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Data-Driven Intelligent Port Management Based on Blockchain

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Abstract

This paper proposes a blockchain-based framework to improve the efficiency of ship traffic in port. In the framework, ship agents, terminals, tug company, pilot station, and government share information and the information is stored in a blockchain. Based on the shared information, we discuss three categories of data-driven models that can improve the operations management of the above five parties. The first category is decisions made by a single party. The second category involves decisions of at least two ship agents. The third category relates to multi-party decision making under uncertainty. This study hopes to stimulate maritime practitioners to embrace blockchain technology and data-driven approaches to enhance the competitiveness of the industry.

Key Words: Intelligent Port Management; Blockchain; Data-Driven Model; Ship Traffic

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1 Introduction

Maritime transportation is a high-capacity, efficient, low-cost transport mode that faces a number of time uncertainties. As reported by CargoSmart (2018), ocean carriers' on-time schedule reliability was only 53.1% in September 2018. Although ships spend most of the time sailing in the sea, the dominant sources of schedule unreliability occur in ports. Notteboom (2006) found that unexpected waiting time in port channel access accounts for 7.5% of schedule unreliability, unexpected waiting time before berthing or before starting loading/unloading accounts for 65.5%, and port/terminal productivity below expectations accounts for 20.6%.

To understand potential ways to alleviate the effect of ship delay at ports, let us look at the processes between a ship's arrival at a port and the ship's departure from the port. In the first instance, as shown in Figure 1, when a ship arrives at the mooring area of a port, it may have to drop anchor[1] for the following reasons: other ships in the mooring area have priorities to transit the channel[2], pilot is not available, tugs are not available, berth is not available, tide is not high enough to allow the ship to transit the channel safely, or there is another departing ship transiting the channel but the channel does not allow the two ships to transit in opposite directions simultaneously. In the second instance, once the ship is allowed to transit the channel, a pilot will board the ship at the pilot boarding location (PBL) and assist the ship's captain to navigate the ship safely through the channel. In the third instance, when the ship is a few kilometers away from its destination terminal, tugs will be fastened to the ship to assist the ship to maneuver and to be berthed. Finally, in the fourth instance, the pilot will alight from the ship and the tugs are unfastened. If the agent of the ship has completed the paperwork and the terminal has its stevedores and equipment ready, then cargo loading and unloading can start. The departure of the ship from the berth follows the opposite process.

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[1] In reality, once the ship sailing at sea learns it cannot transit the channel without delay, it will usually sail at a low speed to save fuel and try to arrive at the pilot boarding location just in time.

[2] In general, departing ships have higher priorities than incoming ships and larger ships have higher priorities. Cruise ships have higher priorities than container ships, which have higher priorities than bulk cargo ships.

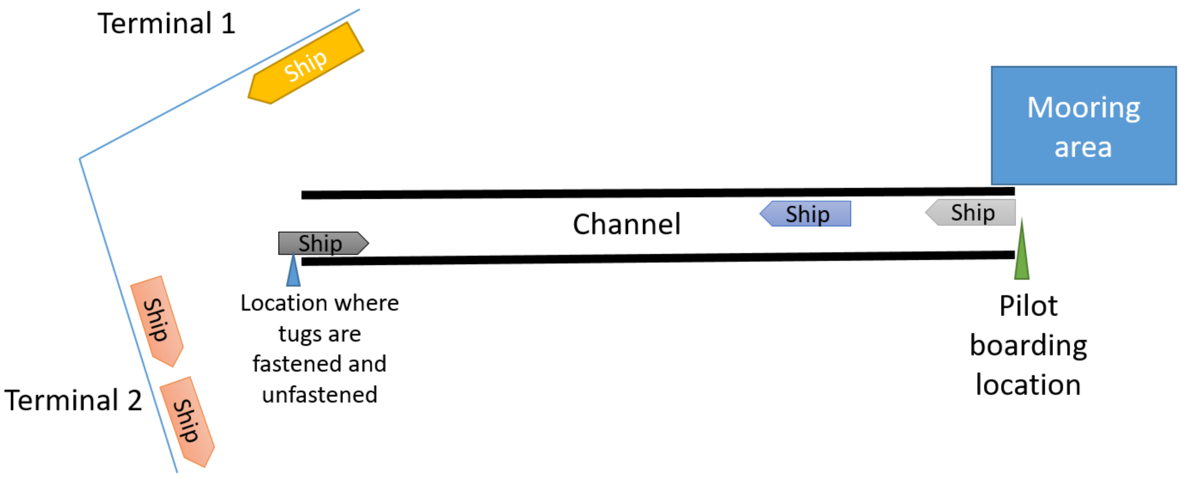

Fig. 1 Illustrative vessel traffic in a port (drawn by authors)

There are mainly five parties involved in the above process and their roles are shown in Table 1. Interviews were held with all the five parties involved and many complained about each other. For example, a ship agent complained that other ship agents do not update the estimated time of arrival (ETA) of their ships in time. If the other ship agents' ships cannot arrive at the PBL on time, then there will be vacant time slots for the ship agent's ships to transit the channel earlier than planned. Another ship agent complained that the pilot station does not provide real-time pilot boarding and alighting information, which is useful for the ship agent to know exactly when its ship starts to transit the channel (or leave the berth) and when it is berthed (or leaves the port). The pilotage scheduler complained that ship agents only inform him about the expected time of departure (ETD) of ships from berth one hour before the ETD. Based on these complaints we find that information sharing among the parties has the potential to significantly improve the efficiency of vessel operations, terminal operations, pilotage, and tugging operations, all of which contribute to the government's objective of achieving an intelligent port management system. We hence propose a framework that integrates blockchain and data analytics to allow the five parties to exchange information and use the information to improve their operations management.

Table 1 Five parties involved in ship traffic at port

Party	Number	Role	Note
Government	1	Manage ship traffic	In China, the government agencies are Port Management Authority and Maritime Safety Administration; in Hong Kong Special Administrative Region of China, the government agency is Marine Department; in Singapore, the government agency is Maritime and Port Authority.
Pilot station	1	Pilot ships	A pilotage scheduler will communicate on behalf of the pilots with other parties.
Tug company	1	Tug ships	There may be more than one tug company at a port.
Terminals	5+	Provide berths for ships and handle cargos	Ships that visit all the terminals share the same channel.
Ship agents	20+	Act on behalf of the ships	Ship agents are local companies and they will communicate with other parties on behalf of the ships they represent.

1.1 Literature review

The uncertainty of arrival time at berth (i.e. ready time for container handling) and the uncertainty of cargo handling time have been explicitly modeled in several berth allocation studies for container ships. Golias (2011) and Zhen (2015) have incorporated cargo handling time uncertainty into berth allocation decisions. Zhen et al. (2011), Liu et al. (2016), and Umang et al. (2017) have formulated both uncertain arrival time at berth and uncertain cargo handling time in berth allocation models. Most the above studies treated the ship arrival time at berth as exogenous. However, as mentioned by Notteboom (2006), the time from when a ship arrives at the mooring area to when it is berthed accounts for 73% (=7.5% + 65.5%) of the uncertainty of arrival time at berth, and we will focus on the management of the 73% of the uncertainty. Most the above studies treated the ship handling time at berth as exogenous (either deterministic or random). We do not optimize the ship handling time either, however, in our proposed framework, the uncertain cargo handling time will be updated regularly to allow parties other than terminal operators to allocate their resources more efficiently. For example, as a ship's fuel consumption will be decreased at a low speed (Wang and Meng, 2012), a ship can slow down to save fuel if its berth is occupied by another ship that will require excessively long handling time (Du et al., 2015). Therefore, the essence of our proposed framework is to allow information sharing among related parties and to use a data-driven approach to alleviate the management complexity brought by the uncertainty. In contrast, existing academic research focuses on using an optimization methodology to handle the uncertainty. Shifting from an optimization-driven perspective to a data-driven perspective may be a realistic way for practitioners to improve the operational efficiency under uncertainty.

As an advanced and safe information sharing and management platform, blockchain is a distributed digital ledger system that can be used in many areas such as finance, pharmaceuticals, consumer electronics, energy, and supply chains (Babich and Hilary, 2019). In this section a review of a number of blockchain applications in shipping and transportation is presented.

Maersk Line and *IBM* have established a joint company that uses blockchain to digitalize the paperwork in container shipping and to allow cargo tracking. *ZIM*, another global container shipping company, conducted a pilot program that employed blockchain to digitalize the bill of lading. *300 cubits*, a Hong Kong based company, designed "TEU token" using the blockchain technology. TEU tokens can be used by shippers to book slots on containerships and the idea of the TEU token is similar to that of bitcoin. The most relevant blockchain application to our framework is the *Blockchain in Transport Alliance* (*BiTA*). Founded in 2017, *BiTA* is "the largest commercial blockchain alliance in the world, with nearly 500 members in over 25 countries that collectively generate over $1 trillion in revenue annually" (BiTA, 2019). Its business model is similar to that of *Uber* and its main function is to provide a platform to efficiently match cargos and trucks. Due to the large number of trucks, there is no problem for a shipper to start to find a truck when his cargo is ready. In our problem, there are a few tens of ships and a few tens of pilots. It is highly inefficient if a ship informs a pilot when the ship is ready to leave the berth. All the parties have to make decisions based on uncertain (also inexact) information. More importantly, ships interfere with each other because of limited resources of berths, pilots, tugs, and channel. Many resources have to be managed in a holistic way. Therefore, in some sense the proposed blockchain framework, although involving a much smaller number of participants, can be more challenging than that of BiTA.

Last but not the least, it is a key issue to find suitable data sources for implementing the above proposed data-drive approach for handling uncertainty in the framework of blockchain. The most frequently used data in shipping is the automatic identification system (AIS) data. The AIS automatically tracks ships' positions. AIS is often used to analyze ship traffic in order to identify unsafe navigation areas (Zhang et al., 2019). Zhao (2018) used AIS to predict ship arrival time at port. Our framework integrates data from a number of sources, such as AIS data, ship agents' reports of ETA, and terminal operators' reports of cargo handling progress, the parties can actively make decisions, and the decisions will affect the future data (e.g., a ship agent may suggest slow steaming and then the ETA of the ship will be postponed).

1.2 Objectives and contributions

The objective of this research is to propose a framework that integrates blockchain with data analytics for intelligent port management. In this framework, blockchain is used for data storage, and data analytics utilize the data for the parties to make informed decisions. The overall purpose of the framework is to reduce costs for ships, terminals, tug companies, and pilot station.

The contribution of the paper is the proposed blockchain framework for ship traffic management in ports based on data analytics to improve the operations of the relevant parties and to identify some key challenges that require future research efforts.

The remainder of the paper is organized as follows: Section 2 presents the application of blockchain for information storage and sharing. Section 3 proposes a few applications of data analytics to improve the operations management of the parties. Section 4 concludes and discusses extensions of the framework.

2 Information sharing using blockchain technology

2.1 Blockchain rather than a centralized database

An approach to managing data is to use a centralized database by, for example, the government or port authorities. The disadvantages of a centralized system include the high risk of hackers[3] who find centralise systems an easy target, and entire system failure whenever the centralized system is shut down for whatever reasons, including necessary software upgrade and power off. Moreover, a centralized system operated by the government may give the other parties the impression that the government intends to expand its power and control over all operations. A decentralized system, such as blockchain, can eliminate these concerns to a large extent.

2.2 Permissioned blockchain rather than permissionless blockchain

The blockchain should be a permissioned (i.e. private) one as only verified participants can join the network. All the participants such as those parties shown in Table 1, must be checked by the government in order to join and access the blockchain network.

2.3 Transactions

The transactions of the blockchain are real-time information updates. The list of information to be updated and the party in charge of updating the information is shown in Table 2. The information to be updated is elaborated further on in this section.

Table 2 Information to be updated and the party in charge

Information	Party in charge	Updating time
Incoming ships' ETA	Ship agent	Whenever there is new information
Ready time of pilot to board ship	Pilot station	When the pilot is ready to board
Pilot's actual boarding and alighting time	Pilot station	When the pilot just boards/alights
Ready time of tugs to tow ship	Tug company	When tugs are ready
Tugs' actual start and end towing time	Tug company	When tugs just start to tow/finish towing.
Cargo handling progress of ship (which is used to estimate the ETD from berth)	Terminal	Almost real-time (e.g., every 5 minutes)
Expected draft of ship at departure	Ship agent	Whenever there is updated information
Closure of the channel	Government	Whenever the channel is closed or reopen

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[3] The IT systems of Maersk Line and China COSCO Shipping were attacked by hackers in the past few years.

A ship’s ETA may not be accurate. An incoming ship, via its agent, reports to the government its ETA 24 hours in advance. However, the ship may not have left the previous port yet and there can be significant delay at the previous port as well. Moreover, during the sailing, the ship may encounter adverse weather conditions which prevent it from sailing at the planned speed and the ship’s machineries may malfunction or break down. Therefore, ship agents must regularly communicate with the ship captain or shipping company to learn the most up-to-date ETA.

The ready time of pilot and actual boarding and alighting time will be inputted by the pilot using a mobile app.

The ready time of tugs and actual start and end towing time will be inputted by the tug masters using a mobile app.

The cargo handling progress of ship will be updated by terminals in real time. Actually, the terminals will connect their internal production system to the blockchain so that the real-time cargo handling progress will automatically be inputted into the blockchain. According to our interviews, some terminals already allow ship agents to access their internal production system to check their ships’ cargo handling progresses.

The expected draft of ship at departure will be provided to the blockchain by the ship agent (the draft determines the number of tugs required and the minimum tide height for the ship to transit the channel). In fact, the ship agent has to communicate with the terminals to learn the draft information. A natural question is: why not let terminals provide the information? Our interviews show that the information is of little use to terminals but very useful for ship agents. Therefore, terminals may be reluctant to input the information to blockchain. Moreover, this information generally only needs to be updated once or twice for a ship.

The government also provides information, such as the closure of the channel due to poor weather conditions and its decisions about the sequence of the ships to enter the channel. Since there is no new information provided to the blockchain, we do not explicitly specify the information provided by the government.

2.3.1 Transaction input

Blockchain is a database with a specific structure. It cannot ensure that there will be input and cannot ensure the input information is true. In our problem setting, the inputs from pilot station, tug company and terminals will not incur significant extra efforts or costs. Hence, the government can mandate these parties to provide inputs. Ship agents need to update ETA and expected draft at departure, which may be burdensome for them as the information has to be manually updated for each ship (the ETA can be updated for a number of times). However, according to our interviews, ship agents are the party that is in the most urgent need of this information. Therefore, we do not expect that there will be obstacles from ship agents for information sharing. As a final note, the blockchain system will improve the operations management of all the parties and it is expected that all parties will be more willing to share information once they have benefitted from the system.

2.3.2 Privacy

In a blockchain system all parties can access all the information stored; therefore, privacy is usually a concern. In our problem setting, the shared information in Table 2 is hardly sensitive. For instance, there are only one pilot station and one tug company and they have no competitors. The terminals disclose the cargo handling progress but they do not have to disclose, for example how many containers in total will be handled; that is, a terminal does not disclose information on its productivity. As mentioned above, some terminals already allow ship agents to check their ships' cargo handling progresses. The ETA and the expected draft of ship at departure are not confidential because the ship's ETA and draft will be recorded in its AIS anyway.

2.4 Consensus mechanism

The blockchain system for our problem is aimed at information sharing rather than monetary transactions. Therefore, the consensus mechanism should be much simpler than the proof-of-work or vote mechanisms to allow fast transactions. We argue that the information provided by a party can directly be appended to the chain; the system can limit each party a certain number of transactions (e.g., at most 1 transaction per minute by each party[4]) so that

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[4] A transaction may contain more than one piece of information. For instance, a transaction submitted by a ship agent can be "ship A's ETA is updated to 18:30 1 Jan 2019; ship B's expected draft at departure is 15 m". One minute's delay in information updating is negligible in shipping.

hackers cannot write too many transactions and no party (e.g., a terminal) can write too many transactions by mistake.

3 Improve operations management using data analytics

Blockchain is a technique used for data storage rather than data exploitation. Our blockchain framework is on information sharing and we now discuss how the information can benefit the parties in the blockchain network.

3.1 Basic data analytics applications

We first discuss the most straightforward applications of the blockchain system, which are called basic applications (BAs) for short. A basic application involves only one party and the potential improvement in operations from a piece of new information can be identified manually. In the sequel, the ETA refers to an incoming ship's expected arrival time at the PBL, the ETD refers to the expected time for a ship to be ready to leave its berth, and it takes 1 hour to travel between the PBL and a berth. A summary of the basic applications is shown in Table 3 and further elaborated below.

Table 3 Basic and advanced applications of data analytics of the blockchain system

Application	Key pain point	Strategy
BA1	A ship is delayed and its time slot to use the channel is wasted.	Share the new available time slot information to later ships to allow one of them to use the time slot.
BA2	A ship's ETD is postponed and the next ship that will use the same berth have to wait.	Share the information to the next ship to allow it to slow steam for saving fuel.
BA3	A ship's visit is cancelled and the next ship that will use the same berth still arrive at a very late time due to tide constraint.	Share the information to the next ship to allow it to arrive earlier.
BA4	A ship's ETD is postponed and the next ship that will use the same berth has to wait for a long time due to tide constraint.	Share the information to the next ship to allow it to slow steam for saving fuel.
BA5	Two mega ships (ship 0 and ship 1) are not allowed to enter the channel in opposite directions and hence ship 1 has to compromise its time to transit the	Share the information to ship 1 to allow it to optimize its time to transit the channel.

	channel. However, ship 0's schedule is changed and ship 1 still compromises its time to transit the channel.	
BA6	A ship is delayed but the terminal still prepares all resources for serving the ship at the planned time.	Share the information to the terminal to reschedule its resources and save costs.
BA7	A ship is delayed but the pilot still prepares to service it at the planned time	Share the information to the pilot to reschedule his tasks.
BA8	A ship needs fewer tugs than planned but the tug company still prepares the planned number of tugs	Share the information to the tug company to reschedule its tugs.

BA1: Suppose that ship 1's ideal ETA is 08:00, but there are several other ships of higher priority whose ideal ETAs are also 08:00. Therefore, the government plans to allow ship 1 to enter the channel at 10:00. To save fuel, ship 1 will sail at a lower speed. Suppose that a higher-priority ship is suddenly delayed. Once the agent of ship 1 learns this information, it can discuss with the captain whether it is preferable to speed up to use the vacant time slot[5]. If the answer is yes, the agent will seek permission from the government to use the time slot, and once permitted, the captain will be informed to speed up. The value of the information is that the ship can arrive at its preferred time.

BA2: Suppose that ETA of ship 1 is 08:00. Hence, if nothing wrong occurs, the ship will be berthed around 09:00 and then cargo handling will start. Suppose that the ship must be moored at a particular berth, which is servicing ship 0 whose ETD is 08:30. At 03:00, the agent of ship 1 receives the information that ship 0's ETD is postponed to 10:30 because a few reefer slots on ship 0 malfunction and must be repaired. Then the agent can inform ship 1 to arrive at the port at 09:30 (so that the ship can slow steam to save fuel).

BA3: Suppose that the ideal ETA for ship 1 is 12:30. Suppose that ship 1 can only transit the channel during high tide (08:00-12:00, 20:00-24:00). As it takes 1 hour to transit the channel, ship 1 must start to transit the channel at a time in 08:00-11:00 and 20:00-23:00. Ship 1 must be moored at a particular berth, which will service ship 0 whose ETD is 13:30. Hence, ship 1

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[5] Before informing the captain, the ship agent will communicate with the terminal to make sure there will be an available berth for the ship.

has to adjust its ETA to 20:00. At 01:00, the agent for ship 1 receives the information that ship 0 will not visit the port. Then the agent can inform ship 1 to arrive at the port at 11:00 (so that the ship does not have to postpone its schedule for 7.5 hours).

BA4: Suppose that the ideal ETA for ship 1 is 08:00. Suppose that ship 1 can only transit the channel during high tide (08:00-12:00, 20:00-24:00), meaning that it must start to transit the channel at a time between 08:00-11:00 and 20:00-23:00. Ship 1 must be moored at a particular berth, which will service ship 0 whose ETD is 09:00. At 01:00, the agent for ship 1 receives the information that ship 0’s ETD is postponed for 5 hours. Then the agent can inform ship 1 to arrive at the port at 20:00 (so that the ship can slow steam to save fuel).

BA5: Suppose that ship 1 is a mega ship and its ideal ETA is 18:00. Suppose that the ETD of mega ship 0 is 14:00. According to the government’s rule, the time difference between the two mega ships’ entry into the channel in opposite directions is at least 5 hours. Therefore, ship 1 adjusts its ETA to 19:00. At 01:00, the agent of ship 1 receives the information that ship 0’s ETD is postponed by 2 hours. Then the agent can inform ship 1 either to slow down and arrive at the port at 21:00 (so that the ship can slow steam to save fuel) or speed up and arrive at the port at 11:00 (so that the ship does not have to postpone its schedule).

BA6: Suppose that ship 1’s ETA is 14:00. The terminal will prepare resources to service the ship from 15:00. At 07:00, the terminal learns that the ETA for ship 1 is postponed to 23:00. The terminal can reschedule its resources and save costs.

BA7: Suppose that the ETA for ship 1 is 14:00, and the ETD for ship 0 is 12:00. A pilot is scheduled to service ship 0 and then ship 1. At 07:00, the pilot station learns that the ETA of ship 1 is postponed to 23:00. The pilot station can reschedule the pilot to service another ship or simply to go home after servicing ship 0.

BA8: Suppose that ship 1 requires two tugs if its draft is less than 15m and three tugs if otherwise. The ETD of ship 1 is 14:00 and its expected draft at departure is 15.2m. At 12:30, the tug company receives the information that the expected draft at departure is updated to 14.9m. The tug company can reschedule one of the three reserved tugs to service other ships.

3.2 Advanced data analytics applications for ship agents

This section discusses advanced applications (AAs) for ship agents. An advanced application involves more than one ship agent. A summary of the advanced applications for ship agents is shown in Table 4 and further elaborated below.

Table 4 Advanced applications of data analytics for ship agents

Application	Key pain point	Strategy
AA1	Tug unavailability	A ship that has a lower urgency to use tugs shares its tugs to the one that urgently needs tugs
AA2	Pilot unavailability	A ship that has a lower urgency to be piloted shares its pilot to the one that urgently needs to be piloted
AA3	Limited channel capacity due to ships in the opposite direction	A ship that has a lower urgency to transit the channel gives way to the one that urgently needs to transit
AA4	Limited channel capacity due to ships in the same direction	A ship that has a lower urgency to transit the channel gives way to the one that urgently needs to transit to earn some credit
AA5	Limited channel capacity due to its reopening after bad weather	A ship that has a lower urgency to transit the channel gives way to the one that urgently needs to transit to earn some credit

AA1: The ETD of ship 1 is 08:00 and it is urgent. But the tugs are available only at 09:00. The agent for ship 1 learns from the blockchain that the tugs are reserved for ship 0. The agent for ship can then negotiate with the agent for ship 0 to see whether ship 0 can allow ship 1 to use the tugs first. Our interviews with ship agents show that this often happens between ship agents who know each other. The agent for ship 1 does not pay the agent of ship 0, instead, the agent of ship 1 owes the other agent a favour and will allow the latter's ship to depart first next time.

AA2: Ship 1 and ship 0 both have an ETD of 08:00. Two pilots are scheduled but the pilot of ship 1 falls suddenly sick at 07:30. Ship 1 is urgent. The agent for ship 1 can then negotiate with the agent for ship 0 to see whether ship 1 can be piloted in first.

AA3: According to the government's rule, the time difference between the two mega ships' entry into the channel in opposite directions is at least 5 hours. The ETD of mega ship 1 is 11:00 and the ETA of mega ship 0 is 09:00. In the current practice, the government has to decide which ship enters the channel first based on a set of rules. With blockchain technology, the government can require the two ships' agents to negotiate which ship will use the channel first. If there is consensus, the government will adopt this consensus; otherwise the government adopts its rules to decide which ship has the priority.

AA4: Suppose that two ships in the same direction can enter the channel with a minimum headway of 5 min. The ETAs of eleven ships are all 09:00. In the current practice, the government has to decide the sequence of the ships to enter the channel: the first one enters at 08:35, the second at 08:40,…, the 11th at 09:25. With blockchain, the government can specify the sequence and allow ships to exchange their sequences with each other. There may be a potential problem: a ship's ETA is 10:00 but may report an ETA of 09:00 in order to take advantage of other ships whose true ETA is 09:00. However, it can be seen that the time difference between the first and the last is only 50 min and hence in reality it does not make sense for a ship to falsify its ETA unless the channel is very crowded.

AA5: In case of bad weather, the channel will be closed. Once the channel is reopened, there are many ships waiting both in the terminals and in the mooring area. The government has to specify the priority of the ships in using the channels. In general, cruise ships have the highest priority; then the mega ships that leave the berths have priority; then container ships have the priority, etc. The government can then announce the plan. The ships that have the highest priorities are piloted immediately, and hence there is no time to exchange their sequence. Because there are many other ships whose sequence can be changed, it is not practical for a ship agent with an urgent ship to phone all the other ship agents to find an earlier ship that would like to swap its sequence. This study proposes a tradable credit approach, which is essentially the one proposed in Yang and Wang (2011) where the government can distribute some tradable credits to ship agents for free. Ship agents can then buy or sell their credits from or to other ship agents. If an agent's ship is the 23rd to enter the channel, the agent may announce in the blockchain that it would like to pay 2 credits to swap for one of the first 10 positions in the sequence, pay 1 credit to swap for one of the 11th to the 20th positions, and charge 1.4 credits to swap for one of the 24th to the 33rd positions. When more than one ship agent announces the information, the blockchain system can automatically match the ships to swap their positions in the sequence.

3.3 Advanced data analytics applications for terminals, tug company, pilot station, and government

Terminals, tug company, and pilot station can also benefit from the information in the blockchain. Terminals need information about the time a ship can be berthed, the tug company needs information about the time a ship needs to be towed and how many tugs are required, and the pilot station needs information about the time a ship needs to be piloted. The proposed framework provides not only the information but it also provides it digitalized so as to be accessible by computer programs. We highlight the importance of digitalized information using two examples below.

Example 1: Our interview with the pilot station shows that currently many planning processes are conducted manually because a significant amount of information is obtained over the phone and the pilotage scheduler has no time to input the information into the computer system. As a result, the information cannot be utilized by any decision support system; moreover, a lot of historical information obtained over the phone is recorded on paper and the papers are trashed, making it challenging to use historical data for further analysis.

Example 2: We interviewed a container terminal operator. The terminal has a comprehensive decision support system for yard management. Although the system has the function of allocating yard space to containers, this function is not used. The reason is that in order to use the function, a huge number of parameters (e.g., the driving and turning speeds of trucks, the time required for a crane driver to pick up a container) must be inputted in the system. Since these parameters have to be manually inputted, the yard managers simply allocate yard space based on their experience.

The government also needs all the information to propose an initial plan (sequence of ships to enter the channel). For instance, in the above AA4, when the ETA of 11 ships were all 09:00, if the tugs can service at most four ships simultaneously and it takes tugs 30 min to service a ship, then the government may schedule 4 ships to arrive at 8:25, 8:30, 8:35, and 8:40, 4 ships to arrive at 8:55, 9:00, 9:05, and 9:10, and 3 ships to arrive at 09:25, 09:30, and 09:35.

All decisions made by the terminal operators, tug company, pilot station and government are made under an uncertain environment. In the literature, there are studies that consider such uncertainties (Zhen et al., 2011; Umang et al., 2017). But almost all of the studies have simplified the uncertainties from reality. For instance, it is often assumed in the literature that the cargo handling time of a ship is uncertain and its actual handling time is known when the vessel arrives (Zhen et al., 2011). This is an over-simplification because in reality a ship's handling time is known only when all the cargo has been handled. The decision-making processes faced by terminals, tug company, pilot station, and government are somehow similar to humanitarian operations after a natural disaster (Natarajan and Swaminathan, 2014), in which the environment is uncertain and there is no or little data (although our problem has more available data than humanitarian operations). New modeling methodologies for the decision-making process have to be proposed.

The decisions of different parties interact with each other, as shown in Figure 2. The government, based on available information, proposes an initial plan. The initial plan is announced to pilot station, tug company, terminals and ship agents. In the implementation of the plan, pilot station and tug company will regularly check with each other because a ship cannot leave berth without a pilot or tugs. The pilot station and tug company will also interact with terminal operators to learn the cargo handling processes, and terminal operators learn from pilot station and tug company whether a ship starts to enter the channel. All the decisions of terminals, tug company, pilot station and government affect the ship agents, who may request the government to revise the initial plan. Then the terminals, tug company, pilot station have to reschedule again. We believe that in such a multi-party highly uncertain decision-making environment, identifying the local rules (by "local" we mean rules that affect a small number of ships/parties; e.g., BA1 to BA8 are all local rules) based on the data and the testing of the local rules in field implementation, are a more realistic approach than trying to come up with a holistic model. For one reason, the extensive data required by a holistic model is not available; for another reason, a holistic model is a "black box" and it may be hard to convince the parties to adopt a result that is not apparently better[6] and that has no intuitive rationale.

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[6] Because of the uncertainties, even if the holistic model generates an optimal solution, the solution is optimal only in an average senario. In a particular realization of the uncertainties, it is highly likely that an experience-based solution or a local-rule based solution outperforms the averagely optimal solution.

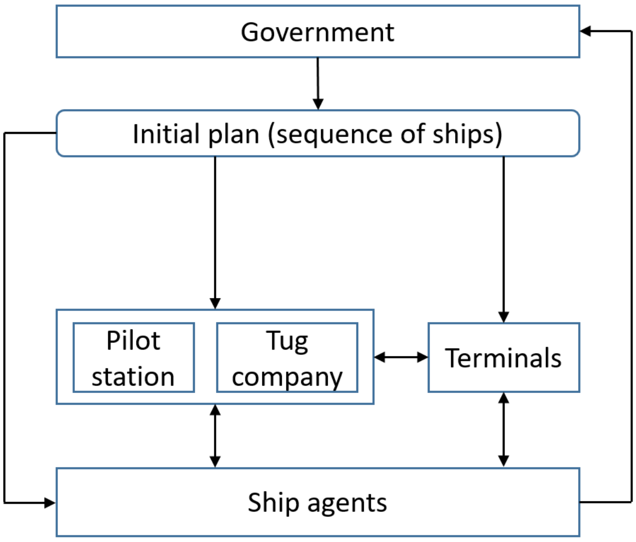

Fig. 2 Interactions of the parties in ship traffic management

4 Conclusions

This study has proposed a blockchain-based framework that aims to improve the efficiency of ship traffic in ports. In the framework, ship agents, terminals, tug company, pilot station and government share information and the information is stored in a blockchain. Data-driven models can be developed to utilize the information to improve the operations management of the parties in the blockchain. Given that port delay is a significant component in shipping schedule unreliability and ship traffic is mainly manually scheduled, the proposed framework has the potential to significantly improve shipping schedule integrity, which benefits the shippers and society at large.

The proposed framework is a basic version and many more features can be added. Further research can be carried out for instance, where a framework can use multi-source data for cross-validation. Currently, the AIS data is widely available and if AIS data show that a ship's ETA in the blockchain is evidently wrong (the ship agent forgets to update the ETA), a reminder can be sent to the ship agent. Another extension is that trucking companies, rail transport companies, shippers and consignees may join the blockchain and access the information that they need, for example, the expected start time of cargo handling for a ship.

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