Risk of electronics failure on digitalization of shipping industry

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Abstract. While digitalization drives the development of autonomous ships, the risks rising out of digitalization were reviewed. Adoption of digital technology has many benefits, but the technology itself has its own faults, which will have users suffering from the learning curve. The digital devices onboard are not permanently reliable, and they can fail due to harsh utilization conditions, fatigue, or latent defects. As the shipping industry continues to move down the road towards digitalization, an alert need to be delivered ahead in order to minimize the potential future risks.

1. Introduction

Digitalization is becoming a key word within the shipping industry as various subsystems onboard are now being equipped with digital devices that enable them to measure speed, fuel efficiency, cargo temperature, etc. The onboard devices, such as communication systems, propulsion and machinery management, power control systems, and cargo management systems, are connected to the bridge system and onshore operation center located far away from the ship. This measurement data is then received by the central server and processed in order to produce data needed to operate the ship. The remarkable progress of digital technology is also pushing autonomous ships into development for commercialization in countries such as Norway, Japan, and Korea. The autonomous ship will reduce the number of seafarers on board and consequently human errors. Figure 1 shows various onboard measurement systems and the world’s first zero emission autonomous container ship Yara Bilkeland, developed by Yara and Kongsberg, and she will gradually move from manned operation to fully autonomous operation once launched [1, 2].
Though the immediate benefits from utilizing digital technology onboard are well recognized, there are a few points to review from a risk management perspective. Cyber threat for example is regarded as a major risk, because cyber attacks can corrupt a huge amount of data that is to be processed for operation, and can also paralyze fleet management systems and automated operation systems. Also, the recovery of data from a cyber attack itself will burden a considerable cost on the shipowner [3].

While there is no doubt about cyber threat being a major uprising risk following the digitalization of ship operations, particularly for those who handle massive amounts of operation data, it is worthwhile to note other potential risks that can rise from digitalization such as the lack of reliability of the electronics onboard.

It may be easy to assume digital products as being reliable or to even think their malfunctions as not serious. For example, troubles in consumer products such as mobile phones or home devices can be resolved by simple replacement. However, if electronic devices onboard malfunction during sail, it could lead to significant casualties, particularly when it is an engine controller that does not work properly while berthing in a harbor. In an autonomous ship, the digitalized automation system will play the role of crew, so the reliability of the electronics onboard is a necessity as crew play a crucial role in the safety of the ship.

A question could arise whether electronics are permanently reliable or whether they are vulnerable to wearing out and getting replaced like mechanical parts in an engine. This paper is intended to introduce the risk of electronics onboard as digital technologies are getting adopted to ships in a broad and swift manner. Various failure modes of electronics and past casualties of transportation modes caused by electronics will be discussed. Cyber threat will not be covered, as the shipping industry is well aware of those risks.

2. Incidents due to Failure of Electronics

It is unknown how many incidents at sea related to electronics failure have occurred in the past. It may be because of insignificant casualties triggered by electronics failures or the difficulty in finding the root cause of the incident in terms of electronic failure.

Starting with a brief of introduction of electronic hardware structure, two cases are shown in order to demonstrate how electronics failures can become catastrophic. Although the aircraft incident case in section 2.3 may be thought as irrelevant to ships at sea, the core lesson in terms of the significance of electronic failure can be seen.

2.1 Electronic Packaging

Electronics are built through an electronic packaging technology which interconnects chips and other electronic components into a circuit board. The effectiveness and reliability of electronics are determined by how they are packaged. Electronic packaging is composed of 1) electronic components such as a semiconductor, 2) Printed Circuit Board (PCB), and 3) solder joints that join electronic components onto the PCB through the soldering process. In the PCB, the solder provides electrical,
thermal, and mechanical connections. Solder joint reliability is one of the more critical issues in the development of the electronic packaging technologies. As the semiconductor gets smaller and denser, the electronic board assembly gets smaller in size as well. Also, electronic packages are exposed to various environments such as temperature, humidity, dust, shock, and vibration, which can all contribute to the failure of electronics [4].

![Solder joint components](image)

**Figure 2.** Semiconductor plastic package (left) and electronic components assembled on PCB (right) through solder by surface mount technology

2.2 *River Aframax Fire*

On 6 Sept 2016, the Tanker River in ballast collided with 2 mooring dolphins in the Houston Ship Channel. As a result, her fuel tank was punctured during the collision, leaking 88,000 gallons MGO. The conning pilot ordered all stops to avoid the collision, but the engine did not respond. Tugboats tried to slow the ship, but in vain. The spilled oil ignited and burned for about 45 minutes, shown in Figure 3. There were no human casualties, but there was damage to the tanker and other vessels [5].

The NTSB (National Transportation Safety Board) report showed that the heat generated from friction during the collision with the dolphins ignited the fuel and caught fire. The report concluded the electronic unit within the main engine governor actuator encountered a momentary abnormality. Therefore, the incident was caused by abnormal function of the electronic module [6].

![Tanker River on fire](image)

**Figure 3.** Tanker River on fire
2.3 AirAsia crash
On 28 December 2014, Indonesian airline, AirAsia Flight QZ8501 (Airbus A320), departed the Indonesian city of Surabaya for Singapore and its communication with air traffic control was cut off just 42 minutes after it took off. The aircraft was later found crashed into the Java sea, and all 162 passengers and crew onboard were killed in the crash [7].

Indonesian NTSC (National Transportation Safety Committee) report showed cracked soldering on the electronic module called the Rudder Travel Limiter Unit (RTLU), shown in Figure 4. The cracked solder resulted in the intermittent failure of RTLU and four warning signals were given throughout the flight. When the pilot powered off the circuit breaker to reset the system to resolve the issue, autopilot mode turned off and the plane crashed due to inability to control the aircraft. The maintenance record showed the RTLU malfunctioned 23 times over the previous 12 months and investigators have concluded the plane crash was initiated by cracked soldering within the electronic module [8]. Therefore, solder joint cracks can lead to intermittent failures or open circuits within electronics.

3. Failure type of Electronics
There are many different types of failures in electronic packaging due to defects from silicon, electronic components, and PCBs, but only a few are listed in order to provide example. In depth technical details are beyond the topic of paper.

*Failure by Use conditions/ Manufacturing/ Material*
Electronic packages are exposed to various environments such as temperature, humidity, dust, shock, and vibration. Temperature is the major cause of failure because the differences in thermal expansion between the chip and board induce thermal stress in the solder joints under normal operating conditions. Electronic packages can fail under dynamic loads such as shock or drop impacts and solder joints
between chips and PCBs can fail in a brittle manner. The failure of these solder joints under thermal and
dynamic loads can lead to an open circuit in electronics [9].
Electronic packages can also fail by poor manufacturing. Some latent defects were shown after using
the machine for some time. For example, a severe warpage of electronic board assembly, cold solder
joints that did not melt completely, and more can lead to failures during the manufacturing process [10].
Lastly, electronic packages can fail by material. In July 1, 2006, by the ROHS (Restriction Of the
use of certain Hazardous Substances in electrical and electronic equipment) directive, lead (Pb) in
printed circuit boards were banned. The transition into Pb-free electronic packages impacted the industry.
In 2006, a huge batch of Swatch watches were recalled and the Microsoft Xbox360, a video game
console device, had a high field failure rate of up to 20% [11,12].

Failure by No Fault Found
No Fault Found (NFF) is a common failure mode that presents symptoms like intermittent failures.
Failures do occur, but it works again if the device is rebooted. This instance is called NFF. The two
casualty cases introduced in section 2 of this paper can be categorized as NFF coupled with other types
of failure. NFF is found broadly in applications such as automotive, avionics, computers, telecom,
mobile phones, etc. NFF can be caused by various factors such as sneak circuits, printed circuit boards,
connector issues, component-PCB interconnect failures, component failures, manufacturing issues, etc
[13, 14].

Failure by Supply Chain Management
Diverse consumer tastes are pushing products into shorter life, lower costs, and faster time-to-market.
Supply chain management has become a primary interest to many companies as it involves outsourcing
parts in a global supply channel [15].
Effective supply chain management can be achieved not only by a purchasing team to outsource parts,
but by a strong lean organization of cross-functional teams where each team will deliver different tasks
such as: designing products, qualifying parts, testing products, finding the root cause of the failures from
prototypes and the field, manufacturing products, reflecting market changes, auditing suppliers,
outsourcing lower costs, handling logistics to meet leadtime, etc. The end goal of supply chain
management is to place functional and reliable products to markets, essentially meeting customer needs
[16].
Electronics build is challenging because electronics use numerous outsourced parts and services such
as contract manufacturers. Supply chain management, which includes qualification processes to screen
out poor quality parts and sufficient development time through prototyping and redesigning loops, will
be required to ensure a functional and reliable product. It is clear that poor supply chain management,
due to pressure for quick time-to-market, will lead to a loss in the reliability of products.

4. Conclusion
Digital technology currently enables operators located far away from ships to monitor various
measurement data for efficient automated ship operation using digital devices onboard, and the
remarkable progress of this technology has made it to the extent of the introduction of autonomous ships.
The digital devices onboard are built on electronic packaging technology. Electronics are not
permanently reliable, and they can fail due to harsh utilization conditions, fatigue, or latent defects
caused by poor design or manufacturing. Even more so, the nature of an electronic board being
manufactured through a complicated supply chain integration of many outsourced parts makes it
difficult to achieve a reliable electronics without effective supply chain management. Finding the root-
cause failure of electronics is not always a straightforward task. Smaller dimension factors of electronics
and pressure in time-to-market also risk the reliability of electronics. As ships move towards depending
more on digitalization and automation, conventional mechanical systems will be integrated even more
with electrical devices. Therefore, failure of electronics onboard ships will result in a whole mechanical-
electrical system malfunction.
The certain transition into digital technology will launch ships equipped with automated and autonomous equipment, which will then change the way conventional shipping business is done. The effect will impact the legal system, the culture, and the risk. As a whole, the point this paper is intended to deliver is although utilizing the technology may result in benefits such as efficient operation and lesser costs, the shipping industry may suffer from the steep learning curve. This paper also gives the shipping industry an alert of the risks of moving further down the path of digitalization. Along with this alert, the short notes are suggested.

- For the shipping industry to consider prequalification inspection for electronic devices onboard and to maintain use of them according to product life.
- To put efforts in finding the root-cause of electronic failures, so that the industry can collect data to avoid future errors.
- Marine insurers may start to consider product liability for electronic products onboard, which will eventually replace crew in the era of digitalized and autonomous ships [17].

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