepts across a variety of applications in the supply chain and maritime industry, as well as to find interrelations between them. By setting such purpose, the study aims to answer the first research sub-question.

Content. We focus on an overview of academic literature and already existing blockchain-enabling applications (grey literature). For an overview, the conceptual framework is used to define the relationships between found concepts (i.e. an approach to systemize knowledge about a particular business approach, Burkhart et al, 2011) in conditions when existing theories are not applicable or do not exist (Adom et al, 2018). The conceptual framework is chosen also due to the low maturity of the technology, and lack of both implementation experience and quantitative data (Tsiulin et al, 2020a).

The overview was carried out during 2019 with a couple of subsequent updates, selecting applications from both academia and grey literature (white papers, reports and application descriptions) according to predefined search and inclusion criteria. The detailed selection process, as well as analysis of findings is described in the full paper. The final review consisted of 23 projects and 33 academic publications in the period between 2015 and April 2019 (Tsiulin et al, 2020a).

Main results. The majority of blockchain projects for the supply chain and maritime industry emphasize provenance tracking, seeking to establish end-to-end monitoring over cargo. That is, tracking starting from the place of origin (e.g., manufacturer) to the destination. By doing so, according to found applications, it can gain credibility from the final customer, and provide better transparency throughout transportation and the status of the cargo (damage, delays, document-related disputes, etc).

Moreover, it was possible to distinguish and combine projects into three conceptual categories: 1) Document workflow management, 2) Financial processes, and 3) Device connectivity. A considerable share of projects could be compiled into more than just one conceptual area, lying at the overlap between the two concepts. However, none of the projects, by their proposal, combine all the areas at once (Figure 10).

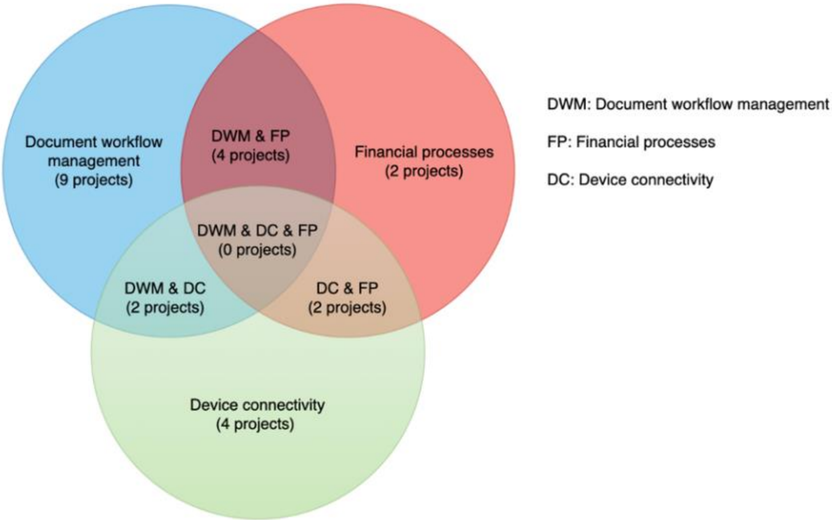

Figure 10. Distribution of projects across the conceptual frameworks (Tsiulin et al, 2020a)

As for the concepts, the proposals are the following.

Document workflow management implies shifting shipping document correspondence to a distributed blockchain platform, to which all necessary supply chain parties are connected. Thus, documentation could be shared digitally, and be executed by approving the documents online, hence having full trackability of the process. Blockchain's internal algorithms help to redirect documentation to the next parties once the approval is received. This can minimize delays, unify transportation around digital format, and increase cooperation along the supply chains.

Device connectivity is similar to the scenario with *document workflow*, yet emphasizes tracking of a cargo unit e.g., a container. By embedding IoT sensors (damage, temperature, location, etc) to a container, the status of a particular cargo could be monitored throughout the transportation and shared across actors of the distributed database. Therefore, passing each stage along the route is considered "a checkpoint" – with complete information available, which can be useful in terms of value-added services, disputes resolution, etc.

For the two scenarios above, the roles of supply chain parties are meant to spread across four categories: *registrars* who identify and access supply chain parties as blockchain nodes; *standards organizations*, who define consensus parameters for data to be stored; *certifiers* who approve actors to participate in the blockchain, and *actors* i.e. participants of the transportation such as manufacturer, retailers, freight forwarders, etc (Steiner and Baker, 2015; Saberi et al, 2018).

The last scenario, *Financial Processes*, digitalizes the coordination of payment (Letter of Credit) between cargo sender and receiver as well as between sender's bank and receiver's bank. To put simply, *both banks act as intermediaries to collect payment from the buyer in exchange for the transfer of documents (Letter of Credit) that enable the holder to take possession of the goods* (Hinkelman, 2015, p 312). Blockchain, in this case, speeds up the transaction between buyer and sender by connecting the information exchange between both banks, i.e. creating a community. A big part of such projects, however, base their payments on cryptocurrency which is doubtful due to strict regulation across countries (Figure 11).

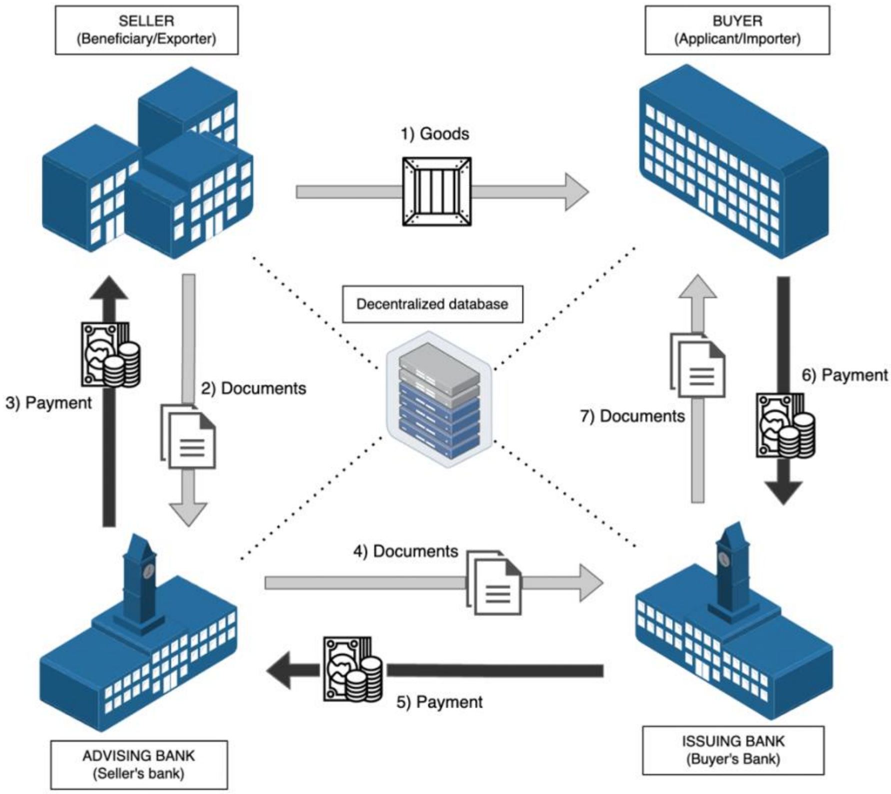

Figure 11. The workflow of Letter of Credit and blockchain as communication tool (modified from Hinkelman, 2015)

Overall, the paper provided an insight into the variety of technology scenarios for the industry, as well as uncovering that projects are specific-oriented, which can lead to implementation problems due to insufficient elaboration, use of alternative currencies, etc.

Paper B. Blockchain for trailer pick-up error in maritime ports. Using hackathon to prototype potential solutions: the case study

Tsiulin, S. & Reinau, K. H., (2022) (ICICT 2022, Proceedings of Seventh International Congress on Information and Communication Technology)

Motivation. Previously, the conceptual framework was defined for blockchain applications in sea shipping and supply chains, with three main development directions has been revealed. For the next research, the focus was narrowed down to the port local level – whether blockchain could be of use within the port area exclusively. For example, for terminal cargo operations, cargo security, or port gate monitoring.

The case for the study is brought from one of the local ports in Denmark in relation to cargo security. The port had previously experienced problems with trailers taken by mistake i.e. pick-up errors. When a driver comes to the port, at the gates the driver claims to take a particular cargo unit. For instance, a trailer. However, at the port yard, the driver eventually takes another trailer rather than the intended one. This way, the terminal operator fails to identify the number of the taken trailers and hence provides a cross-check of driver/cargo. That causes problems with monitoring the empty slots at the trailer yard and creates additional confusion for the terminal operator due to losing a track of free/occupied yard space.

Having the lack of literature on the topic with the emphasis on blockchain for port security, the purpose of the study is to prototype possible solutions for trailer pick-up error using a hackathon event. The *hackathon* as a term refers to a marathon and hacking simultaneously – meaning an event where teams, within a short period of time, compete to develop and prototype a solution to the problem. Gaining popularity since the 2010s, hackathons became a popular instrument for early-stage software development, prototyping, testing and bringing new solutions to the industry (Raatikainen et al, 2013). Thus, the goal was to analyze how the teams at the hackathon, throughout the event, will solve the provided study case with pick-up errors using blockchain. Therefore, the paper continues on revealing scenarios of potential blockchain usage, answering the first research question (Tsiulin and Reinau, 2021).

Content. The hackathon was organized in accordance with four challenges, one of which fully relates to the maritime sector, namely pick-up error in a maritime port. Out of 32 teams total (or 137 participants), 8 were assigned to the current case study. Each team had four to five people on average. The event was split into two days, having an introduction to the study case, status updates, feedback from challenge supervisors, workshops, etc (Figure 12). Students generally had mixed knowledge of blockchain development as well as on maritime industry, ranging from beginners to the topic to experienced developers, working with Hyperledger Fabric, Solidity and other related platforms. Details on the method are provided in the full article at the end of the thesis.

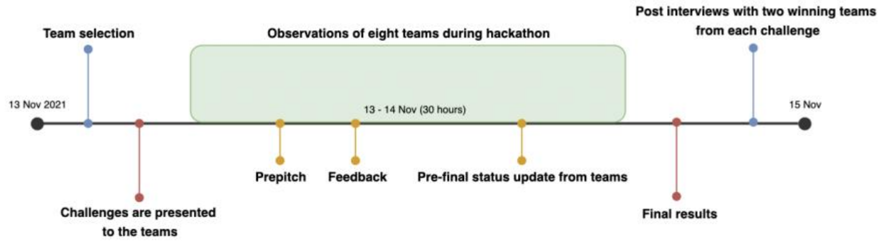

Figure 12. Workflow of the hackathon event (Tsiulin and Reinau, 2022)

Main results. Most of the teams proposed a scenario where monitoring over cargo security is meant to be provided with greater control over the port gates. The solution implies a digital community based on distributed database, to which terminal operator and freight forwarder are connected. For each cargo pick-up, a driver is assigned with a cargo unit, generating a QR code for entrance and way out. However, still it had not secured the terminal from drivers taking a wrong trailer. Therefore, according to the prototypes, the proposed decentralized solution needed a combination with a hardware. For example, RFID chips, as radio-frequency signal indicators, could potentially minimize any manual input and eliminate human factor when providing a cross-check of driver and the cargo upon terminal exit.

Having the prototypes presented by teams at the hackathon, the study provided an opportunity to consider blockchain technology as a pilot solution for port local challenges with pick-up error. Hence, the study has broadened the range of possible scenarios for the use of decentralized technology in the industry, adding a new concept to the framework developed in Paper A (further explained in the Discussion chapter).

3.2 Understanding port area and previous port community developments

The second part introduces a port community and an overview of developments within a port area. Namely, Paper C reveals an overview of the previous attempts of shifting port communication to digital space. Also, Paper D investigates the developments regarding energy efficiency at ports and how cargo handling can be optimized in terms of costs and emission reduction. That is done to map the overall progression of the terminal as a transport cluster. This overview serves to indicate whether innovations are happening on a digital level, or cargo equipment is undergoing changes as well. In that case, the study will shed light on interconnections and possibilities for blockchain to work in conjunction with the recent port developments.

Paper C. Conceptual comparison of Port Community System and blockchain scenario for maritime document handling

Tsiulin, S., Reinau, K. H. & Goryaev, N., (2020) 2020 Global Smart Industry Conference (GloSIC). IEEE, p. 66-71 6 p.

Motivation. Having an overview of the main conceptual developments of blockchain for maritime industry, it holds an interest to study the background – namely, what were the previous attempts to digitalize communication between maritime actors, but on the scale of a port. That is, the concept of Port Community System (PCS) that existed prior introduction of blockchain. Following the similar goal, PCS intended to transform the workflow towards intelligent exchange of information between port actors and supply chain parties (freight forwarders, carriers, etc, Figure 13). The concept is important being the first attempt to shift port communication to a digital platform, with unification of workflow, inclusion of port parties and frequently customs, with functionality extending to advanced navigation etc.

Figure 13. Port Community System (Notteboom et al, 2022)

Thus, the purpose of the paper is to study and compare the previously found blockchain concept "Document workflow management" from Paper A and the concept of Port Community System. The focus is kept on an understanding of similarities and differences between the two concepts. Thus, by researching on the background and previous developments, the paper aims to answer the second research question.

Content. Certain existing studies pointed on similarities between the applications for maritime industry and PCS, yet the two concepts have not been covered or compared side-by-side. The conceptual comparison method is used for the current study. That is the method for defining interrelations between the selected concepts, collecting the knowledge and mapping the findings. The comparison is done along the four dimensions: context, users, content and validation. Each dimension implies a set of questions for mapping the concept, e.g. “What is the specific goal of the approach?”, “What aspects does the approach cover?”, “What are the benefits/stakeholders?” and “What are the architectural viewpoints and constraints of the selected approached?”. More detail on the methodology and the findings could be found in the full article.

Main results. The comparison confirmed a close similarity of the two concepts. Both PCS and blockchain for document handling tend to solve similar problems (digitalization, speeding up the document flow) while involving identical port actors (port authority, terminal operator, freight forwarder, customs, etc). In general, both concepts aim to interconnect and engage various port organizations into cooperation for joint benefits.

The difference lies in network coverage. While blockchain applications intend to create an end-to-end solution, also embedding cargo senders and carriers, PCS commonly focuses entirely on organizations based in a port. Another significant difference is the degree of data ownership. PCS is established as a centralized system that aggregates data as a single unique intermediary which could potentially lead to data security risks. Moreover, PCS lack standardization as they are made and adopted according to individual port projects (Port of Valencia, Port of Singapore, etc).

Blockchain technology, on the other hand, acts as a decentralized platform with distributed data management. Also, due to encryption mechanisms, sensitive and corporate data are more secured as the data of a particular transaction can only be read by the sender and the recipient who possess the encryption keys. Another competitive advantage of blockchain is being an open-source tool for further possible network upgrades.

Generally, PCS implementation varies greatly, both in the degree of network coverage, tasks of the system and user software interfaces. To put it simply, there was no unified PCS software solution across countries, and each port, if wanted to, tended to develop its own. Consequently, the systems differed in the success of their implementation. Certain PCS systems still work successfully while others, due to the large network of planned participants faced challenges not being able to unite all into a single electronic system. The complexity lies in processing transactions across members from different locations, which led to redundancy and inaccurate data.

Moreover, the success of PCS was limited due to data security concerns and organizational issues. PCS is, by nature, meant to be a centralized data authority and hence process data from different stakeholders who as well could be competitors to each other. In this case, certain pilots for the community system failed because of the unwillingness of parties to share corporate data. Another issue was, despite overall the attractiveness of the PCS concept, to adjust toward new workflow, changing internal correspondence standards, etc, which is a common issue when implementing IT software across different enterprises and institutions.

Overall, the PCS served as one of the attempts to transform the current state of port communication, seeking to improve forecasting of demand and hence build better relationships with partners with the inclusion of inland terminals. It demonstrated the obstacles and challenges to port efficiency, and that further development of smart technologies can solve barriers faced by the industry, also contributing to the environmental agenda.

Paper D. How to reduce emissions in maritime ports? An overview of cargo handling innovations and port services

Tsiulin, S. & Reinau, K. H., (2022) (IntelliSys 2022, volume 542 of the Lecture Notes in Networks and Systems series, pp 308-325)

Motivation. As modern technologies tend to automate current business processes across various industries and projected to maritime industry as well e.g. decentralization or various types of port community systems – it becomes of interest to study the terminal area itself. Namely, to understand whether the widely discussed innovative technologies fit within the current terminal area development. And, since the terminal area regards to operations with cargo, the emphasis is on cargo handling equipment.

The situation is gradually changing in maritime terminals, and along with state and EU regulation, is moving towards energy efficiency and transition to ecological-friendly types of energy. Technologies, accordingly, can redefine the way how terminals generate, store, consume and transmit energy. Energy transition could also be achieved by improving and optimizing the current port operations not directly regarded to cargo handling: correspondence, communication between port parties, security monitoring, etc.

This way, the purpose of the study is to reveal the range of various technologies and innovations that contribute to emission reduction in port terminals, including port administrative area. Such study could provide a better understanding of the status of port cargo handling equipment and innovations in the port. The study shades light if such technological upgrades can be automated and if blockchain can also be considered as a contribution to emission reduction. Thus, the paper aims to answer the third and fourth research questions.

Content. The study considers maritime port terminal area and port administration. For better clarity, the terminal is split into five areas that are commonly associated with cargo operations: *berth*, *quay*, *yard moves*, *storage yard* and *gates*. Port administration represents a landlord and a decision-making actor (port authority) that is important in terms of overall infrastructure development, long-term investments and hence has a direct influence on cargo handling capacities as well.

The critical review method was used (Grant and Booth, 2009) as it helps to introduce a new perspective on the port development and practical use of undergoing upgrades to cargo handling equipment. The study focuses on equipment that deals with cargo unloading/loading and transporting, optimization of terminal space and workflow, usage of digital technologies etc., contributing to the reduction of harmful environmental emissions levels in the port area. The literature search included academic and grey literature as well as commercial solutions provided by industry majors. More information on methodology could be found in the full article in the attachments.

Besides that, the paper serves as an in-depth introduction to the agenda of emission regulation, i.e., a retrospective of how regulation has intensified over time in regard to climate change and specifically to the maritime industry and maritime ports.

Main results. The paper provides an extensive overview of cargo handling equipment across the port areas (Figure 14). For berth area, the main contributions to emission reduction are automation of *mooring operations* and provision of energy supply to served vessels through *cold ironing*, when a vessel is fully able to switch to port energy from vessels' auxiliary engines.

For quayside and yard moves, the main means of improving air quality is through an upgrade of fuel engines to hybrid or electric. This way, *ship-to-shore cranes*, *yard cranes*, *straddle and shuttle carriers*, *terminal tractors* and *reach stackers* could, when electrified, be also automated and work in conjunction. Thus, routing within the yard can be optimized and hence costs on manpower, human factor, etc.

For the storage yard, the main improvements lay within the optimization of yard space and rearranging the *container stacking*, choosing between several layouts depending on the yard cranes and available spacing. According to certain layouts, it allows to significantly minimize the number of unnecessary moves by terminal tractors and reach stackers, saving costs for the port and hence reducing environmental impact. Another innovation namely *container reshuffling*, allows, with a certain probability, depending on the level of connectivity with Terminal Operator System (TOS) to predict the duration of the container staying at the yard – and reposition it in the container stack according to the duration of stay. This way it can minimize the number of reshufflings – restacking of containers in order to reach the intended one.

For port gates, the main optimization is implied by the *track appointment systems* and *gate monitoring* to minimize queuing of trucks in front of the port entrance. Moreover, such means allow to extend ports' value-added services, provide security over cargo units and have better monitoring over upcoming drivers.

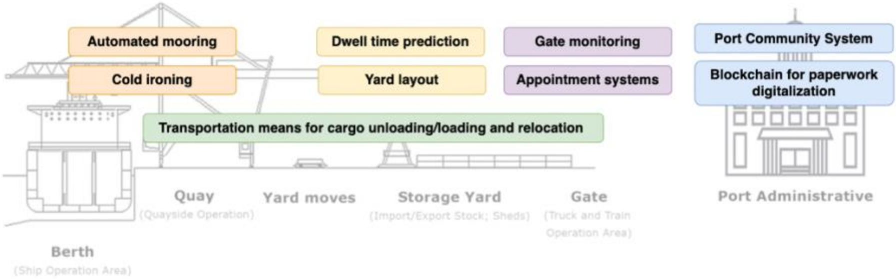

Figure 14. Summary of port innovations (Tsiulin and Reinau, 2022b)

For port administrative, the innovations are mainly represented by creating a community of port actors and establishing a digital network. The examples are *Port Community System* and ongoing *blockchain applications* for maritime industry that enhance correspondence and information exchange, which indirectly could have an influence on port's decision-making process and infrastructure strategic development.

The results show that found innovation upgrades are scattered yet forecast positive trend for the port industry. Also, the range of cargo handling innovations highly contributes to Port 4.0 – the concept of a digitalized port with partial or fully automated cargo operations.

3.3 Challenges of blockchain adoption

The third part uncovers the practical explications of blockchain technology with an emphasis on port organizational structure in Denmark, and strategic development of the largest Danish ports. The goal is to find out how development strategies and state-of-an-art of cargo ports in Denmark can correlate with the proposal from blockchain projects and scenarios found earlier. Moreover, with Paper F the study concludes on challenges that prevent blockchain from implementation in the industry, combining previous findings with literature.

Paper E. The role of port authority in new blockchain scenarios for maritime port management: the case of Denmark

Tsiulin, S. & Reinau, K. H., (2021) Transportation Research Procedia. Proceedings of 23rd EURO Working Group on Transportation Meeting, EWGT 2020; Transportation Research Procedia. 52, p. 388-395 8 p.

Motivation. After defining the core scenarios of blockchain applications in maritime industry and understanding the relations with previous developments, including the terminal area, the goal was to have a closer look at the practical explication of the found blockchain scenarios. That is, what is the likelihood of the found scenarios being implemented, and how digitalization aligns with the port development agenda, particularly in Denmark. That is, to have previous research findings as a basis to identify Danish ports' strategic development and whether digitalization, data collection and management could be seen as a possibility for future ports investments. Moreover, one of the goals was to find out to what extent port authorities and terminal operators cooperate with each other across selected ports. That is, if they have data collection and exchange similarly to Port Community System, and if not, what are the practical challenges.

Also, the paper could be of great interest as a case study. The largest seaports in Denmark, when comparing them to a global or EU scale, are considered as small ports. Thus, the results could be represented as an example of long-term development priorities, challenges and feasibility of blockchain technology regarding small-size ports. Thus, the paper addresses both the third and fourth research questions.

Content. The study uses semi-structured interviews with representatives of the six largest maritime ports in Denmark: Aarhus, Copenhagen-Malmö, Esbjerg, Aalborg, Fredericia and Hirtshals. Ports vary by location, size, operational volumes and type of operated cargo. The interviews have been conducted separately with respondents in positions of chief executive officer, chief of the terminal, general manager and chief operating officer. The discussion was structured around the current state of the maritime industry in Denmark, long-term development strategies, practical challenges and blockchain scenarios for the maritime industry found in the previous studies. The results are validated through the second round of interviews which, however, do not completely exclude biases since the decision-makers might not be willing to criticize their own organization. Thereafter, the method of Meaning Condensation was used to analyze the statements and assigned them according to the topic (Kvale and Brinkmann, 2015; Tsiulin and Reinau, 2021). For the full explanation of the used method, the reader can navigate to the full article in the attachments of the current thesis.

Main results. When discussing long-term development strategies among the selected ports, port authorities prioritize land expansion. That is, infrastructural upgrades mainly towards containership and bulk cargo, and connectivity for land distribution via rail or road transport. According to respondents, it can provide better coverage with further distribution, including the last mile, and thus bring a possibility for value-added services for the port. Improving multimodality is has been mentioned as the top priority.

Digitalization of the port terminal is in hands of terminal operator, yet with "*relatively small container volumes, the importance of implementing such IT systems proportionally decreases*". Moreover, since the port authority could not be directly involved in terminal operations due to EU competition law, it creates uncertainty on further port development. Port authorities generally welcome a more flexible exchange of data collection and cargo origins as it directly influences decision-making and infrastructure development. However, at the time of the interview there is no specific software solution capable of providing information on general cargo flows without revealing corporate and critical client data as well as not violating the state law.

Digitalization at port authority level is considered low while it considerably varies for terminal operators. For port authorities, the opportunity of working with data is seen from strategic perspective – to get closer contact with terminal operator as an advisor and better predict and fulfill the demand. In this case, existing software applications show potential, including blockchain projects, yet port authorities have a low level of understanding of its work on the fundamental level (also due to low maturity of such projects).

Another challenge for blockchain projects is incorporating different port actors in one network. According to respondents, it is unclear how customs, despite a will to join the system, are likely not to contribute to database transaction processing (i.e., read-only). Another barrier to the adoption of large blockchain projects is seen from industry majors aiming to build end-to-end software i.e., turnkey solutions. Port authorities are concerned if such end-to-end solutions are likely to exclude certain participants from the network and be replaced with the company's own services, which could limit the value-added services provided by the ports.

Paper F. The key challenges of blockchain implementation in maritime sector: summary from literature and previous research findings

Tsiulin, S., Reinau, K. H., Hilmola O.P. (2022) (Article was submitted to ISM – International Conference on Industry 4.0 and Smart Manufacturing)

Motivation. The previous research findings have established the main conceptual scenarios of blockchain usage for the maritime industry, also the concepts of using the technology specifically within seaports. Moreover, the connection to previous developments of port digitalization have been found along with the interviews, conducted with Denmark's largest ports to reveal practical challenges that could prevent port network from implementing digital solutions and decentralized databases in particular.

Understanding the context around blockchain technology that is still considered immature, the goal is to reveal what are the other challenges that prevent the maritime industry from implementing the found applications. That is, summarizing barriers from previous research as well as combining them with academic and grey literature sources. Therefore, it is possible to build an understanding of the complexity of blockchain adoption and to what extent the scenarios are feasible within a particular industry – sea shipping and port management. Thus, the paper addresses the fourth research question.

Content. The main goal of the study is to identify the challenges of blockchain adoption in the maritime sector, so it can be used by the academic community and industrial practitioners for further experiments and practice.

The study follows the ‘multivocal literature review’ method as it combines academic sources and grey literature, e.g., white papers, public reports, web sources and publications in field-related sources. Instead, the current approach is more subjective and is built on earlier experiences in the field (e.g. academic projects, interview studies, theses and field visits) which are used for literature selection, including new knowledge added from the secondary sources. Subsequently, the results are categorized into four categories: operational, organizational, technological and human factor.

Main results. The results showed an extensive number of barriers towards blockchain implementation mainly from organizational, operational and technological sides. Organizational challenges are largely represented by divergent port development strategies, where digital solutions are not prioritized over infrastructural upgrades. Significant obstacles are represented by the complexity of integrating port parties into one network e.g., the inclusion of customs, cargo senders, port of origin, port of destination, etc. Moreover, the level of trust between the port authority and the port operator is considered sufficient.

Another difficulty lies within embedding and integrating new software solutions into already working IT systems, which is likely faced with the unwillingness of company employees toward changes in business routines. Also, the costs and benefits of decentralization are unclear – due to the back-end nature of blockchain integration.

A great number of challenges are also found on the technological side. Most of the large blockchain developments that got covered in media during 2017-2019 are still in development by the middle of 2022. Moreover, the consensus mechanism i.e. an algorithm to confirm the saving of data remains unclear upon the different scale (e.g. within port, within mid- and last mile, etc). This process is particularly complicated in case of projects that imply provenance i.e. tracking transportation across a wide supply chain network.

Besides, it is uncertain how to optimize the mandatory nature of blockchain decentralization – the mechanism that involves every party as node of the system. According to previous research and literature, not all parties of the business network are willing to run and maintain their own servers, especially within a lack of IT-related manpower in the company. Also, government regulation is doubtful towards certain projects as they apply to multiple numbers of countries, thus the application should comply with regulation in each involved country. For example, to comply with EU port competition law, handling of personal data (GDPR) or a procedure of alternative currency treatment.

The short summary of all reviewed challenges is listed below in Table 2.

Category	*Challenge*	*Short Description*
Organizational	Ports prioritize land expansion	Among strategic development, most cargo maritime ports in the EU and Denmark prioritize territorial expansion mainly for bulk and containerized cargo, while investments into digital solutions are not considered as IT infrastructure is not ready.
	Customs, landside integration and final customer	Difficulty of incorporating parties along the supply chain, especially local authorities, customs, hinterland transportation, etc.
	Concern of one-party ownership	Despite the distributed nature of solutions like blockchain, port authorities and terminals are generally afraid of the company that integrates decentralization and is further becoming “the developer, the maintainer and the implementer” of system, being able to exclude, on the long run, certain unwanted participants from the system to replace them with company’s own services.
	Legal uncertainty	Uncertain how to regulate data participants (nodes) across different countries and comply with General Data Protection Regulation (GDPR) as well as maritime sector regulation. For instance, port competition law.
Operational	Ports have low level of digitalization	Maritime ports, as well as parties along hinterland and last mile, significantly range by level of digitalization and the used IT software. Therefore, it affects the level, to which staff members are skilled with the software as well as capable of working with the integrated products.
	If blockchain is about tracking, then the industry is already doing that	A big share of blockchain projects announced in 2017-2018 implied precision in cargo tracking possibility, yet the tracking range was different across the projects and often unclear. At the same time, there are software solutions that provide tracking without the need of decentralization. Moreover, decentralization potentially puts corporate data at risk of leakage, fraud and storing of misinformation from the involved parties.
	Unclear costs/benefits	As blockchain is a not a standalone solution, but rather an integrated part (like database such as Oracle or SQL), it is difficult to quantify the costs and benefits of the technological setup. Also, it is hard to track the numerical impact of blockchain in regard to the whole company’s software system.
	Conceptual similarity to Port Community System	On the conceptual level, certain blockchain solutions show high similarity to Port Community System – a concept of digitalizing communication between port parties. Potentially, both concepts can supplement each other organizationally and technologically for creation of the product that suits the environment and the network.
Human factor	Dependency on manual input	Maritime sector is still highly dependent on manual input, regularly done by e-mail, telephone, fax, or with ERP. Blockchain, on the other hand, could not act as a full substitute to existing data input approaches, which makes it hard to align all participants to an equal technological level.

	Reluctance to change business processes	When applying a new software to a network with multiple stakeholders, the integration could be faced with a number of expertise, time, support and human factor-related barriers. Generally, integration is slowed by unwillingness of parties to adapt to new workflow, including its personnel. That is also burdened by blockchain's distributive nature of establishing data connectivity – as an open-source database, it can require to educate staff to operate the system.
	The level of trust is sufficient	Blockchain commonly refers to the issue with lack of trust between actors, but, if blockchain is projected to the scale of a maritime port, the level of trust is sufficient between port authority and terminal operator. Moreover, the roles of these actors are different, where port authority is willing for better data transparency with terminal operator but is restricted by EU competition law. In this case, distributed systems need to overcome the challenge of sharing information without 1) revealing confidentiality of data, and 2) not violating local regulation.
Technological	Scalability of blockchain-based systems	It remains unclear how to guarantee security of data, visibility and governance upon different scale depending on transportation coverage – i.e. if blockchain is meant to be applied on the scale of a maritime port, first mile, last mile, etc. Another challenge is how to organize data storage for various corporate levels of the same enterprise.
	Distributed systems are confused with limited responsibility	Having the equality of data distribution, it is still unclear how to organize responsibility among the participants in case of breakdowns, data leaks, etc. The lack of central authority creates a confusion how to handle risks as the data is processed by involved parties.
	Participants are likely to not run their own servers	Decentralization of data could not be a convenient solution for certain enterprises that do not possess the high digitalization of data. Considering database members as nodes, certain participants can reject to constantly maintain their individual server in parallel with organization's main business.
	Distributed systems are attached to centralized platforms	There is a practice when blockchain platforms that are meant to incorporate multiple and diverse range of users, enlarge throughout the time, and recede its decentralization to the background, which turns the service into a centralized platform, moving it away from the original concept.
	Big part of applications is attached to cryptocurrency	After several years of technology progression, tokens appeared no longer to be the necessity for system to operate and process transactions. Despite that, a significant part of applications do implement systems with alternative currencies in order to monetize their projects, which eventually complicates the adoption and aligning the business model with existing state regulations.

Table 2 – Summary of challenges from Paper F

CHAPTER 4. DISCUSSION

4.1 Blockchain potential expands in maritime sector

One purpose of this PhD project was to investigate the potential scenarios of blockchain usage within maritime industry and supply chains. As such, a part of this PhD project was focused on literature analysis to define whether found blockchain applications could be systematically grouped and analyzed according to their proposals. Upon results, Paper A revealed three conceptual scenarios namely Document Workflow Management, Device Connectivity and Financial Processes.

Despite the differences in objectives, proposals and problems the scenarios intend to solve, all three commonly tend to cover the entire supply chain. Specifically, the scenarios bring together the cargo sender and receiver as well as their banks (Financial Processes scenario) or the parties related to the exchange, verification and validation of the supply chain documentation accompanying the cargo (Document Workflow Management and Device Connectivity scenarios). Thus, a seaport within such complex workflow represents just an intermediate spot throughout the delivery towards middle and last-mile transportation.

The idea of decentralization used specifically within a seaport was embodied in Paper B. At the hackathon, eight teams were given a task to develop a pilot solution for greater control over the port yard trailer pick-up and going through the port gates, as well as monitoring of drivers and cargo pick up. Among the solutions, the most common was usage of blockchain as a communication tool between the terminal operator, port authority and freight forwarders. By working in conjunction with RFID chips, the monitoring over the taken trailers is allowed across terminal area, also determining whether a freight forwarder had picked up the declared trailer. For further research, a good prospect is to validate such scenario through rounds of interviews with ports actors, as well as calculating the costs of RFID chip installation.

Thus, the scenario from Paper B can be added to the conceptual framework developed in Paper A. Moreover, since the scenario found in Paper B involves a combination of a hardware solution and software solution, it conceptually suits the scenario of Device Connectivity. The overall framework, based on two papers, could be modified as seen in Figure 15.

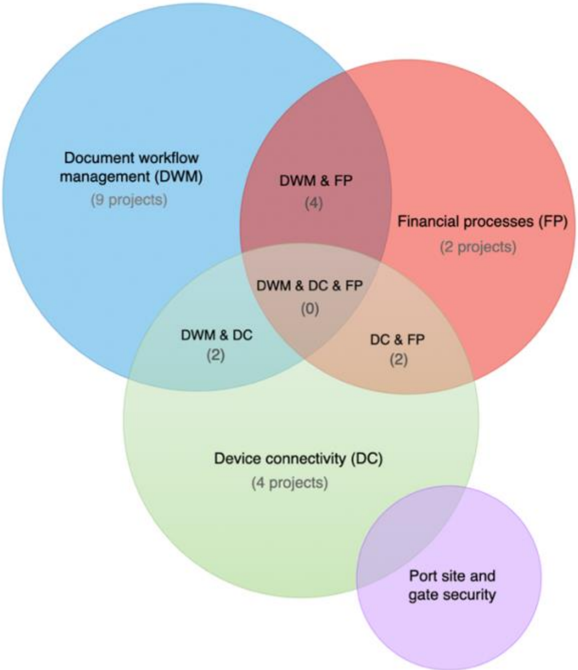

Figure 15. Updated conceptual framework of blockchain applications in maritime industry based on Paper A and Paper B

4.2 Development of Danish ports contributes to growth of port clusters

In Paper E, throughout the rounds of interviews with port authorities of the largest Danish maritime ports, the long-term development strategy has been discussed as well as port digitalization and their usage and collection of data. Also, the practicalities of implementing blockchain scenarios found in Paper A were part of the interview.

The results from Paper E showed, as well as the results from Paper F, that generally the long-term strategic plans of the interviewed ports diverge from the solutions proposed by blockchain applications revealed in Paper A. The major seaports in Denmark prioritize land expansion, designated for bulk and container operations. The other priority is the extension of port services toward last- and middle-mile delivery. The importance of data collection and digitalization within inner-port operations is low. Moreover, interviewed ports varied not only by the level of digitalized solutions, but also by the software they use, and the extent this software can be synchronized with the rest of the port network (freight forwarders, customs, terminal operators).

When discussing the blockchain scenarios, the interviewed port authorities expressed a concern whether the found scenarios, if being implemented, would anyhow represent an end-to-end solution made by the industry majors. In this case, the concern is to be forced to join such systems without being able to choose between the alternatives. Moreover, the success factor of such systems is questionable due to the complexity of engaging customs to be a part of the distributed systems.

Importantly, all interviewed port authorities expressed plans not only toward expansion of terminal operational capabilities but also toward different stages of the logistics chain: construction of distribution centers within port sites, the establishment of better-designed rail and road connectivity with hinterland and hence the creation of value-added services. This trend clearly correlates with the development of clusters proposed by de Langen (2019).

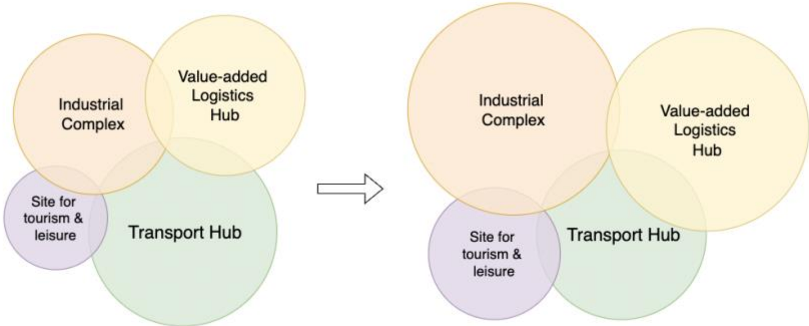

Figure 16. Future development of port clusters (de Langen, 2019, 2017)

As was discussed previously in the Introduction chapter, port clusters are seen as the development of co-existing and interrelated businesses of mainly four categories: transport hub, industrial complex, value-added logistics hub and tourism, with each cluster having its own importance growing over time. According to de Langen (2019), ports in the future are seen as expanded infrastructural assets with greater role within in-land distribution and local production. This implies not only land expansion to cargo operations, but also to industrial facilities: warehousing, landside connectivity and adding value to transportation. Also, due to proximity of some ports to local city areas, certain ports are undergoing of becoming an urban-friendly environment and a place for tourism and related businesses. The results of Paper E, F and A indicate that as well. Therefore, the role of currently dominant, conventional cluster of cargo operations will gradually reduce while the importance of the other clusters will increase accordingly (Figure 16).

Also, the role of port authority, being the landlord of the site, is likely to change as well (Verhoeven, 2010; Zhang and Lam, 2017). Within growing significance of clusters, port authority will possibly become the communication and coordination link between the clusters representatives.

4.3 Combination of blockchain and PCS for future developments

In Paper C, a conceptual comparison was made between the blockchain scenarios found in Paper A and Port Community System (PCS), an organizational system that connects port actors into one single digital network. Also, Paper F revealed the difficulties and challenges found across implementing the concepts of using distributed technology.

The results showed that the found blockchain applications and PCS concept as the whole are strongly overlapping with each other across various parameters. Mainly, the overlap happens in purpose of use and partially in the set of actors meant to be included in the network. The differences lie within the type of storing data (decentralization in blockchain and centralization in PCS) and the breadth of coverage along the supply chain (PCS is formed exclusively within a port). Moreover, both concepts gained academic and media attention at different times. Discussions about PCS took place from the middle of the 2000s and including the late 2010s, while blockchain is a relatively new trend.

Thus, seeing the two technological concepts overlapping by the purpose of use, the concepts can potentially take each other's technical and/or organizational and business developments. The distinctive feature is that PCS was created in the maritime sector, referring to organizational and communication needs, while the technological part of blockchain has been extrapolated to the maritime industry and ports.

At this point, the problem is the lack of unification among existing and adopted PCSs. Most of the study cases have various requirements, capabilities, and breadth of stakeholders' involvement in the network. In other words, each community system has been adapted to suit the local business environment and hence no standardized architecture/software solution has been promoted in the industry.

For the blockchain, respectively, the challenge lies in the implementation stage. The projects announced back in 2017-2019 are still ongoing and 'in development'. This way, the technology is still considered immature for the industry by the middle of 2022.

The attention in academia and media have given to the digitalization of the industry shifted the emergence of technologies seeking to improve supply chain communication and digitalization. This indicates the gradual progression of the industry despite semi-success of recent developments. The widespread publicity of ongoing projects signals the relevance for the solutions in the field, whether it is a blockchain, port community system or a hybrid between the two.

Considering the large number of challenges (Paper F), hindering the adoption of the technology, it is likely to emerge a scenario that will combine previous developments, for example, blockchain for port environment and port community, to address the currently faced issues (Paper F). Hence, the solution could become more digitalized and data-driven (Figure 17).

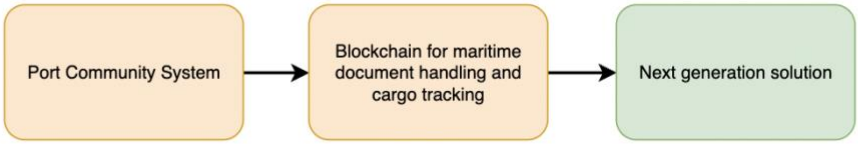

Figure 17. The likely scenario of further development of digital solutions for the maritime and supply chain industry (BLING 6)

What represents an opportunity for future research is the combination of found blockchain scenarios and best practices of PCS that can help with shaping the practically possible solution: architecture, network participants while considering the strengths of both concepts. According to a critical assessment of existing and already implemented PCSs, the success depends on the degree of actor's involvement. For example, according to overview of the lessons learned from Polish port communities (Marek, 2017), the chances of success increase exponentially when a greater role is given to customs. Customs, as well as port authorities, should be better involved as facilitators, contributing to the design and requirements of future system.

According to Marek (2017) and practices of PCS in Poland, the digital community system should work in conjunction with port actors' individual, non-integrated systems, and comprise the following components: origin of documents, logistics transactions, freight risk management, identification of credentials, integration of traffic monitoring and electronic payments. Moreover, the inclusion is necessary for national port association, customs and port authorities to set up the framework jointly with the rest of community participants.

4.4 Port Industry 4.0

Paper A and Paper B detailed scenarios for the use of decentralized technology in the supply chain industry, also scaling it down to a maritime port. Paper C showed that these innovations were driven by the demand to digitize communication between transportation actors. Moreover, the attempts of doing so existed decades before the introduction of blockchain technology.

On the other hand, Paper D revealed that an average port site is undergoing the range innovations which do not prioritize the software development. Instead, ports are actively introducing eco-fuel for cargo handling equipment, and partially replacing fuel engines with hybrid or fully electric ones. The innovations also include automation of mooring operations, saving energy on LED and smart lightning, and container reshuffling. Gradually, this trend could shift to a partial and fully automated transport and cargo handling equipment in the port area. This will allow to reduce the inefficiency of extra movements within the port area, as well as greatly minimize the costs on human resources. Additionally, this is also confirmed by competition on cargo handling market, where companies e.g. Kalmar, Konecranes and ABB offer electrified solutions for quay cranes, forklifts, etc.

Thus, the current situation shows that port development goes in parallel both on the software and hardware levels. Moreover, such improvements correlate with the historical development of ports discussed in academia, where maritime ports were divided into four generations, explained in Chapter 1 (Notteboom et al, 2022; Olesen, 2015; Beresford et al, 2004). Hence, today's concept of partially or fully automated port services and digitalization correlates with the fourth generation of ports (Beresford et al, 2004). Moreover, while the division of ports into generations refers to academic environment, the mass media and experts promote the term "Port 4.0" – the organizational shift from asset operation to service manager. Being the part of Industry 4.0, the new port aims to generate more value from operations, suppliers and SMEs within the site. Finally, the move toward such business model will require rethinking of conventional ways of collaboration. The concept of a Smart Port is centered around the customer and lies within urban sprawl, where the port is one of the integral parts of the local urban environment (Molavi et al, 2019; McKinsey, 2018).

4.5 Blockchain as a technology on the global scale

In this thesis, Paper A presented an overview of distributed applications in supply chains and shipping. The overview covered academic and commercial projects formed in 2017-2018. According to Google Trends (Google Trends, 2022), the interest to blockchain technology peaked at the beginning of 2018 with a gradual decline throughout the next years. However, by the middle of 2022, a significant part of projects selected in 2018 no longer exist. The remaining projects are still in development.

According to the literature, there is a scheme that shows average project viability that can be applied to technology startups (Gartner, 2022). The Gartner cycle is described as a visual representation of the maturity and adoption of various technologies and how they are relevant to solving current problems and opening new business prospects (Gartner, 2022). At the same time, the diagram (Figure 18) represents a benchmark of project success – whether the project got rid of excessive media attention, found its product niche and continues to develop.

Following the cycle, five years after the introduction and gaining attention from media, blockchain have reached the peak of expectations and is now either showing practical results, finding a specialized segment/niche or gradually withdrawing from the market.

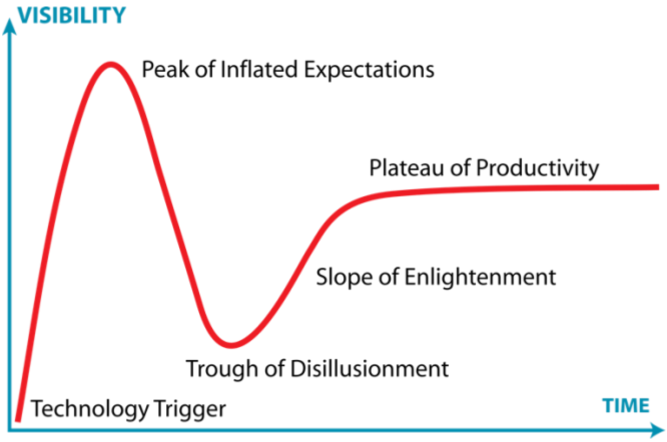

Figure 18. Gartner cycle (Gartner, 2022)

Interestingly, the most media-acclaimed projects from 2017-2018 were supported by major industry companies like Maersk, IBM, Amazon, including ports e.g. Port of Antwerp, Port of Singapore (Tsiulin et al, 2020). Those projects still exist though showing semi-success, being in development up to date. Certain of them, such as T-Mining, Blockshipping or TradeLens, stopped using the word blockchain in their project proposals. Instead, the applications refocused their business offer, using less of decentralization as the basis of their solution (T-Mining, 2022; TradeLens, 2022). Partially, the decision was driven by a number of great organizational and technical complexities regarding the distributed nature of maritime networks. The complexity of implementing such a mechanism is described in detail in Article F.

Considering the above, it appears that the technology, which has been extrapolated to various industries, is currently facing a great challenge to enter the implementation stage in supply chains.

Despite the challenge with product execution, blockchain as a technology can lose its importance already within the next years. This assumption is supported by the theory of electronic transistor development proposed by Gordon Moore in 1965 (Moore’s Law, 2022), which later generalized to the pace of various technological advancements afterward.

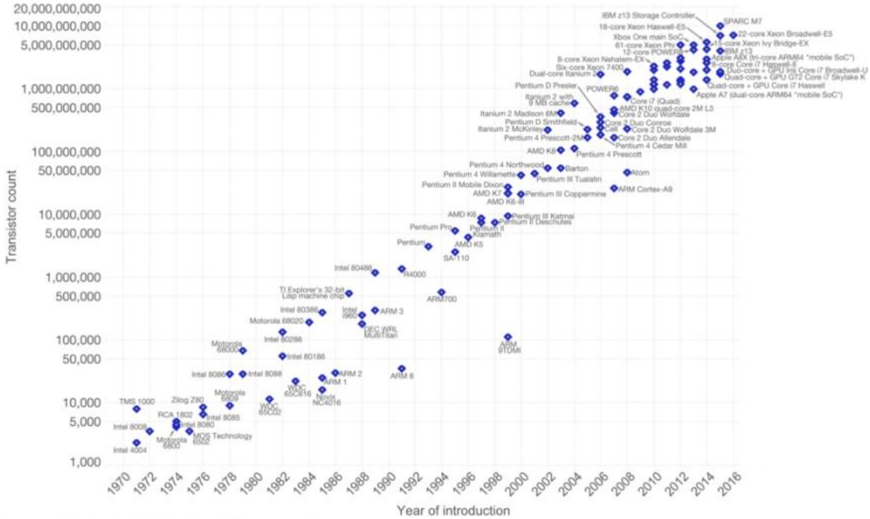

Figure 19. Moore’s law with example of evolution of CPU chips (Moore’s Law, 2022)

According to Moore’ observations, the number of transistors on a microchip doubled approximately every two years since 1970. Even within the increased complexity of semiconductor process, the number of transistors kept growing exponentially during the next decades as seen in Figure 1 (Moore’s Law, 2022). At the same time, in parallel to the technology progression, the costs of such transistors halved accordingly.

Thus, following the theory of transistor progression by Moore, the success or failure of some developments will not matter in mid-term perspective as the industry accelerates on capability of technologies every couple of years. The hypothesis is representative on the development of web services and hardware market. In particular, the rapid transition from Web 1.0 to Web 2.0 (and ongoing Web 3.0), CPU progression, as well as cloud storage capacity, adoption of machine learning, etc.

Similarly, supply chain industry will undergo a series of transformations, using the combination of previous developments such as blockchain or Port Community System.

4.6 Limitations and future research

4.6.1 Low maturity of the technology and its consequences

This study has several limitations. Primarily, the immaturity of decentralize-based solutions and blockchain technology prevents from defining the mapping success cases, as many projects related to maritime sector are still under development. Moreover, the immaturity of the technology complicates possible conduction of a quantitative research. For example, calculation of costs and benefits of decentralized solution. The problem persists also due to blockchain *not* being a stand-alone solution, yet rather an integrated part of the technological setup.

Blockchain, as a decentralized database, does not commonly imply a separate interface, yet works in conjunction with the company's software. In fact, the direct users of blockchain are other software systems from the corporate environment. Final users as individuals do not interact with blockchain directly as they do not with databases such as Oracle or Postgres (SQL). Similarly to other databases, blockchain integrates across other systems while residing within architecture, and is kept for improving the current business processes.

Therefore, due to the back-end nature of the technology and the ongoing status of the majority of the projects, the track of the numerical impact of blockchain is complicated to the entire system. Moreover, blockchains are different in terms of established algorithms, method of work and saving data, and hence vary regarding costs within a particular system and its associated network (Sahebi, 2020).

4.6.2 Studying the overlap of PCS and blockchain

Another set of limitations relates to a clearer disclosure of scenarios and existing concepts, which represents an opportunity for future research.

For example, Paper A in this thesis revealed that the blockchain scenario Document Workflow Management (DWM) is conceptually similar to Port Community System (PCS). As discussed earlier in the Discussion chapter, the two developments (DWM and PCS) have the potential to use each other strengths, where the organizational advantages of PCS and the technical structure of decentralization could form a synergy effect for a new product that specifically targets the maritime sector and its existing challenges.

The subject of taking advantage from overlapping DWM and PCS represents an opportunity for future research. Namely, in-depth research on successful and failed PCS study cases. That should include architecture, mapping of stakeholders, and analysis costs and benefits to provide an understanding of running PCS success criteria. Failure cases also of importance i.e. what primarily are the organizational/networking issues that limited implementation? The analysis of existing practices will allow to define a framework of organizationally possible solution that can be later projected to the distributed nature.

Additionally, after looking at existing practices and defining the stakeholder model, it is of interest to simulate the workflow of information exchange on the example of a single document from the maritime sector e.g. Bill of Lading. How realistically the document can be put and coordinated digitally with distributed network of peers (nodes), taking the lessons learned from PCS and DWM practices.

4.6.3 Other research opportunities

Besides the deepening into practical aspect of implementing community systems at a port, it is of scientific interest to complement the Paper E with further understanding of the relationships between Terminal Operator, Port Authority, Customs and Freight Forwarder – especially in terms data exchange. To understand what data are exchanged between these parties, how to improve the transparency of communication without revealing confidentially of data or violating the EU competition law. In particular, to what extent Customs could be involved into the system and the process of information exchange (and contributing to data creation). The study could take a form of interviews with representatives across selected maritime ports.

Another opportunity for research is the projects that have been analyzed under literature review in Paper A. That is, the numerous commercial projects that were selected for the study and served as a basis for the conceptual framework. As discussed previously in Discussion chapter, a large part of the 2018 reviewed applications have got closed. At the same time, the advanced projects, supported by large industry companies have minimized the usage of the term blockchain across official their applications. Thus, having the lack of implementation results and the repositioning of some projects away from blockchain, it makes sense to conduct an additional status overview for 2022.

CHAPTER 5. CONCLUSIONS

The overall aim of this PhD study was to analyze the feasibility of the blockchain technology in maritime sector, including, in particular, port logistics. The study implies to define the existing trends of technology development regarding maritime and port sector i.e., whether the proposed solutions meet port strategic development priorities, what preceded the technology in the industry and what stops it from actual implementation. To reveal it, along with the main research question, the thesis answers four additional research questions.

The first research question addresses the trends and categories of existing blockchain initiatives regarding maritime sector:

- *How can blockchain technology affect maritime industry and port logistics, and what are the possible scenarios of its implementation?*

To answer this question, a systematic literature review was carried out to build a conceptual framework, and due to the novelty of the technology, both academic sources and gray literature were considered. The work was the first to identify conceptual intersections between existing blockchain applications that map the ongoing trends of application development. The results showed an exponential growth of projects within years 2017-2019, which can be divided into three directions, two of which relate to cargo unit and correspondence tracking, mostly associated with containerized cargo. The third category implies an alternative system of shipment payments. The conceptual framework summarizes the found scenarios.

Moreover, to extend the range of blockchain scenarios, an offline hackathon was organized. Despite the hackathon limitations e.g. short prototyping time, the study indicated that blockchain could be of use locally in a port for better port gate security and yard monitoring. However, there is a necessity for such a decentralized system to work in conjunction with a suitable hardware solution i.e. lock mechanism. Overall, along with the developed framework, the study has broadened the range of possible scenarios for the use of decentralized technology in the industry.

Furthermore, the study indicated that the found projects predominantly focus on linking the supply chain participants into a single information network. The approach implies several barriers, considering risks of disclosure and the confidentiality of processed corporate data. Also among the gaps is the lack of detailed information on the operating scheme and architecture of proposed applications. Nevertheless, the overview pointed on a shift toward digitalization in global logistics and greater interconnectivity through connectivity of devices for better trackability opportunities.

The second research question addresses the previous digitalization concepts:

- *Prior introduction of blockchain, what have been the concept to digitalize port communication or the workflow between port actors?*

To answer this question, the study focused on Port Community System (PCS), known as a concept of a digital platform to unify the workflow among certain port actors. PCS has been introduced years before blockchain, with each system varying depending on the exact port and local environment. The results showed close similarity between PCS and blockchain scenario for document handling, while the difference lied in network coverage and type of data storage. Interestingly, the configuration of certain blockchain projects tend to replicate PCS rather unintentionally, which indicates that both systems can bring larger impact when complementing each other. Unlike PCS, which have been developed within a maritime port network, blockchain has been extrapolated to many industries, including supply chains – thus, increasing the likelihood of technical success cases.

Therefore, the study opens the prospect for further analysis on the topic. Concretely, the comparison between existing models of PCS, as well as their main success and failure criteria. The research gap lays in lack of unification across PCS as the industry knows a variety of systems developed and assembled independently from each other. Hence the potential of the topic within revealing the success criteria and mapping practices for future technological solutions.

The next question addresses possible adoption of found scenarios in Denmark:

- *To what extent do blockchain have practical explication from the perspective of maritime ports in Denmark?*

To answer this question, a qualitative study was conducted with representatives of six major cargo ports in Denmark. Besides the found blockchain scenarios, the survey emphasized the state of port strategic development and digital communication with associated actors e.g. terminal operators and customs. Moreover, an overview of innovations across port cargo handling equipment in relation to energy transition was made — to better understand the development of the port besides digital solutions.

The results showed that strategic development of Danish ports is primarily tied around land expansion and land connectivity i.e. infrastructural updates. The general trend is seen to expand port services with providing more space for bulk, container and trailer cargo, as well as improving multimodality and connectivity with the hinterland. Thus, the development relies on increasing infrastructure capacity, rather than investing in digital solutions. The level of digitalization at the port administration level is considered low but varies for terminal operators. Another problem is the inclusion of various port entities in the network, as well as the regulation of data distribution among such participants.

Moreover, the review of port handling equipment showed that changes are taking place also on the operational side, including cargo equipment. Ports undergoing changes toward energy transition and cost efficiency, as well as gradually embedding electric engines, opening avenues for partial automation of port facilities and their operation in tandem. Consequently, with a high degree of automated and electrified equipment, there is a prospect for future research on establishing a platform to systematize such equipment.

The next question addresses the summary of discovered adoption challenges:

- *What are the challenges of blockchain technology in the industry that prevent the technology from implementation?*

To answer this question, a study was conducted to collect and scale the barriers and challenges already found across the previous studies, also adding challenges that have been discussed in the literature. Thus, it allowed to map an understanding of the complexity regarding blockchain adoption and to what extent the scenarios are feasible within a particular industry – maritime sector and port management. The peculiarity of the method is that the majority of academic literature cover commonly discussed blockchain implementation challenges across industries, rarely delving into the specifics of them. Such studies are important for the field, yet do not provide explanation on practical and business-related problems as they apply to different fields. Therefore, this study explores barriers specifically in relation to supply chains, setting the benchmark for further analysis and qualitative research.

The results showed a considerable number of challenges, preventing decentralized technologies from adoption. Most of them can be attributed either to organizational, operational, technological or human factor category. The biggest challenge is within creation of mutual contribution to the system and the complexity of integrating port parties into a network. The problem points to a wide variation of software used across enterprises and organization, as well as their level of advance, which in turn becomes an integration challenge. This is compounded by local corporate cultures across organizations, as well as the technological limitations of the blockchain itself, which is still being under development.

Having the above, it brings the main research question:

What is the feasibility of blockchain technology in maritime sector and port development in particular?

According to the literature and IT market, blockchain as a technology has shown variable and partial success. Successful practices include industries such as governance, public voting, identity management and several others in which the technology has been implemented and brings benefits up to date. Throughout this study, with respect to shipping industry, the technology however has shown the low level of feasibility and adoption. Most of the projects reviewed in 2018 have moved away from decentralization by their proposal and offer digital solutions not based on distributed approaches. Despite the large number of potential use cases, the industry has not seen decentralization fully used in practice.

From practical and organizational perspective, decentralization of maritime and port community data brings a considerable number of barriers to become an integrated system. It also demonstrates that either decentralization is not demanded by port/shipping actors, or the importance and benefits of such system are not yet evident.

While blockchain projects have been widely discussed in academia and mass media, maritime ports – being the target users of such decentralization, prioritize other improvements. Namely, ports emphasize infrastructure expansion and hinterland connectivity, reduction of operating costs and compliance with energy transition agenda. This way, investments into new and not fully researched technology imply high risks for companies, especially considering low marginality of maritime sector. Only large global and European ports have piloted such initiative, cooperating with local startups – such as ports of Hamburg, Antwerp, Rotterdam, Singapore, Los Angeles, etc.

Summarizing the barriers toward adoption, it can be stated that main issues lay mainly within organizational side i.e. uniting supply chain participants, integrating their software to a unified level, supporting and protecting sensitive data. Thus, blockchain is still considered as ‘immature technology’.

Nevertheless, the interest that has arisen in the maritime sector with the introduction of blockchain projects – indicates on relevance of current problems in the industry. It also indicates on further development of solutions, despite the final use of blockchain as the technology. For example, as the study showed, blockchain has a significant overlap with previous developments - at least within overall objective. Blockchain, potentially combined with PCS, can transform the industry by driving it to new solutions that will combine the best from both approaches.

Thus, blockchain is still poorly adopted, and is now likely to become an intermediate stage in the development of port digitalization or become a driver for upcoming digital products in the future. The impact of the technology is, however, assessed as positive. The industry, lagging modern technological advances, has been able to receive a great number of prototypes and pilot projects, as well as discussions on potential improvements. All this, in turn, has brought attention from public, as well as investment and, as a result, new talents to the field of maritime practice.

For future work, a more in-depth analysis of port network structure is promising. Also, the possibilities of data exchange between port actors e.g. terminal operators, freight forwarders and customs could be explored in more detail – especially in relation to the EU data use regulation. Other research prospects relate to mapping of the workflow along the supply chain – both from the seaside as well as from the landside perspectives.

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ISSN (online): 2446-1636
ISBN (online): 978-87-7573-805-2

AALBORG UNIVERSITY PRESS