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The art of orchestrating nautical services in a port call: A literature classification

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Abstract. Global carbon dioxide emissions are forecast to increase by around 15% by 2050 compared to 2020. In order to move towards a sustainable transition to net zero emissions by 2050, more energy-efficient operations are a prerequisite. In response, terminals are looking for ways to optimise port processes to reduce energy consumption while also keeping waiting time and costs low. This paper focuses on optimisation approaches for the individual actors in the nautical service that can support these objectives. A comprehensive review, classification and discussion of the relevant literature on current methods and procedures for the stakeholders of the nautical service is conducted. In this regard, current challenges and limitations are identified. The results of the classification scheme show that tugboats in particular are examined in more detail. The objective is often to reduce costs and increase safety in the port area. For this purpose, mathematical approaches, or various types of algorithms are usually applied. Future research activities could be based on more detailed analyses of the approaches used in the identified papers.

1. Introduction and Background

Seaport terminals are regarded as an interface between the various modes of transport and are challenged by the growth in global traffic. Around 80% of global goods traffic is handled by sea [1]. They are therefore under pressure to either expand infrastructures and suprastructures or to improve the efficiency of processes. The former is difficult, as available space is scarce. This applies in particular to ports that have grown historically. Therefore, investments are often made in new concepts to improve operational efficiency [2-3]. This is also a basic prerequisite for a sustainable transition to net zero emissions by 2050 and also applies to port calls. The port call itself is characterised by various actors and sub-processes (see Table 1). Optimising the associated process areas is therefore crucial to the efficient operation of the entire port call. A more detailed description of all terminologies/definitions and the actual business process of a port call can be found, for example, in the papers by Hagaseth et al. [4], IMO [5-6], or ITPCO [7].

Table 1. Port Call Parties based on IMO [6].

Port call parties	Description	Stakeholders (examples)
Authorities	Receives information related to the port call and provides clearance to the vessel's arrival and departure	Harbour master, Coastguard, Customs
Berth planner	Plans the berth call	Terminal operator, Berth operator, Port authority
Hydrographic services	Provides hydrographic data and all necessary for safe navigation during passage and berthing of the vessel	National hydrographic office, Regional charting agency
Nautical services	Provides nautical services to the vessel	Pilot, Tugs, Linesmen, Vessel Traffic Service (VTS), Maritime Single Window (MSW)
Port planner	Plans the port call	Port authority, Terminal operator
Vessel or cargo services	Provides vessel services to the vessel	Vessel or cargo service providers

The main obstacle to a more sustainable port call is the common practice of 'first come, first serve' [5]. This type of vessel operation has many disadvantages and can be improved in terms of safety, environment, and efficiency [5]. Figure 1 shows that vessels leave the port of departure at a certain speed in order to reach the port of arrival at the Requested Time of Arrival (RTA). The RTA is a request from the terminal to the vessel to arrive in a certain port area at a given time. Unplanned delays at the port of arrival can cause the previously requested arrival time to change [5]. In practice, this updated information is often not passed on to the vessel concerned, so that the speed cannot be adjusted [5]. As a result, the vessel continues at the same speed in order to reach the port at the originally requested time. Due to occupied berths, unavailable fairways, or nautical services, the vessel cannot enter the port [5]. This means that the vessel must remain outside the port at anchorages or manoeuvre in the approaches [5].

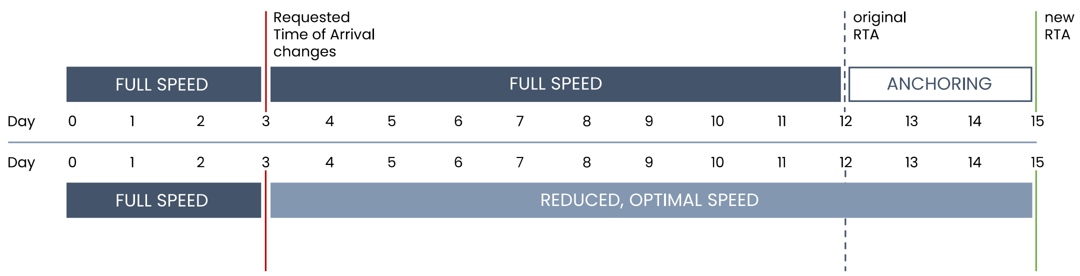

Figure 1. Port call with and without adjusted speed based on IMO [5].

The resulting waiting time leads to a decrease in the operational efficiency of the vessel in terms of time, costs, and energy. At the same time, ports are under pressure to handle vessels rapidly in order to maintain competitiveness and be considered an appealing transhipment point for shipping companies. However, if the updated time is transmitted to the vessel, the speed can be adjusted and optimised so that both the waiting time and the fuel consumption of the vessels can be reduced. The terminals are also able to handle vessels without further waiting times. The optimisation of the associated processes is therefore crucial for the efficient operation of the entire port call. With suitable approaches, the procedures between all parties involved within the individual processes could be optimised for both the port and the vessel. Processes can be better coordinated and organised more efficiently.

The main objective of this paper is to provide a comprehensive and broad overview of relevant approaches and methods for optimising the sub-processes of the nautical service. Section 2 describes the literature research procedure. The results of the literature review are presented in Section 3. Section 4 is focused on the classification. The results of the classification are discussed in Section 5. This is followed by a conclusion and an outlook in Section 6.

2. Literature Review

A systematic literature search is carried out as part of this paper. Based on a comprehensive review of the literature published between 2000 and April 2024, a classification scheme is developed and applied to the publications that are deemed relevant.The Web of Science (WOS) database is used for this purpose. Keywords have been determined for the formulation of the search string. When selecting the search terms, the focus is placed on the stakeholders of nautical services. This is due to the scope of the stakeholders involved in the port call process. It should also be noted that operational optimisation problems in connection with berth planners or port planners, for example, are often seen as a separate planning problem and treated independently of the port call in the research. The individual keywords are based on the terms used by the IMO. In addition, the term port call itself was taken into account in order to identify publications relating to maritime use cases in ports. This has resulted in the following search: *(port AND call) AND (pilot OR tugboats OR (vessel AND traffic AND service) OR (maritime AND single AND window) OR linesman).* Figure 2 shows the framework for searching, and filtering the academic literature. Entering the formulated search string into the selected database on 23 April 2024 returned 317 publications. Based on title and abstract, the first review of the literature are carried out. Only those publications containing approaches or methods for optimising nautical services are considered further. In the next step, the remaining 78 publications are checked for their full texts. Excluded literature often deals with more general and explanatory content [4,8], with berth optimisation [9-11], or with optimisation approaches to the vessel itself [12-15]. A total of 33 articles are categorised as relevant for the present analysis.

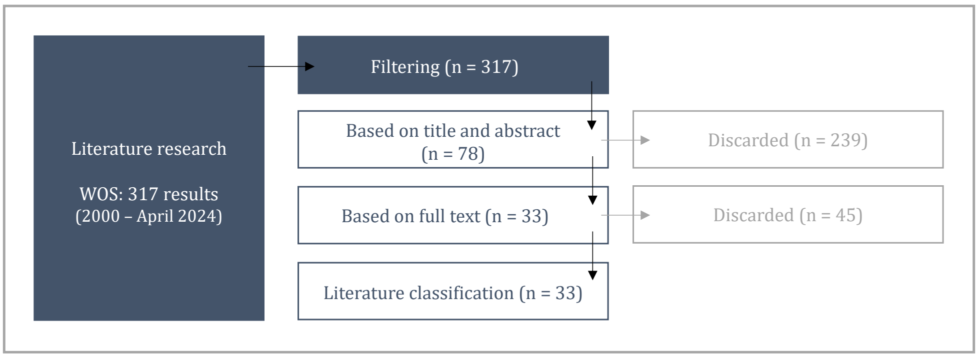

Figure 2. Framework literature research.

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3. State of the Art

This section deals with the state of the art and reflects the current state of research. In this regard, the approaches proposed by the authors (sorted alphabetically) are presented in brief. Çakıroğlu et al. [16] propose an approach for selecting a suitable propulsion type for tugboats alternative based on numerical analysis in order to optimise the use of resources. On the other hand, Cho et al [17] apply mixed integer programming to condense the schedule for cargo traffic and optimise costs. Choi et al. [18] present a comprehensive overview of various projects related to autonomous tugboats in terms of safety. Chou et al. [19] analyse tug operations and suggest possible improvement approaches to minimise port congestion and increase vessel safety. Durán et al. [20] present a secure technological system for the MSW based on machine learning and blockchain to make document control and traceability more efficient. Han et al. [21] develop a model for the VTS to increase safety in ports with regard to navigation. Both Ihle et al. [22] and Ihle et al. [23] propose a lagrangian approach for tugs. In the proposed approaches, robust steering laws for surface vessels are developed to counteract uncertainties. Ilati et al. [24] investigate, among other things, the optimisation of the assignment of tugs to vessels and propose an algorithm to reduce waiting times for vessels. Jia et al. [25] use a use an integer programming for the effective deployment planning of tugboats to minimise operating costs. Kang et al. [26] develop a mathematical model for the tug scheduling problem to minimise the total operating time of tug operations and reduce costs. Kasm et al. [27] propose an optimisation approach for the allocation of tugs to vessels based on heuristics. The aim here is to minimise delays. Kim et al. [28] present a deep learning approach to predict medium-term and long-term vessel traffic in caution areas, such as intersections of vessel routes or congestion areas. The objective is to increase safety in areas with a certain risk of vessel collisions. Kumar et al. [29] develop a control strategy for the effective operation of the various energy sources aboard the tugs, based on a real-time tug operation cycle. Lee et al. [30] use a mathematical approach to operate a tugboat to reduce fuel consumption while increasing safety during manoeuvres. Li et al. [31] present an algorithm for scheduling tugs to reduce overall fuel and delay costs. Based on interviews and surveys, Nikghadam et al. [32] develop a suitable approach for improved information sharing in ports to mitigate delays in turnaround times. Furthermore, Nikghadam et al. [33] analyse the cooperation between tugboats and pilots. For this purpose, a simulation study is carried out using the example of the port of Rotterdam. The results show that waiting times could be reduced by up to 30%. Park et al. [34] present a model using a queuing model to increase safety in the waterway areas. By quantitatively analysing the communication of the VTS in the northern port of Busan in South Korea, Park et al. [35] suggest how to reduce congestions on the radio communication channel. Paulauskas et al. [36] propose a mathematical model to reduce fuel consumption and emissions during the manoeuvring activity of tugs. Sun et al. [37] develop a genetic algorithm to make tugboat deployment planning more efficient. The objective here is to minimise idling distance. Van Bui et al. [38] present an algorithm for mooring vessels during slow manoeuvres with the help of autonomous tugs in order to minimise the power input and thus to determine the thrust and direction of each individual tug. Wang et al. [39] use an algorithm for the allocation of tugs to reduce the processing time of the vessels. Wang et al. [40] propose an algorithm to deploy tugs more efficiently and to reduce costs. Furthermore, Wei et al. [41] presented a branch-and-cut algorithm to optimise the scheduling of tractors with a reasonable amount of time. In addition, Wei et al. [42] propose a method that dynamically updates tugboat scheduling when new service requests arrive to minimise tugboat operating costs for the entire scheduling horizon. Yang et al. [43] construct a chaotic quantum adaptive satin-bower-bird optimisation algorithm to reduce tugboat operation costs. Yao et al. [44] optimise tugboat scheduling to achieve savings in terms of operating time, costs, and emissions. Yoo et al. [45] use a model to determine the optimal number of workstations in the VTS with the aim of ensuring timely services, even with high traffic volumes, and thus avoiding shipping accidents. Furthermore, Yoo et al. [46] propose a deep learning approach that predicts the time required for a vessel to enter and leave in different situations. This provides more accurate information for the vessel and determine waiting times. Zhang et al. [47] propose a rule-based method for VTS operators to ensure maritime safety. Lastly, Zhong et al. [48] proposes an algorithm for tugboat scheduling to reduce overall fuel consumption and emissions and lower the operating costs of tugboat companies.

4. Classification

The classification scheme is presented in the Appendix in Table 1. In Table 2, the associated categories and attributes of the classification scheme are shown.The characteristics are mainly derived from the retrieved articles. The first criterion describes the actors covered in the respective study. In the second step, the publications are classified according to their objective(s). The next criterion refers to the selected optimisation approach in the respective paper. Lastly, two further criteria help to categorise the publications: This includes whether a specific port is addressed or whether reference is made to a specific type of cargo or vessel. The categorisation of the 33 publications in the developed classification scheme is shown in the appendix. Attributes that apply to the respective articleare marked in grey. In the first three categories, more than one attribute may be selected.

Table 2. Criteria and attributes of the classification table.

Criteria	#	Attribute
Stakeholder to be optimised	1	Pilot
	2	Tugboat
	3	Linesman
	4	VTS
	5	MSW
	6	All Stakeholders
Objective	1	Reduce costs
	2	Reduce emissions and fuel consumption
	3	Increase safety
	4	Minimise operating time, waiting time and/or delays
	5	Other
Method	1	Analysis
	2	Mathematical approach
	3	Algorithm
	4	Artificial intelligence
	5	Other/not specified
Port reference	1	Yes
	2	No
Special type of vessel or freight	1	Yes
	2	No

The stakeholders to be optimised are first discussed in the following regarding their objectives. Regardless of the stakeholder, the optimisation approaches examined frequently focus on increasing safety in regard of navigation and manoeuvring activities and minimising processing times, waiting times, and/or delays (see Figure 3). It is noticeable that none of the identified optimisation approaches cover linesmen. Pilots, the MSW, or all stakeholders are only addressed to a limited extent. In this regard, the focus is again mostly on increasing safety or reducing waiting times or delays. The tugboats are analysed most extensively in the selected literature with regard to all objectives. VTS is the second most frequently discussed topic. Here, safety and waiting times also take centre stage.

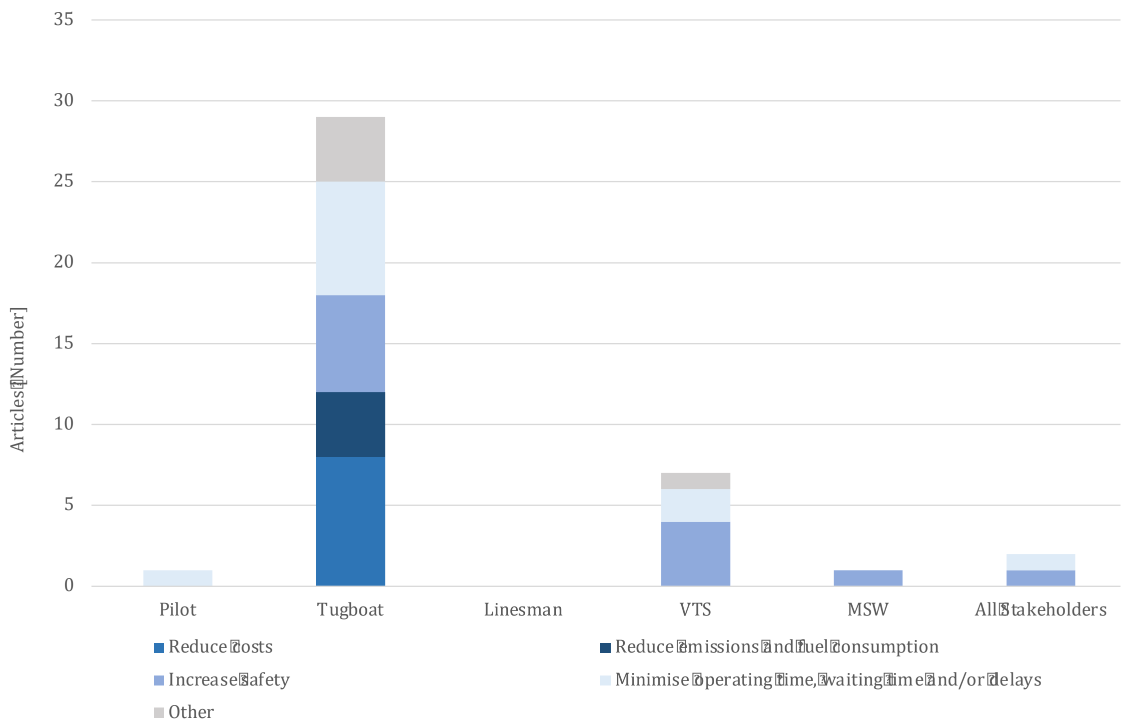

Figure 3. Optimisation areas and objectives.

Figure 4 provides an overview of the methods used to solve the optimisation problems in connection with the objectives. It can be seen from the diagram that algorithms, like genetic algorithms as well as self-developed algorithms or mathematical optimisation, were often applied in the studies. In particular, these two approaches were used most frequently to *reduce costs, minimise waiting times, processing times, and/or delays* and *reduce emissions and fuel consumption*. In order to increase safety, analyses of the respective process are often carried out to derive possible improvement approaches.

Furthermore, 12 out of the 33 publications refer to a specific port. These case studies examine the proposed solution in practice. Six publications refer to a specific type of cargo vessel and propose optimisation approaches for the respective stakeholder in this regard.

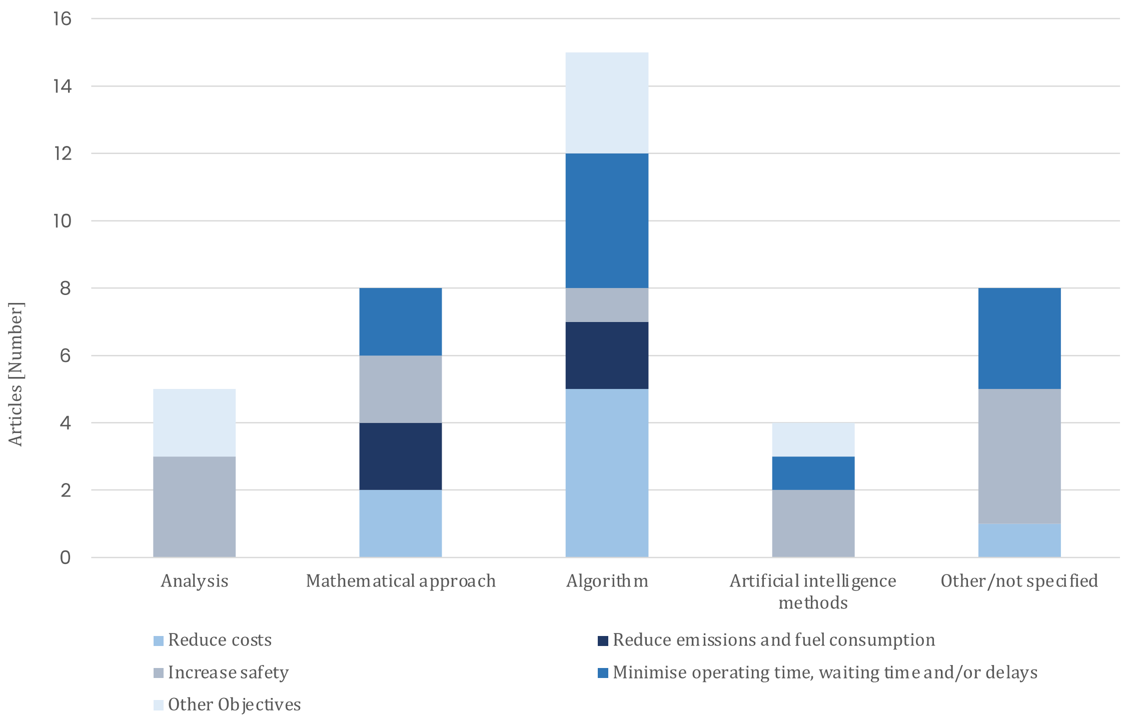

Figure 4. Optimisation methods and objectives.

5. Discussion

The range of challenges is causing seaports to rethink their approach to operational efficiency. For this reason, investigating approaches to operational optimisation is important here. The publications examined in the present literature review propose optimisation approaches to increase operational efficiency for the nautical services. In most cases, the stakeholders of the nautical service are considered individually. In addition, the papers deal with rather simplified problems. Nevertheless, the classification scheme shows directions of development. The proposed solutions show the potential for improvement for most of the stakeholders in nautical services. Only for linesmen, no approach could be identified.

Cho et al. [17], Nikghadam et al. [32], and Nikghadam et al. [33] propose an approach that addresses at least two stakeholders of the nautical services. Six publications include multi-objective optimisation. This means that almost all approaches deal with just one objective and trade-offs inherent to multi-objective optimisation are less frequently examined. The authors advocate for focusing on these trade-offs more in future research. For example, increasing safety in regard of navigation and manoeuvring activities can cause waiting times for all stakeholders in the port or delays for the vessel. At the same time, waiting times, processing times, and delays should be minimised in order to handle vessels quickly and efficiently and thus maintain the competitiveness of a seaport. The effectiveness of some proposed methods are demonstrated using data from a specific port as part of a simulation. The results are mostly positive or at least a promising outlook was mentioned.

6. Conclusion and Outlook

The use of suitable optimisation approaches can better coordinate the individual port call processes and make them more efficient. Despite the fact that research in this area has increased in recent years, only a few publications are identified that take a holistic perspective.

In the present study, a comprehensive overview of operational planning of nautical services is provided. In addition, a classification scheme is developed as a basis for analysis and discussion and applied to the literature identified in the systematic literature review. The scheme and the literature search, which is currently limited to the WOS database, should be expanded in the future. Furthermore, despite the authors' thorough literature search, it cannot be guaranteed that individual sources have been overlooked, so that this literature search cannot claim to be exhaustive. The evaluation of the individual literature sources has shown that the search string cannot cover all possible terms used in the literature. Therefore, this literature review would benefit from an extensive snowball search in the future. Furthermore, due to the number of stakeholders involved in port call process, the focus was initially on the nautical service. In future research, the classification scheme could therefore be extended to include other stakeholders.

According to the classification scheme, there are optimisation approaches for almost all stakeholders of the nautical service in research. Often, the objective of the optimisation approach is to reduce costs and increase safety in the port area. For this purpose, mathematical approaches or various types of algorithms are usually applied. In addition, there are few articles that offer an integrated solution for more than one stakeholder in the nautical service. It should be noted that all processes are interlinked and influence each other. Nevertheless, individual objectives are usually formulated and a multi-objective view is not applied. This should also be taken into account in future research. Furthermore, the proposed approaches were not investigated in depth. For example, within future research activities, it would be advisable to analyse and classify the algorithms used in the papers in more detail.

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Appendix

Table 1. Literature classification scheme

	STAKEHOLDER TO BE OPTIMISED						OBJECTIVE					METHOD					PORT REFERENCE		SPECIAL TYPE OF VESSEL OR FREIGHT	
	1	2	3	4	5	6	1	2	3	4	5	1	2	3	4	5	1	2	1	2
Çakıroğlu et al. [16]		■									■	■						■		■
Cho et al. [17]						■			■				■					■	■	
Choi et al. [18]		■							■			■						■		■
Chou et al. [19]		■							■			■					■			■
Durán et al. [20]					■				■						■			■		■
Han et al. [21]				■					■							■		■		■
Ihle et al. [22]		■							■							■		■		■
Ihle et al. [23]		■							■							■		■		■
Ilati et al. [24]		■								■				■				■		■
Jia et al. [25]		■					■						■				■		■	
Kang et al. [26]		■					■			■			■					■		■
Kasm et al. [27]		■								■			■				■			■
Kim et al. [28]				■					■						■			■		■
Kumar et al. [29]		■									■			■				■		■
Lee et al. [30]		■						■	■				■					■		■
Li et al. [31]		■					■			■				■				■		■
Nikghadam et al. [32]						■				■					■		■			■
Nikghadam et al. [33]	■	■								■						■		■		■
Park et al. [34]				■					■							■	■			■
Park et al. [35]				■					■		■	■					■			■
Paulauskas et al. [36]		■						■					■					■	■	
Sun et al. [37]		■									■			■			■			■
Van Bui et al. [38]		■							■					■				■		■
Wang et al. [39]		■								■				■				■		■
Wang et al. [40]		■					■							■				■		■
Wei et al. [41]		■									■			■			■		■	
Wei et al. [42]		■					■									■		■	■	
Yang et al. [43]		■					■							■			■		■	
Yao et al. [44]		■					■	■		■				■			■			■
Yoo et al. [45]				■						■						■	■			■
Yoo et al. [46]				■							■				■			■		■
Zhang et al. [47]				■						■						■		■		■
Zhong et al. [48]		■					■	■						■			■			■

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