The Electrification of the Marine Industry
By Jan Emblemsvåg

All technological changes follow certain predictable patterns typically referred to as Kondratiev (often spelled as “Kondratieff”) waves or cycles, named after the Russian economist Nikolai Dmitrievich Kondratiev (1892–1938). It is generally acknowledged that these cycles typically last approximately 50 years for the world economy at large. More accurate timing, however, is not always easy to predict, and there is also a question regarding if it is the technological changes that cause the Kondratieff cycles or the economy that drives technological changes. Although there is no universally accepted precise description of these waves and how they work, most tend to agree that it is technology that drive these cycles. It was van Gelderen and Schumpeter that first saw technological change in a wide sense as a driver of these waves (Figure 1).

Regardless of the question of cause and effect, industries are affected by this process. If we analyze the Kondratieff cycles more closely, we will notice that there are similar, shorter cycles covering industries and minor technological changes. Although major changes take time, they typically consist of many of these shorter cycles that converge into a new path-breaking technology.

For example, the sail ship effect is well known in innovation. It took decades to displace sail ships by...
steam ships because improvements were made in sail ships that kept them competitive longer. More recent, and more relevant to the discussion here, is the introduction of the personal computer (PC). The PC required no fewer than the following six separate strands of knowledge:

1) binary arithmetic
2) the concept of Charles Babbage (1791–1871) of a calculating machine, in the first half of the 19th century
3) the punch card, invented by Herman Hollerith (1860–1929) for the U.S. census of 1890
4) the audion tube, an electronic switch invented in 1906
5) symbolic logic, which was developed between 1910 and 1913 by Bertrand Arthur William Russell (1872–1970) and Alfred North Whitehead (1861–1947)
6) the concept of programming and feedback that came out of abortive attempts during World War I to develop effective anti-aircraft guns.

Although all the necessary knowledge was available by 1918, the first operational digital computer did not appear until 1946. The point is that much knowledge existed in small pockets that were not interconnected for a long time. The information for a number of major technologies is shown in Table 1.

Although much knowledge exists in small pockets that are not interconnected, as the web of knowledge grows and the speed of search and transfer increases, these pockets can be found more and more effectively, and this brings us probably to the core of the disagreements concerning speed of development and time. As Chauncey Starr points out, ...the time from conception to first application (or demonstration) has been roughly unchanged by modern management, and depends chiefly on the complexity of the development. However, what has been reduced substantially in the past century is the time from first use to widespread integration into our social system.

In other words, the speed of inventing has remained largely unchanged, whereas the speed of commercializing it into an innovation and diffusing it into society has been substantially reduced.
TABLE 1. The time lag (years) between discovery and application for several relevant technological events.

<table>
<thead>
<tr>
<th>Event</th>
<th>Discovery</th>
<th>Application</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photography</td>
<td>1727</td>
<td>1839</td>
<td>112</td>
</tr>
<tr>
<td>Steam machine</td>
<td>1769</td>
<td>1854</td>
<td>85</td>
</tr>
<tr>
<td>Telephone</td>
<td>1820</td>
<td>1876</td>
<td>56</td>
</tr>
<tr>
<td>Radio</td>
<td>1867</td>
<td>1902</td>
<td>35</td>
</tr>
<tr>
<td>Radar</td>
<td>1925</td>
<td>1940</td>
<td>15</td>
</tr>
<tr>
<td>Transistor</td>
<td>1948</td>
<td>1953</td>
<td>5</td>
</tr>
</tbody>
</table>

Information in table from J. Grompone (see “Further Reading” section).

This is important background for the discussion surrounding the overall electrification—including digitalization—of the marine industry. Although the diffusion of technologies is much quicker on average than in the past, it is likely that a major shift in the marine industry will also take time, perhaps several decades. How long is impossible to predict, but it will come. The question is how? When it comes to the broader electrification of ships, that transition was used in a number of U.S. navy vessels. After the war, it has grown in application due to its versatility and fuel efficiency in a number of operational modes.

In the early 20th century, those working toward the invention of the car experimented with fossil fuels, steam, batteries, and other elements. But batteries were used in ships even earlier. In 1839, Moritz Hermann von Jacobi (1801–1874) constructed a 28-ft electric motor boat using battery cells (according to Wikipedia). The boat took 14 passengers on the Neva River against the current at the speed of 3 mi/h. Indeed, small boats were very popular from the 1880s until the 1920s, when the internal combustion engine took dominance. Batteries in larger vessels were piloted toward World War II, as they were a crucial component in submarines. Batteries were used when the submarines dived, but it stopped there. The challenge has been the quality of the battery technology: both its ability to store enough power for larger vessels and also its recharging time. However, recent developments in battery technology have sparked the idea of using batteries on surface vessels again. There are already several vessels where batteries serve as load balancers (in various hybrid diesel-electric propulsion system configurations), reducing the need for running the diesel engines up and down and thus saving fuel. There is also a ferry in Norway in operation that runs entirely on batteries (Ampere) on the Lavik/Oppedal fjord crossing. With a transit time of about 20 min, batteries work well.

Digitalization, however, is a far newer concept relating to the overall use of information technology in society. It is therefore safe to assume that the volume of marine digital equipment can be traced back to the 1980s, and since then, it has grown enormously. However, as always, some technologies come earlier and slowly. The dynamic positioning (DP) technology came in 1961 with the drillship Cuss 1 as a manual solution, but the same year, Shell launched the Eureka equipped with thrusters capable of rotating 360°, an analog controller, and a basic taut wire solution. Eureka was the first true DP vessel, and the man who made this possible was Howard Shatto. He worked in Shell and pioneered the idea of DP using analog technology. However, in 1967, it went digital. A major player in the corporate side was Kongsberg with Nils Albert Jenssen, and on the academic side, Jens Glad Balchen (1926–2009) of Norwegian University of Science and Technology (NTNU) was instrumental.

The big strategic question many grapple with in the marine industry is “Where do we go from here?” To better understand that, it is useful to discuss the end state first. There is no doubt that, for a number of market segments, where point-to-point logistics is the modus operandi, the end state is fully automatic vessels or drones. This would include smaller ferries crossing sounds, straits, and fjords with batteries only and short-sea and all ocean-crossing vessels using various configurations of the hybrid diesel/hydrogen-electric propulsion system. At the other end of the scale, we find passenger vessels such as cruise vessels and large ferries crossing seas and oceans. Regulations are likely to prevent full automation of these vessels just like we still have pilots in the airplanes today for safety reasons. In between, we find different types of work boats such as tugs, offshore vessels of different categories, and fishing vessels. These various modes of digital assistance are presented in Figure 2. Today, we are in manual mode for all vessel types, although there is an increasing number of vessels having remote health monitoring and assistance. This is just the first step in the direction toward either fully automatic vessels or autonomous vessels.

The systems that will come will also likely be able to switch between the modes, which will require some
manpower on shore or on the vessel (as in the case of passenger vessels). The Maritime Unmanned Navigation Through Intelligence in Networks (MUNIN) project has defined this, as shown in Figure 3. However, we have seen different developments within the various market segments of the marine industry related to their needs. This is likely to continue; therefore, when we talk about the digitalization of the marine industry, we must keep in mind that some segments will be earlier than others. There are three reasons for that.

First, technological maturity will be crucial. Vessels going point-to-point (PtP) are naturally easier to make autonomous than vessels going a little bit here and there, doing some work and then some transit, and so on. However, rest assured, these vessels will also become heavily digitalized but differently and more slowly because the payback is lower, as discussed later. As of today, the digital technology is immature, but it is also likely that the mechanical technologies in the

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**Figure 2.** Modes of digital assistance. (Image courtesy of the MUNIN project.)

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vessels must be improved considerably concerning reliability and maintenance intervals as well. Otherwise, automatic mode will not be reliable enough. Essentially, the level of ambition must be that a vessel should travel at least 30,000 km without any maintenance needs or alarms or repair, like a modern car. It is likely due to the safety aspects that such demands will become part of the regulations, as discussed later. The vessels that will take the longest to automate, if at all, are passenger vessels, just like in airplanes today, which in principle can be flown without a pilot, there is the psychological aspect for the passengers of having their life at the mercy of a machine [for example, artificial intelligence (AI) using big data to assemble and analyze vast amounts of data before making decisions] that seems very hard to overcome at present. However, this can change after decades of experience with automatic shipping if the track record is so good that there is a compelling case for letting the AI take over routine jobs such as guiding a vessel from a point to another point via a defined route. In the foreseeable future, passenger vessels can therefore be equipped with health monitoring and possibly some remote controlling to help them in certain harbors.

Second, regulations are the most significant hurdle as of today. Various nation states have a number of incentives for digitalization depending on their socio economic development. A poorly developed country would want employment and hence not be too interested in such a development. This is particularly true for industries such as shipping and ship building, which are both seen as a low-entry industries for many developing countries. Different nation states therefore also have different interests in how these industries should develop. It is therefore likely that progressive states like those in northern Europe will move first. They have a cost disadvantage today and will normally welcome automation/robotization in general. We will consequently see autonomous vessels in these waters first. Indeed, in Norway, the first autonomous ferries for short fjord crossings are underway.

However, it is beyond doubt that the largest savings are from crossing the world oceans. This will require international agreements on a completely different scale. After all, having an autonomous vessel at 50,000 t traveling around should be of interest to regulators from both traffic management and safety points of view. The safety aspect will be huge and involve equipment reliability, network reliability, failure modes, AI performance, redundancy, etc. Today’s performance levels of marine equipment are not sufficient for automatic mode. It is therefore likely that remote and autonomous modes will come first. Health monitoring is available today and used by a number of vessels, so the step to remote mode is definitely within reach in the next few years. Both Kongsberg and Rolls-Royce Marine, to mention just two companies, are working hard on this issue.

Third, the economic performance of the new technology is usually closely linked to the needs, the willingness to pay for these needs, and what can be simplified/improved compared with incumbent technologies to reduce costs. At the end of the day, it is likely that in the marine industry, being so dealing oriented, that cost will be the deciding issue after regulatory requirements are met. The complete elimination of crew is therefore an important goal because crews constitute approximately 25% of operating expenses (OPEX). This is where vessels going PTP will have their greatest advantage over work boats of various shapes. However, there is a subsequent advantage as well. Once the crew is eliminated, the transit time is less of an issue from a cost perspective. Indeed, by reducing the speed, fuel can be saved. With fuel constituting approximately 50% of OPEX, great savings can be achieved here if the speed is reduced. For example, a containership of around 8,000 TEU would consume about 225 t of fuel per day at 24 kn, whereas at 21 kn, this consumption drops to approximately 150 t/day, which is a 33% decrease. Clearly, the potential for cost savings is staggering—roughly 50% compared with the OPEX today—if the digitalization at sea takes a similar route as it is doing in many other industries. There is no reason to believe that this will not take place.

In the remainder of this issue of IEEE Electrification Magazine, we will read about the latest technologies from a number of sources. I think that it will be demonstrated quite amply that technologies are moving toward the scenarios outlined here. The only questions are when and how quickly.

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**Figure 3.** Switching modes. (Image courtesy of the MUNIN project.)
Major technological changes come and go, but it may take decades before all complementary technologies are developed and available for a major innovation to take place. The electrification and digitalization of the marine industry has been underway for some time already, but with the advent of big data and AI, there now seem to be more well-founded reasons for believing that automatic ships and autonomous ships can start to be designed, built, and operated. Even when the first autonomous ships are in place, it is likely that it will take decades before we have a major fleet of such vessels roaming around on the seas of the world. This is partly due to the life span of ships, socioeconomic development in various countries, economic performance, and ship types. However, there is no doubt that the end state of automatic/autonomous ships will be nothing short of a revolution in terms of the OPEX levels of shipping. However, technologies must mature, regulations must be in place, and the cost/benefits must be positive before we can expect major changes.

For Further Reading

J. van Gelderen, “Springvloed Beschouwingen over Industrielle Ontwikkeling en Prijsbeweging (Spring tide, reflection on industrial development and price fluctuation),” De Nieuwe Tijd, vol. 184, no. 5 and 6, 1913.


Biography

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