Are modern safety systems leading to deficiencies in post-accident control measures?

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Abstract

Modern advances in technology and highly coordinated safety systems have successfully reduced the frequency of major accidents in the marine industry. Has this decrease in frequency come at a cost? The myth of an "unsinkable" ship went down with the Titanic and yet accidents resulting in loss of life still occur. On occasion the control measures put in place to mitigate against disaster are not sufficient due to reliance on human factors or technology which may not be available after the accident. This paper discusses the issues caused by the focus on pre-accident mitigation and scenarios deemed too implausible by hazard identification techniques.

1 Introduction

There are many hierarchies of risk control in place and followed as best practice across a number of industries. All of these hierarchies abide by the principle that, where possible, a hazard should be designed out to reduce the risk associated with a given task or operation. This has had a positive effect within the marine industry achieving a reduction of accident frequencies and severities, but with an unforeseen side effect.

By making the likelihood of an accident significantly lower the time, effort and ultimately money spent on control measures for that accident may be reduced, while still satisfying an As Low As Reasonably Practicable (ALARP) argument.

This paper will explore examples of accidents at sea, showing how the scenario was attempted to be prevented and how effective, or otherwise, the post-accident control measures were in reducing the accident severity. The major elements to be explored are the unforeseen side effects of the human factors and safety culture; declared the cause of most accidents at sea in the 2013 Safety and Shipping Re-view (Allianz, 2013).

2 Lessons from the past

A number of historical incidents have shaped the approach to maritime safety we have today. Undoubtedly the most famous of these is the loss of RMS Titanic in 1912. The sinking of a high profile vessel and the deaths of 1517 people, including many celebrities of the day transformed the approach to provision of life saving equipment on-board passenger ships and saw design improvements relating to watertight integrity and ultimately survivability of a craft until rescue was available. The International Convention for the Safety of Life at Sea (SOLAS) which is used today as the benchmark for maritime safety standards was born out of the events in the Atlantic that night. For example until that incident the provision of life boats was determined by ship size not number of passengers.

Further changes to vessel design for Roll On Roll Off ships and procedural controls to ensure watertight integrity control measures were improved after the 1987 capsize of the MV Herald of Free Enterprise shortly after sailing from Zeebrugge. This disaster that was accompanied by the loss of 193 passengers and crew, followed the failure by crew to shut the bow doors, resulting in water ingress and the subsequent free surface effect (Department of Transport, 1987).

Further changes in vessel design standards occurred in 1989 following the inquiry into the fire on board the Tor Scandinavia passenger ferry resulting in recognition that greater provision for fire fighting alarms and equipment was necessary. Although the ship was saved, two people died in the fire and had it not been for the actions of individuals this total would have been far higher after the failure of passenger alarm systems (Steele and Steele, 1996).

Over 100 years since the Titanic was declared by some, although notably not the designers at Harland and Wolf, to be "unsinkable", similar complacency is being shown by reliance on design to ensure safety while controls put in place post-incident are often found to be lacking when thoroughly exercised or called upon for real. With accident rates still averaging 9 losses a month globally (Allianz, 2013) the importance of controlling these risks remains high.

3 Regulation, design and emergency provision

It is clear that significant events, especially in this age of transparency and media coverage, are always followed by extensive inquiries and analysis to identify failings and root causes. Each subsequent tightening of design rules and modifications to procedures makes an accident less likely and improves safety, but as the perceived likelihood of an incident is reduced the potential for complacency grows. This section discusses how the lessons of accidents are translated into formal requirements by regulatory bodies.

Much has been written on the subject of ship classification and the rigours that are applied to ship design so this section will briefly outline the links between regulatory bodies, classification standards and the manner in which ships are operated and equipped in order to maximise the safety of the vessel and those on-board.

3.1 Regulation

Regulation at sea is laid down by the International Maritime Organisation (IMO). They have established best practice and protocols to be followed. In addition to this nations can set their own rules for their own waters or vessels operating under their flag provided the local rule conforms to the conventions of the IMO and is an enhancement, not relaxation of the rules.

Although they are the de facto arbiter of standards the IMO do not have any enforcement capability. This responsibility is passed to the Flag Sate Authority who will enforce the IMO rules and any of their own. Some countries have adopted significantly higher standards of safety, environmental protection and welfare which need to be met for a vessel to fly the flag of that country and be registered therein. Other nations have lower standards merely adhering to IMO minimum requirement and are often dubbed "flags of convenience" giving opportunity to circumvent improvements in best practice and thereby reduce the level of safety achieved; the second highest country for registered tonnage is Liberia with 99.10 million tonnes (Allianz, 2012), but its safety standards are below that of less popular flag states. In an attempt to deliver uniform implementation of the rules the IMO introduced an amendment to SOLAS in 1994 called the International Safety Management Code, or ISM code; although local variation still applies the ISM code reduces this variability of standards (Trafford, 2009).

3.2 Design and classification

The classification societies set the technical standards and specifications that must be achieved in order for a vessel to be certified as conforming to classification standards. This certification is not a warranty or guarantee of safety or that a vessel is seaworthy or fit for sea; it only certifies that a ship conforms to the standards developed and published by the society issuing the classification.

Design and classification also considers the future operating environment of the ship, for example any vessel wishing to use the Panama Canal must conform to Panamax (or new Panamax) criteria for size and tonnage, similar restrictions apply for the Suez Canal.

3.3 Emergency provision

As previously stated the SOLAS regulations detailing the Life Saving Apparatus (LSA) to be a carried by ships are a result of the 1912 Titanic disaster. Although the rules have been revised over the years the fundamental principle still remains that the ship in question should have sufficient provision of LSA appropriate to the vessel's size, number of passengers and task. The scope of SOLAS has also increased to include the firefighting arrangements onboard, first aid, radio communications etc. as well as details on technical specifications for vessels and their management and operation. Further details on vessel management and operation are described in the ISM Code issued by the IMO in response to the loss of the Herald of Free Enterprise.

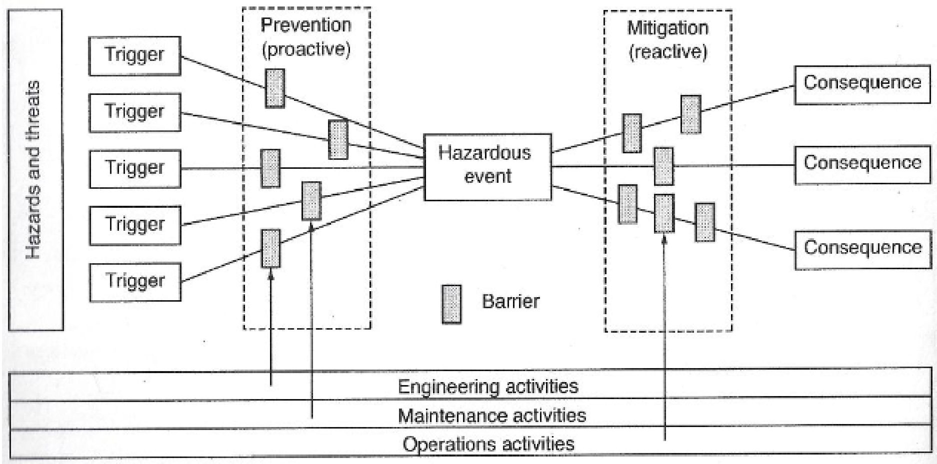
In addition to stating the equipment to be carried there are standards for the performance of LSA given in SOLAS. Additional product specification and quality checks are afforded through the work of other organisations. For example the European Union has detailed the Marine Equipment Directive (MED) to give de-tails on product requirements and manufacture of that product.

While the requirements for emergency provision are clearly defined it must be noted that these measures are reactive and are present to deal with the situations caused by failures of design or procedure that have led to an accident. This emergency provision will only reduce an accident severity post initiating event, not reduce the frequency of the event occurring.

4 Pre vs. Post Mitigation

The regulatory regime outlined in section 3 provides the basis for well-designed ships with systems that attempt to prevent failures through effective systems and controls. Secondarily it details measures to be taken to alleviate the severity of an accident where it cannot be prevented completely. The engineering response to a failure is to identify the probable causes and then design features to reduce the frequency of such an event. These design features typically form the barriers on the left hand side of a Bow Tie Diagram (Figure 1).

Fig 1. Bow Tie Diagram



In the context of marine accidents the threat would come from fire, collision or grounding while the control measures are typically designed features to meet regulation or best practice e.g. watertight integrity, propulsion and manoeuvrability. The recovery measures would include the LSA or firefighting equipment coupled with procedures for their use to prevent the consequences of loss of ship, loss of life, loss of cargo etc.

The engineering response of putting additional barriers in place to prevent the initiating event can result in a left loaded Bow Tie Diagram where focus is on prevention to the detriment of recovery. As will also be seen some of the recovery measures may not be available after an incident if there is insufficient resilience in design e.g. LSA being unavailable due to the list of the ship or electrical and hydraulic supplies for ship services being out of action after an incident. The other feature that can occur is that control measures are engineered design solutions while recovery measures are procedural and subject to greater variance because of the actions of the people involved.

5 Failures of designed control features

Globally the marine industry spends significant time and money to ensure that ships are well designed, maintained and operated. Despite this, accidents occur which result in loss of life, vessel and goods. The example of the Estonia (Figure 2) shows adherence to requirements; the provision of indicator lights for the status of the bow doors. However this design feature was insufficient to prevent the sinking of the ship when damage was sustained to the bow.

The passenger ferry Estonia was sailing between Tallinn and Stockholm when she sank on 28 September 1994. It was established at the subsequent inquiry that the bow visor (shown raised in Figure 2) that was designed to protect the ship's ramp and access to the car decks had suffered a catastrophic failure. This led to it separating from the hull and pulling the ramp open allowing water to access the car deck (HSVA, 2008). Although fitted, neither the door nor ramp sensors indicated as open on the bridge, because the nature of the failure was such that it did not move the sensor from the closed position. This system was a lesson identified after the Herald of Free Enterprise accident yet was not sufficient on this occasion to alert the bridge watch keepers to the failure that had occurred.

Fig 2. Estonia

The water that flowed onto the car decks caused a free surface effect and the ship to capsize in a manner similar to that of the Herald of Free Enterprise. On this occasion however the depth of water meant the vessel was lost with 852 fatalities. With the ship on its side evacuation was nearly impossible and most of the casualties failed to escape the ship before she sank. Of those that did make it to the upper deck approximately half perished in the cold water of the Baltic Sea (HSVA, 2008).

As with the Costa Concordia this accident shows that LSA can only be used in the right circumstances and that while in many cases the casualty vessel is the safest place to be, early preparations for evacuation are essential in case the situation deteriorates.

A second issue identified was associated with the bow door. Although the Es-tonia was built to the correct specifications, the bow door was more suitable for coastal work, not the heavier seas experienced out in the open waters of the Baltic (HSVA, 2008). Whilst this may not have precluded the Estonia from this particular route it should have seen a review of the maintenance schedules, especially the degree of material fatigue around the bow visor; the focal point for the wave's energy as the ship crossed the rough water. Faith in the design and classification approvals could have led to complacency in this regard. Modern ships will frequently pass to new owners across the course of their life in service and changes in their operating environment must be considered to ensure the applicability of existing checks and controls.

Without doubt the most prominent accident in recent memory is that of the cruise ship Costa Concordia (Figure 3). Unlike many accidents, where a ship will disappear beneath the waves, the wreck of the Costa Concordia has until very recently been sat on the foreshore of Isola del Giglio. Of note in figure 3 are the two life rafts hanging redundantly on the ship's port side unable to reach the water for evacuation and rescue.

Fig 3. Costa Concordia

Based on the account given in Marine Emergencies for Mates and Masters (House, 2014) the Costa Concordia was sailing on the 13 January 2012 when she manoeuvred too close to land and tore a 50 metre hole in the ship's port side. The ship soon began to list and lost power before drifting back onto the island where it came to rest. Of the 4252 people on-board just 32 died, but had the ship rolled over instead of resting on the shore this total would have been far higher.

A point of continued debate in the media, and in the courts, is the role of the crew in the evacuation, especially the senior members of the ship's company. It is understandable for passengers to be panicked and afraid, however crew responses should be more proficient especially when looking at the command and control of an evacuation. Crew responses are discussed further in subsequent sections. Fol-lowing Costa Concordia the cruise industry has already implemented further safety policies as a direct response; particularly with regard to passenger briefings and muster drills (Allianz, 2013). Although too late for the 32 that died this self-regulation and drive to greater levels of safety shows the positive stride in safety culture that are being made.

As the example shows once a significant list had developed (regulations allow for up to 20˚) the ability of crew to deploy and for passengers to use the life boats was severely limited and evacuation along corridors now became a desperate attempt to climb seeming vertical shafts. Costa Concordia carried the mandatory number of life rafts and lifeboats (125% of the maximum number of personnel on-board), however some of the equipment on her starboard side was out of use by being under the overhang of the ship or submerged while that on the port side could not be lowered to the water because of the list. Sadly this demonstrates that adherence to regulation and class requirements may afford sufficient equipment, but does not provide any guarantee that it will be available post incident.

While trials are conducted to establish evacuation times they are done in harbours and in controlled situations, not in the rapidly evolving scenario of a genuine emergency. In spite of compliant passengers and controlled environments simulated evacuations conducted on-board the Stena Invicta in 1996 saw just 315 of the 800 passengers evacuated within the target time of 30 minutes (Steele and Steele, 1996). Now imagine that scenario for a cruise ship, such as that in figure 4, with over 4000 passengers and crew on-board as was the case with the Costa Concordia and it is easy to see how such high loss of life can occur in a short space of time. Current regulations require evacuation within 30 minutes from the order to abandon ship with the ship to have sufficient systems to be able to sustain conditions to continue the evacuation for a further 3 hours (MSC Circular 1214, 2007). It is worth considering that the Herald of Free Enterprise, Sewol (discussed in the next section), Estonia and Costa Concordia all sank or capsized in less than three hours.

Fig 4. Cruise ship evacuation exercise

An additional example is that of the Costa Allegra (Figure 5). On 27 February 2012 she suffered a fire in the generator room. In a testament to the fire suppression systems fitted on-board the fire was extinguished and there were no casualties however the ship was left without power (Carnival Corporation and Plc, 2012). The ship was taken in tow by a French fishing boat and taken to the Seychelles for repairs.

It is once again interesting to see that although the ship dealt with the initial emergency, the follow-on actions to resume operations or evacuate passengers were hampered by the damage caused. In this instance a lack of power led to poor conditions on board. Passengers slept on deck to escape the stifling heat below deck and there was no hot food or sanitary facilities. Additionally there were security concerns because of the threat of pirates in the Indian Ocean.

As shown in other examples the ship carried the right firefighting equipment to successfully deal with a dangerous situation. However this incident shows that post-accident control measures are not always available and the severity of an incident may still be high even though designed counter measures are present. This is particularly significant given the relatively high number of fires on cruise ships; 72 between 1990 and 2011 (www.shipcruise.org, 2014).

It is not the intention of this paper to discredit the design process, technological advances or the adherence to standards. They are crucial to establishing the base-line of a vessel which is safe to function. However they must be considered in conjunction with the likely failures of the designed features and the behaviours of those involved when faced with such a failure, which is something that will be discussed further.

Fig 5. Costa Allegra under tow

6 Safety culture

It is very difficult to determine the safety culture that was present on-board the ships in question at the times of their accidents. Culture cannot be measured or established by referring to a shipping forecast or the passenger or cargo manifests as one would for physical issues in force at the time of an incident. In order for a culture to be effective it must be accepted by all those on-board regardless of their position or responsibilities (Ritchie, 2012). Although anecdotal evidence may exist of crew not following procedures or owners cutting corners or overloading a ship as a matter of routine it is very hard to substantiate or quantify this. There may be signs indicative of problems such as high rates of accidents or lack of audit trail or accountability for decisions which would suggest that a poor safety culture is in place. But these cannot be considered as definitive.

A recent example with clear evidence of a failure in safety culture is the loss of the South Korean ferry the Sewol, in April 2014 while on route from Incheon to Jeju Island. She capsized and sank with the loss of 294 of her passengers and crew, many of the passengers were secondary school students which increased the media attention on this accident.

Fig 6. Sewol

The inquiries into this loss have suggested that a sharp turn to starboard resulted in the cargo shifting and the ship developing a list from the offset loading from which she could not recover. The loading of the vessel with over 3000 tons of cargo was over three times the 987 ton limit, this coupled with a lower than recommended amount of ballast water being carried all contributed to the instability that ultimately led to the ship's sinking.

Parallels may be drawn to the Costa Concordia where the reactions of passengers and information from the crew were confused in the immediate aftermath and led to delays in evacuation. Sadly on this occasion the ship did not come to rest in shallow water and people drowned while trapped inside the hull. This again highlights the importance of preparing for the worst scenario with full evacuation in good time.

Also significant is the failure of those responsible to adhere to loading guide-lines and heeding warnings that the ship was overloaded. Much like the sinking of the Estonia the issues of loading were not inherent design issues. The ship was deemed safe by the flag state. It was the subsequent actions by owners and crew that led to an unsafe situation developing; a situation not identified by class or state inspection.

More significant to gauge the safety culture is the presence of a questioning attitude towards safety issues. In the case of the Sewol concerns were raised by a former master of the vessel that she was being routinely overloaded and the ballast was at a dangerously low level to accommodate this extra loading. Every accident is always accompanied by people being wise after the event, but it is clear that in this case concerns were raised, but played down by the operator of the ship. This has highlighted broader issues in the safety culture within the South Korean marine industry.

The South Korean regulator was very closely linked to industry which led to a lack of autonomy or genuine ability to look objectively at an issue without being embroiled in the commercial considerations; factors which should not be unduly influencing safety decisions. It is interesting to note that a very similar issue was experienced when looking at nuclear power in Japan and the shortcomings that led to the meltdown at Fukishima Daiichi. This highlights the broader cultural issues which must be overcome, in this instance the strong hierarchal nature of society in some countries which can lead to a failure to question those in a position of authority and investigate problems to the required level of detail.

Interestingly the system in the United Kingdom (and beyond) of classification operated by Lloyds began in Edward Lloyd's Coffee House where ship owners and insurance brokers would get together to share the risk of an expedition or voyage in return for a share of the profits. To agree an acceptable standard for vessels and judge the associated risks a form of classification was needed and this is the origin of the system in place today. This has, over time, seen the required separation of owners, brokers and classification to allow for an effective and objective system.

The safety culture of the ship in question must also be considered. The standards of safety, watchkeeping and overall adherence to standards will be driven by the senior management team on-board. In the case of the loss of the car carrier Tricolor (Figure 7) a number of issues can be seen. The ship itself was sunk in the English Channel in December 2002 after a collision with the container ship the Kariba. The loss of the ship itself is in many ways unremarkable and resulted in no loss of life, although 3000 cars went down with her.

Of greater interest are the subsequent actions of other ships. The Tricolor was resting on her side in approximately 30 metres of water and was only just sub-merged; consequently radio warnings were issued, a buoy positioned to mark the wreck and guard ships allocated. Despite this, another ship, the Nicola collided with the wreck the following night. Further buoys and additional guard ships were provided and yet approximately two weeks on from the original incident another ship, the Vicky also hit the wreck (BEAMer, 2004).

Fig 7. Tricolor

The point to note here is the failings of bridge teams on the Nicola and the Vicky to see warning signs of the new wreck. Procedures were followed by the authorities, but the failure of the watch keepers to adhere to the standards required by IMO regulations for prevention of collision at sea and the standards detailed in Standards of Training Certification and Watchkeeping (STCW) meant that follow on incidents still occurred.

A further point raised in the initial sinking is the confusion that the use of VHF communication caused between vessels when actions to avoid collision were being discussed. As designs and technological complexity increases the faith placed upon it increases too. In the sinking of the Tricolor discussions took place over VHF to try and avoid a collision. By relying on these communications and not seeing the situation unfolding before them a conversation was had with a different ship and as such the discussed collision avoidance and manoeuvring did not have the desired effect.

The example of the Tricolor shows issues that reflect poorly upon safety culture on board ships. The Nicola and the Vicky, which subsequently hit the wreck, both failed to keep an effective look out as required by the regulations so did not see the situation developing which ultimately led to collision. Instead complacency set in and the Navtex and radio warnings and presence of the guard ships went unheeded resulting in further accidents. On these occasions they were fortunate that the secondary accidents did not result in ships being sunk, lives being lost or significant environmental impact.

The final area of safety culture is that of the behaviour of passengers which will be discussed in the context of human factors.

7 Human Factors

Safety Culture extends beyond the management of a vessel and is crucial in its day to day operation. In the examples shown there are several failures of the crew who should be highly trained and familiar with emergency situations likely to face their ship. As seen by the prosecutions in the cases of both the Costa Concordia and Sewol responsibility is placed upon the crew of a ship to safely evacuate the passengers when the vessel cannot be saved.

On both occasions there are reports of senior members of the ship's company abandoning their posts before evacuation is complete and the communication with the passengers was poor, misleading and often slow in being given. This demonstrates poor leadership and a lack of safety culture where people know and understand their safety responsibilities.

The behaviour of crew should be easier to understand and predict; they have been trained to deal with the accident situations they are facing. The passengers however have been put into an unfamiliar scenario and things are starting to go wrong. Research has been conducted looking at passenger behaviour and some key observations made. As stated in section 5, trials of evacuation procedures are conducted on ships, but these will normally be in controlled circumstances and the passengers are often volunteers who will behave in a compliant fashion.

In the paper Human Factors Management of Passenger Ship Evacuation (Jorgensen and May, 2002) non-compliance effects are discussed. In short these are the tendencies for passengers to stick in family groups, or depart from muster points and take undesignated routes between locations to find friends or loved ones. Passengers may also choose to move away from muster stations following a self-preservation instinct; if mustered in a cruise liner's theatre the perceived safety of the upper deck can seem like a long way away which might lead to passengers moving of their own accord to the upper deck. This may in turn cause them to miss vital safety information or updates from the crew.

It is this tendency of the passengers to display non-compliance effects that mean a ship's company must be well drilled in controlling passengers during an emergency scenario and keeping them calm and well informed. This is something which can only be achieved through training and experience. It is important to understand that design features can be used to control the human factors witnessed. Adequate lighting (including emergency lighting) will enable passengers to see exit routes and keep them calm. Good stairway design and provision of hand rails coordinates the flow of people as they move around the ship reducing choke points. Understanding the likely reaction of individuals is as crucial to the design of layout and facilities as regulation or convention. Crucial too is effective communications, both from crew controlling muster routines and via public ad-dress (PA) systems. If passengers are informed and aware they are more likely to act as directed. Without this understanding of human factors it is not possible for the correct features to be designed into a ship or system.

It is human nature to trust a complex system (Lee and See, 2004). We assume that the greater the level of engineering involved the lower will be the probability of failure. While this may be true it does not absolve an individual from failing to follow best practice and pacing all their trust in one system. Indeed within the Convention on the International Regulations for Preventing Collision at Sea (IMO, 1972), the Highway Code for ships, Rule 2 Responsibility, states:

2. Responsibility

(a) Nothing in these Rules shall exonerate any vessel, or the owner, master or crew thereof, from the consequences of any neglect to comply with these Rules or of the neglect of any precaution which may be required by the ordinary practice of seamen, or by the special circumstances of the case

(b) In construing and complying with these rules due regard shall be had to all dangers of navigation and collision and to any special circumstances, including the limitations of the vessels involved, which may make a departure from these rules necessary to avoid immediate danger

To paraphrase; while the rules should be adhered to, sticking to the rules like dogma is not sufficient when judgment and common sense dictates otherwise and the situation requires alternative action. When considered in the broader context of engineered solutions and safety it is not sufficient to build in safe guards and controls if they cannot be demonstrated to be effective or work when put into a real world scenario.

8 Conclusions

It is clear that modern regulations detailing safety requirements have seen significant efforts put into the design of ships, systems and emergency equipment and procedures. These enhanced designs have led to systems that have ever higher levels of integrity and resilience and so improving the chances of surviving a major accident at sea. There remains though the possibility that a failure, no matter how remote, could still happen and that when it does the resilience of design is insufficient to deal with the scenario as it develops.

The safety culture in the broader industry and local to the ship are very important in two regards; adherence to rules, regulation and maintenance routines to keep a vessel operating as intended and then the training required to ensure familiarity with emergency procedures and actions.

While there will always be a degree of uncertainty as to how people will react the understanding of human factors will help in coordinating responses. Design features can be used to assist behaviour and passenger actions and good communications will keep passengers informed about the situation and increase the likelihood of them complying with crew instructions.

The key lessons to observe are that compliance with regulation and legislation are no guarantee of safety, systems fail and people panic, while the building in of suitable safeguards can mitigate this situation, but can never truly eliminate risk.

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