Developments toward the unmanned ship

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Abstract

This paper provides an overview of the initial position and rationale regarding the development of an unmanned ship. This is based on the proposal for the EU-funded project MUNIN (Maritime Unmanned Navigation through Intelligence in Networks). Based on the European vision of an autonomous ship, MUNIN's understanding of autonomy, its contribution towards a sustainable maritime transport system and the current key challenges for implementing unmanned vessels will be explained.

Key words: Autonomous ship; unmanned ship; sensor systems; decision support; MUNIN

1 Introduction

Europe played an important part in maritime trading already shortly after its historical roots five millennia ago. Despite several radical changes over the last century, like e.g. the transition from sail to steam ships, then again to diesel engines, the introduction of containerized cargo and changing trade centers all around the globe, Europe still manages to maintain a leading global position in numerous maritime domains. To maintain and strengthen this position, the European Waterborne Technology Platform (Waterborne TP), which is a cluster of leading maritime-related European stakeholders, has created a vision for the waterborne industry in 2020 that is based on three pillars [1]:

- Safe, sustainable and efficient waterborne transport,
- a competitive European waterborne industry and
- growth in transport volumes and changes in trade patterns.

On the basis of this vision, Waterborne TP has identified twelve prioritized *exploitation outcomes* that shall help Europe developing its maritime sector within these pillars. One outcome that is important for all three pillars is the "Autonomous Ship", which is defined as a vessel with:

Next generation modular control systems and communications technology [that] will enable wireless monitoring and control functions both on and off board. These will include advanced decision support systems to provide a capability to operate ships remotely under semi or fully autonomous control. [2]

To support this outcome, the European Commission called for and accepted a proposal for a new research project on “The Autonomous Ship" to investigate the feasibility of this idea. The selected project was called MUNIN where the name has two meanings: First it is the abbreviation for *Maritime Unmanned Navigation through Intelligence in Networks,* pointing to the project's inherent idea of developing technology for an unmanned autonomous vessel. It is also the name of a raven in Norse mythology that each day flew around the world without guidance, gathering information and in the evening safely returning the information – its "cargo" – to its master, the Norse god Odin. Munin means "memory" or "mind" in the old Norse language. Thus, the autonomous ship shall figuratively act like the raven Munin: Independently and safely bringing its cargo to the destination.

Following Waterborne TP’s description, developing and validating a suitable mixture of remote and automated technology for ships will be the core task of the MUNIN project (see figure 1).

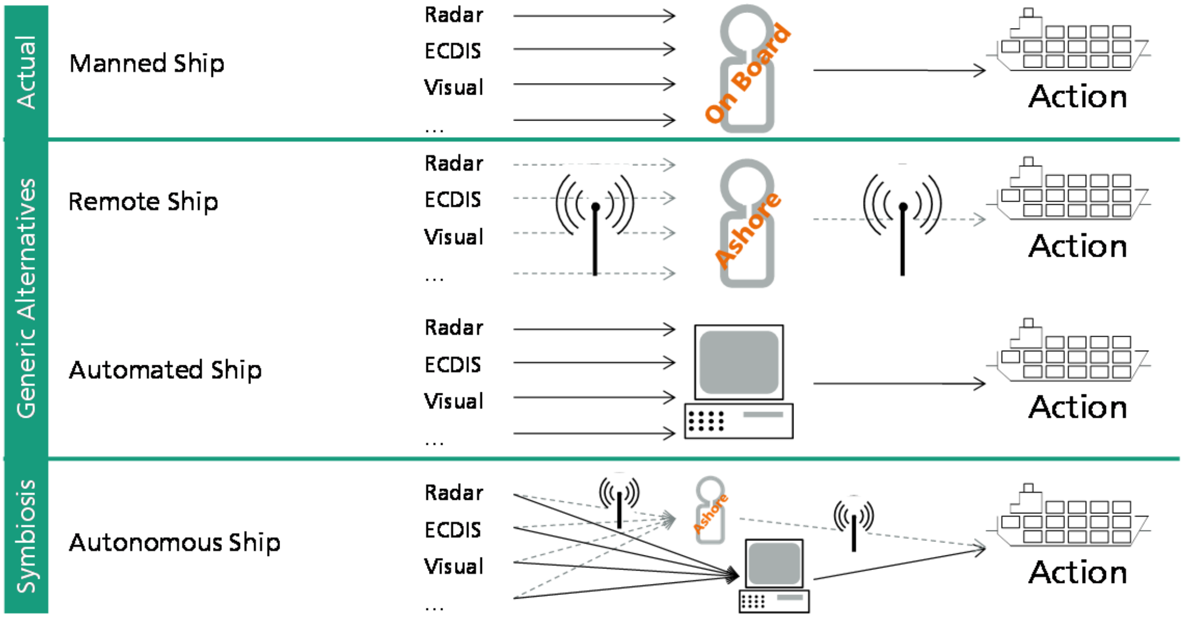

Figure 1 - From manned to autonomous ship

Given that a completely unmanned merchant ship might not be a very realistic scenario in the near future, the project is designed to ensure that many components of MUNIN also have more direct applications in the short term.

Section 2 of this paper gives an overview of the autonomous ship concept as it is understood in the MUNIN project. Section 3 explains the operational rationale behind developing an autonomous ship while section 4 proceeds with depicting the key challenges related to this development. The paper closes with section 5 giving an outlook on expected project results, with a special focus on their short-term benefit besides the final autonomous vessel itself.

2 Unmanned ship and autonomy

An unmanned ship can be achieved by a combination of remote, automatic and autonomous control as illustrated in figure 1. Figure 2 illustrates the automatic and autonomous control possibilities for such a system, where the MUNIN focus is represented by the shaded area.

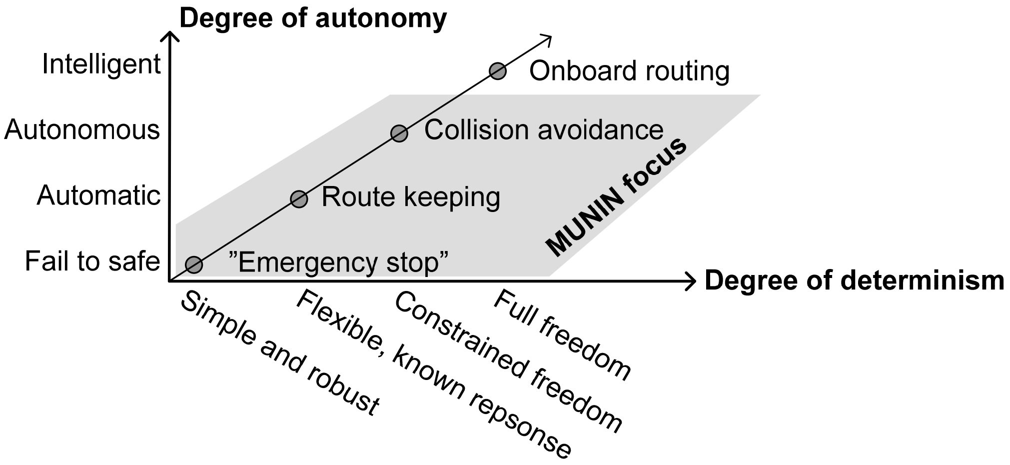

Figure 2 – Autonomy versus determinism

The figure also illustrates how the conceptual increase in autonomy from a simple and robust fail to safe mechanism via automatic, autonomous and up to "intelligent" control reduces the "determinism" of the control system. While fail to safe mechanisms typically will take the ship to one or a few possible "safe" states, e.g., dead in water, more complex control algorithms have an increasing wider range of outcomes. The text to the right of the plot points give examples of such functions or outcomes.

In the context of the MUNIN project, autonomous control is defined as the ability to make complex decisions that may not be easily described through mathematical or logic formulas, but which still are constrained within certain predefined limits. An example of this may be autonomous collision avoidance constrained by the limitations of international conventions such as *International Regulations for Preventing Collisions at Sea COLREGS* [3]. This could be achieved through the use of automatic control routines supplemented by other technologies from the artificial intelligence domain.

If no constraints are defined, the system could be called "intelligent". This implies that the system has full freedom to take actions within its area of expertise and it cannot a priori fully know what the possible outcomes of the decision will be. Thus, "intelligent" is close to the idea of "fully autonomous" in the TP Waterborne description [2].

When remote control is included, the MUNIN onboard decision system may be illustrated as in figure 3.

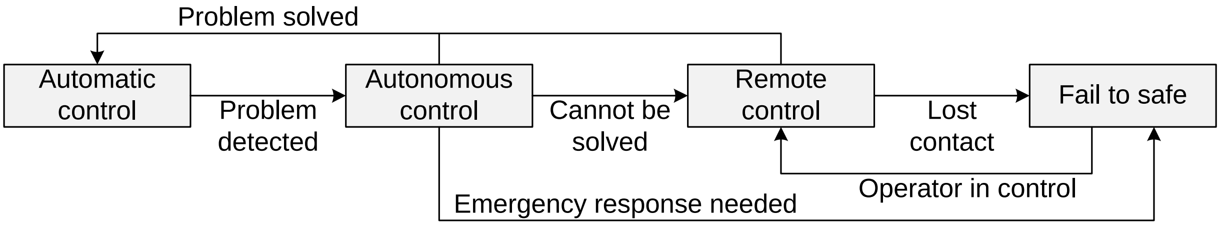

Figure 3 – Onboard decision flow in MUNIN

MUNIN would normally rely on automatic and fully deterministic control functions to run the ship. However, various sensor systems will be needed to detect problematic situations such as unexpected objects in the sea, dangerous weather conditions or danger of collision. If an unexpected situation occurs, an autonomous control module will be invoked trying to remedy the situation within its given constraints. If the system cannot achieve this, it will request support from a remote operator or start a fail-to-safe procedure if the operator is not available.

Referencing to figure 2, it can be seen that MUNIN proposes to exchange intelligent control with human intervention and use fail to safe as a backup when timely operator response is impossible. Properly implemented, this type of autonomy will reduce the need for human supervision while maintaining a high and well defined level of safety. "Intelligent control" will normally be less desirable as operational limits by definition cannot be guaranteed. However, a major challenge is to device sensor systems so that all relevant dangerous situations are detected and acted upon.

Autonomous robots have roots back to the artificial intelligence research starting in the late 1950s. However, more systematic developments can be said to start around 1980 and continued with various speed from that time up to today. Significant research on autonomous systems has been made, e.g., through the US DARPA funded ALV (Autonomous Land Vehicle) program and the EU Prometheus project. In Norway, the remotely operated vehicle designed in the 1990s program led to the development of the Kongsberg Maritime Hugin autonomous underwater vehicle[1], one of the few commercially available autonomous maritime vehicles available today. Thus, the history of autonomous control is long and the general principles for implementing autonomy are well known [4], [5].

However, autonomy is relatively few used in civilian applications. Most systems that claim to have autonomous control functions, even the above mentioned Hugin, are mostly automatic rather than truly autonomous or even intelligent. This is at least partly a result of the above mentioned tradeoff between increasing autonomy and determinism: The more autonomy that is assigned to a robot, the less controllable it is. The ultimate autonomous robot is the fully intelligent robot which in principle is not controllable at all, except by very high level objectives. Higher levels of autonomy will inherently increase the risk that the vehicle is lost or that it causes damage to other objects or humans.

Thus, a fully intelligent ship will have limited commercial utility as safety is difficult to guarantee and control of speed, fuel consumption and arrival times is more uncertain. MUNIN will develop the principles for a basically automatic ship, but with some capability to handle certain unplanned situations within defined constraints. These constraints will be based, e.g., on speed, weather conditions, route deviations, overall ship and environment safety and other factors. If situations develop where the autonomy constraints are violated, the ship will activate a remote controlled mode or in the worst case a “fail to safe” state. This operational "envelope" is indicated in the shaded area of figure 2 and in the flow chart of figure 3.

3 Rationale of unmanned shipping

In thus paper we claim that the most likely case for unmanned vessels will be the dry bulker. This kind of ship is typically rather slow, operates on long distances with only one loading and one discharging port and transports cargo that does not require much in terms of human

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[1] Hugin is the name of the other of Odin's two ravens. Hugin in old Nose means "though".

supervision or intervention during the voyage. In this case, implementing an unmanned vessel offers not only the possibility to increase the efficiency of ship operation but to enhance the sustainability of maritime transport as a whole. This should make the idea attractive for shippers and ship-owners as well as for seamen. In general, sustainable development consists of three dimensions [6], [7]:

- Economic sustainability: efficiency and cost effectiveness,
- Ecologic sustainability: environmental friendliness and
- Social sustainability: work safety and family friendliness.

3.1 Economic sustainability

The most obvious potential of unmanned vessels for maritime trade will be in terms of costs. Labor costs onboard are one of the main operational cost categories. In 2011, these costs are on average between 31 and 36% of the total ship operation costs for bulkers according to the *Drewry Report on Ship Operating Costs* [8] (see also table 1).

Table 1: Costs for dry bulker (data based on [8] and [9])

	Daily operating costs in US$ per day						
	Handysize	**Handymax**	**Supramax**	**Panamax**	**Post Pmax**	**Capesize**	**VLCC**
#Ships (2010)	2963	2124	n/a	1412	387	921	197
#Crew	18	18	18	19	20	20	22
Manning	1.779	1.779	2.247	2.359	2.366	2.648	2.662
Insurance	655	720	770	785	790	1.030	1.190
Stores/Lubes	610	625	650	770	780	875	1.010
M&R	1.590	1.634	1.837	2.099	2.370	2.622	2.765
Admin	651	651	700	749	793	837	833
Total OPEX	**5.285**	**5.409**	**6.204**	**6.762**	**7.099**	**8.012**	**8.460**
Man/OPEX	34%	33%	36%	35%	33%	33%	31%
Trip rates Past	18.640	36.840	n/a	32.760	n/a	65.660	n/a
Trip rates FC	17.700	30.950	n/a	16.283	n/a	19.300	n/a
Man/TR Past	10%	5%	n/a	7%	n/a	4%	n/a
Man/TR FC	10%	6%	n/a	14%	n/a	14%	n/a
Past:= Average 2006-2010		*FC:= Average forecast until 2016*			*TR:= Trip rates*		

If this is compared to the average trip rates for the last five years, manning expenses still account up to 10% of the charter. Looking on the expected future trip rates, it must be noted that the share of manning costs in relation to the achievable charter is expected to increase further, especially for large bulkers. Thus, unmanned or at least partly unmanned shipping offers a potential to reduce a significant part of the operational costs.

3.2 Ecologic sustainability

Besides efforts to increase efficiency, the shipping business also has to acknowledge an increasing awareness in the public of the environmental sustainability of maritime transport. While international shipping represents a relatively small part of current greenhouse gas emissions of about 3%, the industry has acknowledged that it also needs to contribute to future reductions [10]. One of the most obvious areas where fuel can be saved and emissions reduced is by slow steaming. Looking at an exemplary route from Porto de Tubarao to Hamburg, a transit speed reduction from 16 to 11 knots should reduce fuel consumption by about 54% and thus avoid about 1.000 tons of carbon dioxide emissions ([11], [12] and Table 2).

Table 2: Exemplary costs calculation to show slow steaming benefits (based on [11], [8], [9])

Route	**Porto de Tubarao -> Hamburg (Charter = average 2006-2010)**		**Change due to slow steaming**	**Porto de Tubarao -> Hamburg (Charter = forecast until 2016)**		**Change due to slow steaming**
Distance [nm]	5446			5446		
Speed [kn]	16	11	-31%	16	11	-31%
Time [d]	14,2	20,6	45%	14,2	20,6	45%
Fuel [t]	624,0	288,8	-54%	624,0	288,8	-54%
CO2 [t]	1.978,1	915,5	-54%	1.978,1	915,5	-54%
Charter [US$]	464.611,9	675.799,1	45%	230.935,0	335.905,4	45%
Bunker [US$]	405.613,5	187.722,0	-54%	405.613,5	187.722,0	-54%
Total [US$]	**870.225,4**	**863.521,1**	**-1%**	**636.548,5**	**523.627,4**	**-18%**
Manning [US$]	33.456,0	48.663,3	45%	33.456,0	48.663,3	45%
Manning/Total	3,84%	5,64%		5,26%	9,29%	
Distances by www.vesseldistance.com						

Of course, the idea to save fuel through slower transit speeds is not only motivated by environmental friendliness, but also by an economic rationale as slow steaming results in a tradeoff between bunker and charter costs. A general costs calculation of the same exemplary route is shown in table 2. Although bunker cost reductions of 46% represents a huge savings in money, this is offset by a correspondingly higher charter cost and the net benefit with the average charter rates are only on the order of USD 7000 over the voyage. However, an additional savings of USD 50 000 could conceivably have been made if the ship had been unmanned. Even with a relatively much more substantial savings on a forecasted lower charter rate, the manning cost could contribute an additional 50% to the USD 100 000 saved on normal operations in this case.

Economically, the benefits of slow steaming for this type of bulker are not very high given historical charter rates. However, if crew costs could be eliminated, one would get significant savings also for this trade. For lower charter rates, the crew savings will be less, but is still on the order of one third of the overall voyage savings for slow steaming.

Notwithstanding this development, slow steaming faces a further challenge. In the view of continuously raising trade volumes, a growing practice to use slow steaming will put significant pressure on the maritime labor market. In the current situation after the economic crisis, there is still a slight shortage of officers and many concerns about the availability of senior officers for the future [13]. A current market pool in Germany shows that 80% of the maritime stakeholders already claim a lack of nautical and technical officers [14]. Thus, slow steaming is likely to further increase officers' and crew wages [15] and by that also increase crew costs. This will ceteris paribus bias the economic trade-off between fuel and crew costs and consequently reduce the attractiveness of slow steaming. Furthermore, the slow steaming trend might lead to an even more critical lack of officers and thus blocking the concept in itself and hindering an obvious possibility to increasing the ecological sustainability of maritime trade.

In this scenario autonomous and unmanned vessels would provide a possibility to foster ecological sustainability and overcome the shortage of labor that might otherwise arise. Thereby, an unmanned vessel could diminish this effect as it focuses on the reduction of the demand side of the maritime labor market.

3.3 Social sustainability

Of course, in economic theory, a shortage of labor would lead to higher wages making it more attractive for workers and thus possibly solving the deadlock situation. It might be argued that instead of investigating automation technology, education and the labor market should be encouraged to avoid the described scenario. However, especially in Europe the labor market for seagoing personnel faces an inherent problem: It is unattractive for youngsters and suffers from an obvious lack of family and social life friendliness. In several studies, experts and institutions have highlighted that the isolation from family and friends as well as the decreasing ratio between sailing and berthing times make this profession uninteresting for Europeans, while at the same time the administrative procedures and technology developments continuously generates new requirements for seagoing officers [16], [17], [18].

Keeping in mind the expected reduction in sailing speeds, the ratio between aboard and ashore will get even higher and the solitude of deep-sea transit will increase significantly. Deep-sea voyage is in general characterized by routine technical operations and administrative tasks [19]. Therefore with more deep-sea time this might even further decrease the profession’s attractiveness.

While most of the deep-sea transit represents routine and undemanding tasks, economic pressure in the business has already decreased crew sizes to a minimum. When emergencies arise, human errors resulting from fatigue are one of the main causes for ship incidents worldwide [20]. In contrast, an autonomous and unmanned vessel would free officers from routine tasks and let them focus on more cognitively demanding and challenging tasks in a shore side operations center. As discussed in chapter 2, a shore side operations center where the autonomous vessel can be observed and remotely controlled is an important component of the MUNIN concept. This could ensure a more interesting working environment for the maritime professionals while also having the potential to increase the safety of shipping. Due to the fact that such a center would be located ashore, the navigating and engineering professions would get the same characteristics regarding family friendliness and social contact as a normal continuously manned workplace.

4 Challenges of unmanned shipping

It is doubtful if the unmanned merchant ships will be a reality in the short term. This doubt is not primarily caused by technical obstacles, although there certainly are some technical problems to be solved related to sensor and decision technology and, in particular, the increased technical system robustness that is required in unmanned ships.

The main problem is arguably the integration of the autonomous ship into the existing maritime transport systems as well as the lack of legal and contractual frameworks suitable for this type of ships. These issues are organizational rather than technical. One example is the *COLREGS* [3] which is central to safe navigation internationally. Due to their less deterministic nature and the intangible concept of good seamanship, it is currently rather challenging to incorporate them in a holistic automated navigation system of an unmanned ship [21].

The following subsections will give a brief overview of some important technical and organizational challenges.

4.1 Communication, sensor and control technology

Ships are already equipped with a number of systems to support remote or even autonomous operations: Shipping was among the first sectors to be allocated radio communication frequencies around 1910. Electronic navigation systems emerged in the 1930s and ships were among the first civilian adopters of satellite navigation. Anti-collision radar was made mandatory on ships from 1974 and automatic identification transponders from 2002. More advanced sensor systems such as low light and infrared television and small object radar systems are also available in the commercial market. Thus, one can argue that the technology needed to supporting autonomy is not the biggest challenge.

However, during the work on the MUNIN project the following main areas where more research is needed have been identified:

- Merging of detected targets from different sensor systems to classify into objects that either can be ignored, or that can be automatically avoided or that require the attention of a shore operator.
- Automatic avoidance of detected and recognized targets in accordance with good seamanship and established rules such as COLREGS [3].
- Reception of new sailing plans from shore or weather routing services and automatic and safe integration into current sailing plans. This may include remote control from pilot, vessel traffic service (VTS) or shore side operations center.
- Fail to safe functions in case of missing communication during critical operations or other unexpected situations, including assisted or automatic recovery from fail to safe modes.

4.2 Improved system robustness

Ship systems are today designed and built to utilize a combination of maintenance strategies to provide a sufficient safety and reliability level for the complete system. This includes the use of technical and operational redundancy, periodic maintenance intervals and the possibility to repair or replace components by the crew. In the case of an unmanned ship, the latter strategy is obviously not available. Operational redundancy where alternate work procedures are used to achieve a certain task may also be problematic when this involves use of crew intervention. Thus, a major challenge for unmanned ships is to improve the system robustness to a degree where the operator can have a very high confidence that critical subsystems will not fail during the trip. Some important research issues here include:

- Looking at critical system design and improving where necessary to avoid single points of failures with sufficiently high confidence.
- Current preventive maintenance procedures need to be updated to ensure operability during intervals at sea also for components that currently have been designed to be replaceable during voyage.
- Determining the need for new sensors as well as new procedures and analysis methodology to detect early signs of degradation and failure.
- Developing fail-to-safe procedures in case of major system failure. This needs to be complemented with appropriate recovery strategies.

4.3 Integration with existing transport system

Another challenge is the design of a ship concept that can be used in a world where the majority of vessels are still controlled by humans. This puts particularly pressure on an autonomous navigation system, as it also has to interact with manned vessels according to existing rules of road and practices for good seamanship. It also needs to include new concepts for rescue operations at sea. Some issues that MUNIN will investigate are:

- Remote pilotage including integration with ship and the shore side operations center.
- More advanced VTS with some direct control over ship and routes, again in cooperation with a shore side operations center.
- Participation of an autonomously operated ship in a search and rescue operation (SAR). This includes detection of emergency situations, e.g., identifying life boats or rafts and reporting this to the appropriate SAR authority.

4.4 Legal and contractual issues

One of the main obstacles to the fully autonomous ship is arguably existing regulations and contract forms. Some issues that will be addressed in the project are:

- Required updates to general laws of the sea. This includes liability for any accidents and the enforcement of the unmanned ship as flag state "territory".
- Required updates to technical and operational standards such as, e.g., the *International Convention for the Safety of Life at Sea* SOLAS [22] and COLREGS [3].
- Required changes to commercial agreements covering chartering, management and insurance.

5 Outlook

The concept of an autonomous ship provides one important pathway for a sustainable development for bulk shipping. MUNIN will investigate the feasibility of autonomous ships within the next three years by developing technical solutions and suggestions for legal and contractual changes for the challenges that unmanned vessels represent. The developed concepts will be validated in an integrated simulation prototype of an autonomous vessel. An explicit aim is to generate a solution that also allows updating the current fleet and which allows a gradual change from manned to unmanned fleets.

Although full autonomy may be difficult to realize, the results from MUNIN will have direct applications in the short term:

- Better navigation support and obstacle detection can reduce accidents by providing decision support for the officer of the watch.
- Small object detection can provide valuable assistance in search and rescue operations.
- Better maintenance strategies can reduce technical incidents and off-hire costs.
- Improved ship-shore communication and coordination can be used to simplify pilotage, VTS operations and management of the ship.

Thus, the expected results of MUNIN also provide a significant potential to make manned shipping safer and less stressful for the mariners in the near future.

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