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Innovations in Dutch Shipbuilding: A Systems of Innovation Approach

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Originating in a small country with a limited home market, Dutch firms have long been active on a global market. Before the twentieth century their dependence on foreign technical knowledge was striking. The adaptation and subsequent distribution of foreign innovations were common in most industrial sectors. During the nineteenth century, the Netherlands was a country that lacked a strong knowledge infrastructure. This situation changed during the twentieth century. Due to this developing knowledge infrastructure, also referred to as a national innovation system, the innovativeness of Dutch industrial enterprises gradually grew. In this paper, we focus on the shipbuilding sector, which operated in an international market, and address the question of how its innovative capacity evolved over time. Was the Dutch industry able to compete with foreign companies or did they remain "followers" with respect to innovation, and how important was the national innovation system in this respect? To answer these questions we examine the market situation and product as well as process innovations in the first half of the twentieth century. We focus on the whole constellation of actors in Dutch shipbuilding, their relations, interactions, and interdependence, as well as on the institutional setting, to gain a better understanding of the innovation processes in Dutch shipbuilding in the first half of the twentieth century.

Residing in a small country with a limited home market, many Dutch firms have long been active overseas.[1] The international orientation of most

[1] This paper is based on Hans Schippers' with the assistance of Harry W. Lintsen, "Het scheepsbouwcomplex" in Mila Davids, ed., "Industriële Productie" part three in Schot e.a., *Techniek in Nederland in de twintigste eeuw* (Zutphen, 2003), part VI, 339-56 and on Hans Schippers, SHT-rapport "Shipbuilding" Feb. 2002 for Cluster Industriële Productie and Hans Schippers, "De Nederlandse scheepsbouw in de 20e eeuw: een overzicht," *Spiegel Historiael* 39, nr.2 (Feb. 2004): 76-81.

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enterprises, however, is not limited to the export of (final) products. The import of raw materials, components, and machinery has always been important for Dutch industry. Moreover, its dependence on foreign technical knowledge before the twentieth century was striking. The adaptation and subsequent diffusion of foreign innovations was common in most industrial sectors. During the nineteenth century, the Netherlands was a country lacking a strong knowledge infrastructure. This situation changed during the twentieth century when several companies, such as Shell and Philips, started their own research laboratories. Cooperation among universities, industrial companies, and the government grew and societies of engineers and scientists emerged and became important platforms for knowledge exchange. Due to this developing knowledge infrastructure, also known as the national innovation system, the innovativeness of Dutch industrial enterprises gradually grew.

We examine the shipbuilding sector, which operated in an international market, and address the question of how its innovative capacity evolved over time. Was the Dutch industry able to compete with foreign companies or did they remain "followers" with respect to innovations? How important was the national innovation system in this respect? To answer these questions we focus on the market situation and product as well as process innovations in the first half of the twentieth century. We use the "systems of innovation approach" to study the innovation processes in Dutch shipbuilding.

The Systems of Innovation Approach

The "systems of innovation approach" emerged during the last decades of the twentieth century from the work of authors such as Bengt-Åke Lundvall, Chris Freeman, Richard Nelson, and Charles Edquist.[2] The number of publications on innovation systems increased considerably in the second half of the 1990s.[3]

Although there is no standard approach and important nuances in the interpretation of the concept exist among leading scholars, there are several characteristics that the various "system of innovation (SI)

[2] See, for example, Giovanni Dosi et al., *Technical Change and Economic Theory* (London, 1988); Charles Edquist, ed., *Systems of Innovation: Technologies, Institutions and Organisations* (London, 1997); Bengt-Åke Lundvall, ed., *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning* (London, 1992); Bengt-Åke Lundvall, "National Business Systems and National Systems of Innovation," *International Studies of Management and Organization* 29 (Summer 1999): 60-77; Richard R. Nelson, ed., *National Systems of Innovations: A Comparative Analysis* (Oxford, 1993).

[3] A bibliographic search up to 1998 found 255 titles explicitly making use of the concept "innovation system," of which 30 were published before 1992, about 30 annually after 1992, and 40 in 1997. The first publications on this subject also stimulated efforts to locate regional, technological, and sectoral systems of innovation.

approaches" have in common. The starting point is that innovation processes occur over time, they evolve, and many factors influence them. They occur in interactions between institutional and organizational elements, which together we call "systems of innovation."

The SI approach places innovations at the center. However, authors differ in their interpretation of innovation. Some include only technological innovations (product and process innovations) while others, in the tradition of Schumpeter, also include new organizational processes. They all share the assumption that innovation processes do not follow a linear path, but are interactive, characterized by complicated feedback mechanisms with complex relations involving science, technology, learning, production, institutions, organizations, policy, and demand.[4] Although most innovations occur in firms, the innovative firms interact with other organizations in an institutional setting to gain, develop, and exchange various kinds of knowledge, information, and other resources.

The SI approach, therefore, stresses the importance of organizations, institutions, interactions, and interdependence. Organizations can consist of firms, suppliers, customers, and competitors as well as non-firms such as research institutes, universities, schools, government agencies, and financing organizations.[5] The relations between the innovating firm and the various actors are important, because interaction and interdependence are considered crucial for innovation processes. The institutional context not only shapes the organizations, but also the interdependencies among them. Therefore, the context should be included in the analysis. Here we define institutions as "rules of the game" (for example, patent laws, technical standards, cultural norms, routines, habits). They constitute incentives and/or constraints for innovation. We can differentiate between institutions created by design (technical standards, patent laws) and those that have evolved spontaneously over extended periods (cultural norms, social rules). Through institutions, the wider social and cultural context also influences the behavior of firms.

We often see environmental conditions as specific to local, regional, or national contexts. The first studies of innovation systems focused on national systems of innovation. Later, the criteria used to define systems of innovation included supranational, regional, and local systems of innovation. Researchers often identified and studied these in comparison with national systems of innovation. The approaches complement rather than exclude one another. We, however, do not, limit our study to one spatial level, but focus on shipbuilding, using both the insights of those who examine sectoral systems of innovation and a similar approach that

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[4] Edquist, *Systems of Innovation*.

[5] Here we follow Edquist who explicitly categorizes research institutes and universities, for example, under organizations and not under institutions.

starts with technological systems.[6] One of the questions we address is: On what levels (international, national, regional, or local) is the shipbuilding innovation system active?

The starting point of the SI approach is that innovation processes take time and have evolutionary characteristics, that is, the processes are often path dependent over time and open-ended. In the SI approach, researchers often take a long-term perspective. "History matters!" is a common expression, so we will consider the utility of this approach for historical research.

The Shipbuilding System

We begin with an overview of the actors involved in the shipbuilding sector and the links between them, using the market situation for shipbuilding and shipping. The most striking feature of both shipbuilding and shipping is their international character. A ship is typically a capital good and as a means of transport itself, easily transportable all over the world. The shipbuilding market can expand across national borders and can be very competitive, because national restrictions and regulations do not limit this expansion. The shipping market is also very competitive and global in character, because the essence of the sector is mostly international transport. Thus, even before the decades of globalization, this was a global sector.

Shipping and shipbuilding are closely related. Market upswings in shipping increase the demand for new ships and vice versa. In the shipping business economic fluctuations occur frequently and are strongly felt. To make efficient use of the production capacity on the shipyard a steady stream of orders is necessary. Therefore, most shipbuilding companies also do repair work to compensate for periods when shipbuilding orders are down.

The shipbuilding industry, however, has never been a uniform entity; diversity was and is considerable. One way to classify the sector is by the kind of ship produced: large sea ships for intercontinental transport, navy vessels, coasters, barges, and smaller ships for fishing. Other firms concentrated their activities on repair or specialized in parts supply. Shipbuilding companies also differed in size. Small yards with less than fifty employees mostly made smaller ships or parts to order, without having their own design departments. The medium-sized companies (50-500 employees) sometimes made smaller vessels based on their own designs, but mostly worked with the customer's design

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[6] See amongst others Stefano Breschi and Franco Malerba, "Sectoral Innovation Systems: Technological Regimes, Schumpeterian Dynamics, and Spatial Boundaries" in Nelson, *Systems of Innovation,* 130-56; Bo Carlsson, ed., *Technological Systems and Economic Performance: The Case of Factory Automation* (Dordrecht, 1995).

department or with an independent design office. Large shipyards (500-100 workers) and very large ones (with more than 1000 workers) built large sea ships for merchant shipping or the navy. Sometimes they were also active in the offshore sector, for which they constructed vessels and installations for the exploitation of gas and oil at sea. They made most of their designs and drawings in their own design departments. Often, the larger yards were huge industrial complexes themselves, with their own machine factory, foundry, and electro-technical department. However, these classifications are not static; they changed considerably during the twentieth century.

Shipping companies were the most important customers for the shipyards. Orders from the navy were another essential pillar for most shipyards in the Netherlands. The nature of the relationship between the shipyard and the customer could vary considerably. When there was no structural, financial, or contractual relationship between the yard and the shipping company, the company was free to choose among various shipbuilders (Dutch or foreign). However, in most occasions there were long-term relationships between customers and builders. Sometimes shipping owners co-financed shipyards, thereby insuring they had a decisive say in the building process. An exclusive relationship also existed between the navy and a few large shipyards. Because the navy invested a substantial amount of research and development, it possessed a lot of expertise. Sometimes large shipping companies also had such a concentration of knowledge.

The relationship with suppliers also could be very close. Many shipyards were dependent on specialized suppliers for various parts of the ship (for example, steelworks, manufacturers of boilers, machines and motors, propellers) and for the production process (for example, welding equipment). The larger yards often integrated these suppliers, having, for example, their own machine factory and forge.

Other actors in shipbuilding were schools and research institutes, government agencies, investment banks, classification societies, insurance companies, subcontractors, etc. For the workforce traditionally labeled as skilled labor, formal education became increasingly important from the end of the nineteenth century onwards. A growing number went to technical schools.[7] At the same time, the larger yards set up in-company training.[8] Engineers who found their way to the shipyards came from the department of shipbuilding, started in 1864 at the Technical Polytechnic in Delft. These naval architects also found work in engineering firms, design

[7] In 1904, 32 technical schools existed with more than 4,500 students; by 1938, there were 31,000 students in 110 schools.

[8] Frans Meijers, *Van Ambachtsschool tot LTS* (Nijmegen, 1983) 72, 88, 89; Giel van Hooff, *In het rijk van de Nederlandse Vulcanus* (Amsterdam, 1994), 164-165; J. A. Goudappel, *Machinefabriek en Scheepswerf P. Smit Jr.* (Rotterdam, 1994), 27.

agencies, and maritime research institutes, all established in the first half of the twentieth century.[9]

Classification societies played a very important role in the development of Dutch shipbuilding. Classification originated in the United Kingdom in the eighteenth century to spread the risk of insuring both cargo and ship. In 1760, the first *Lloyd's Register of Shipping* was published. This listed classified and insured ships. A place on the list was assured only when the ship was surveyed periodically and was built in accordance with specific "Rules and Regulations" of Lloyd's on the dimensions (length, width, and depth) and building material. Lloyd's, active in the Netherlands from the 1830s onwards, in 1864 appointed three surveyors and opened an office in Rotterdam (the first on the continent). The French bureau Veritas also classified Dutch ships. No classification society was of Dutch origin. In the process of design, these societies' building regulations played an important role; they prescribed the quality of materials, building procedures, and so forth. Moreover, a classification society had to supervise the building process and monitor the quality of the material used. They also had a role with respect to maintenance. Remaining registered required surveying the ships annually and a maintenance service every 4 years. Even after repair activities, a survey was required, and the classification societies sometimes prescribed the repair yard.[10]

The classification societies initially confined themselves to the higher segments of shipping. In the lower segments abuses existed. Overloaded and highly insured ships in bad condition led to numerous shipwrecks. From 1885-1900 more than 440 fishers died. In the first decade of the twentieth century, regulations were instituted and a Dutch shipping inspection bureau (Scheepvaartinspectie) established to end these abuses. No ship could leave a port without a permit. To receive such a permit the ship had to meet specific standards concerning the ship itself (internal and external construction, installation or motor, and so forth), its loading, and safety (for example, alarm installation, life-saving appliances, telegraph [later radio] equipment). The shipping inspection and classification societies, whose work partly overlapped, increasingly worked together.[11]

All these organizations and the institutions for which they were responsible played a role in the innovative development of shipbuilding in

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[9] Jan-Willem. Bonebakker, *Rede uitgesproken bij de aanvaarding van het ambt van hoogleraar in de scheepsbouwkunde* (Delft, 1946), 18, appendix 2.

[10] G. de Rooij and F.N. de Rooij, *Practical Shipbuilding* (Haarlem 1962) part A, 29, 30; Frits Loomeijer, *125 jaar Lloyd's Register in Nederland* (Rotterdam, 1993), 4-10.

[11] F.W. de Klerk, *Klink Los!* (Amsterdam 1933) 147-49; Dirkzwager, ibid., 51, 52; H. Zunker, *Notitie Geschiedenis van de SI* (Rotterdam, 2001), 1.

the first decades of the twentieth century. The central question is to what extent they stimulated and to what extent they hampered innovations.

Shipbuilding in the Netherlands from 1900-1950

In the nineteenth century, shipbuilding made the transition from the use of wood and wind to iron and steam. Improvement in the economic situation in the Netherlands from 1895 onwards stimulated international trade, and shipping increased. Increasing agricultural production in the Dutch Indies, who traded goods in Europe, also stimulated this development. The number of ships under the Dutch flag went from 79 in 1890, to 193 in 1900, and 347 in 1909. Capacity also increased considerably (200 percent between 1890-1909).

More than half of the new ships were built in the Netherlands. In this period, new shipyards emerged next to the existing ones (Fijenoord, De Schelde in Vlissingen and the Nederlandsche Scheepsbouw Maatschappij [NSM]). Shipping companies often provided financial help for new yards, for example, Gusto, the Rotterdamse Droogdok Maatschappij (RDM), Wilton, Van der Giessen, and Piet Smit Jr.[12] Most of these new shipyards were established in areas surrounding Amsterdam and Rotterdam. The small and under-capitalized shipyards in the North of the Netherlands, where vessels for inland and coastal shipping traditionally were made, had not made the transition to iron ships. The shipyards along the rivers below Rotterdam, which also made ships for inland navigation, however, were quite successful. They benefited from the increased shipping on the Rhine, which quintupled between 1895 and 1910. The labor force in the shipyards grew substantially during these years, from 8,600 in 1899 to 22,900 in 1909.[13]

The neutrality of the Netherlands during World War I had a positive effect on the expansion of Dutch shipbuilding. The yards continued their activities. Moreover, those shipping companies that wanted to replace lost ships could buy only from Dutch shipyards. From 1915 to 1918, the average number of new ships was 53 per year.[14] After the war, the situation for the Dutch shipbuilders further improved. They received a large number of foreign orders; one-fifth of the ships made in the 1920s were for customers abroad. Access to German steel gave an

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[12] J. A. de Jonge, *De industrialisatie in Nederland tussen 1850 en 1914* (Nijmegen, 1976) (2nd edition), 150-162; I. J. Brugmans, *Paardenkracht en Mensenmacht* (Den Haag, 1976) (reprint), 319, 319: Cornelis A. de Feyter, *Industrial Policy & Shipbuilding. Changing Economic Structures in the Low Countries, 1600-1980* (Utrecht, 1982), 210.

[13] De Jonge, *Industrialisatie*, 153-155; M. Müller, "De Nederlandse scheepsbouw, 1400-heden," in *Historische Bedrijfsarchieven, Basis-metaal-, metaalprodukten-industrie en scheepsbouw* (Amsterdam, 1992), 160-61.

[14] I.J. Brugmans, *Paardenkracht en Mensenmacht* (Den Haag 1976) 440, 441; Müller, *Ned. scheepsbouw*, 184.

important comparative advantage to the Dutch yards. Other favorable conditions were the relatively low wages and the high professional skill level of the labor force in the Dutch shipyards.[15] Repair work grew mostly because of the classification societies' regulations ordering a thorough inspection in dry-dock every 4 years. Moreover, a growing fleet also meant increasing maintenance activities. In 1930, more than 220 shipbuilding and repair firms existed, and the Netherlands was the third largest shipbuilding nation, after only Great Britain and Germany.

The crisis in the 1930s also had an impact on shipping companies and shipbuilders in the Netherlands. The number of orders declined. In 1934, for example, only 16 trading vessels were delivered, a third of the number in the 1920s. Some large shipyards had to close down, and the workforce declined from 41,000 in 1929 to 12,000 3 years later. The situation improved in the years before World War II when amongst others the large passenger ship Nieuw Amsterdam of the Holland-Amerika Line was finished.[16]

Under German pressure, during World War II most Dutch shipyards produced for the occupier. The efforts, however, varied considerably. The NSM in Amsterdam, for example, avoided orders from the "Kriegsmarine" as much as possible, while the German director of the shipyard Wilton-Fijenoord quickly carried out the German orders. Some individuals and small groups offered resistance by, for example, delivering ships with defects, as did the shipyard Gusto in Schiedam. In general, however, there was not much resistance. Due to material shortages, the transportation of part of the workforce to Germany, and, from mid-1943 onwards, the increasing feeling that Germany would lose the war, production in the shipyards decreased.

In these first decades of the twentieth century, various innovations took place. We focus on three. The steam turbine and the diesel engine replaced the steam engine; the ship material gradually changed from iron to steel; and the shape of the ship became increasingly important. With regard to production, various changes also took place. The enlarging and modernizing of shipyards separated more and more tasks, and welding came into greater use in shipbuilding. Increasing demand sometimes stimulated these developments. This, however, is only part of the explanation. To fully understand these developments requires in-depth analysis. These include focusing on changes in the ship itself: new propulsion techniques, the use of new shipping material, and the shape of the ship as a whole as well as that of the propeller, as well as to technical and organizational innovations in the production process.

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[15] Brugmans, *Paardenkracht en Mensenmacht*, 503, 504; Müller, *Nederlandsche scheepsbouw*, 164, 165.

[16] Müller, *Nederlandsche scheepsbouw*, 167, 189.

New Propulsion Techniques: The Steam Turbine and Diesel Engine

The use of steam was the most important innovation in the nineteenth century. At the end of the century, there were further improvements in the steam engine with the introduction of faster, lighter, and smaller engines with higher capacity, efficiency, and reduced fuel consumption. The development of the triple-expansion engine (with three cylinders) marked the end of this development. Attempts in the 1920s to further improve the steam engine were unsuccessful, mainly because of the development of attractive alternatives.[17]

One of the alternatives to the steam engine was the steam turbine, introduced at the end of the nineteenth century. The electricity sector was the first user of turbines. Steam produced in boilers made a vaned wheel turn quickly. A British technician, Sir Charles Parsons, was the first to use a steam turbine for ships. In 1894, he built the first turbine steamer, called Turbinia. His experiments resulted in ships with more propellers, which moved faster. The British navy saw opportunities in fast turbine steamers and asked Parsons to design a destroyer. The merchant navy followed later with the production of some passenger steamers.[18]

As in Great Britain, the navy stimulated the first application of steam turbines in Dutch shipbuilding. A study commission established in 1910 advised the navy in 1914 to use steam turbines, and a year later the navy gave the order to build four torpedo-boats using turbines. The shipyard de Schelde and the machine factory Werkspoor received the order. Werkspoor (which was formed in 1891 out of the remains of the bankrupt Koninklijke Fabriek) was one of the largest machine factories in the Netherlands. It made steam installations and had already delivered several navy ships. Most of these ships were built in the De Schelde shipyard in Vlissingen. De Schelde, which from 1902 onwards had a license agreement with the Parsons' company, worked with Werkspoor on the production of steam turbines. Later in 1920, Werkspoor also built turbine ships for the SMN and the Java-China-Japan line, for which it used a license agreement with the Parsons Marine Steam Turbine Company, signed in 1919.[19] The close relation between, on the one hand, Werkspoor and De Schelde and, on the other hand, the navy as an

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[17] John Guthrie, *A History of Marine Engineering* (London, 1971), 116; H. Hazelhoff Roelfzema, "Met stoom over de zeeën" in *Verhalen van het water*, ed. H. Dessens, L. Veeger, and J. van Zijverden (Amsterdam, 1997), 68-70; De Klerk, "*Klink Los!*" 215, 216.

[18] Guthrie, *A History*, 156-65; Jan W. Dirkzwager, "Schepen," in *Maritieme geschiedenis der Nederlanden,* ed. R. Baetens, Ph.M. Bosscher, and H. Reuchlin (Bussum, 1978), dl.4, 26-29.

[19] *Gedenkboek Werkspoor 1827-1952* (Amsterdam, 1952), 84-87; Van Hooff, *Vulcanus*, 192-93, 195-97; "Gerard de Rooij (1893-1972)," in A. M. C. van Dissel, et al., ed., *Symposium Marine Scheepsbouw 200 jaar (1795-1995)*, 97-99.

important customer, contributed to the use of a new kind of propulsion technique.

The diesel engine was another, even more important alternative to the steam engine. Almost 10 years after German technician Dr. Rudolf Diesel designed an internal-combustion engine in 1890, the German machine factory Augsburg-Neurenberg (MAN) produced small diesel engines of 30 and 50 horsepower based on his design.

One advantage of diesel engines compared to steam engines was the absence of sparks. This made the diesel engine very attractive for the growing number of tank ships. The increasing importance of oil and the international oil trade in the later nineteenth and early twentieth century also contributed to its growth. Russia already had a river tank ship using a diesel engine in 1904. Other smaller ships, for instance in German inland navigation, were also using diesel engines.

The technical director of the machine factory Werkspoor, C. Kloos, was quickly convinced of the possibilities of the diesel engine, and signed a license agreement with MAN as early as 1902. Kloos, however, aimed to design a diesel engine for larger ships. Various technical obstacles had to be overcome, including the reversibility of the engine. Kloos, working together with director J. Fenenga of the repair yard ADM, managed to produce a 500 horsepower diesel engine by 1907, and placed it in the tanker Vulcanus of the Nederlandsch-Indische Tankboot Maatschappij, a subsidiary of the Dutch oil company, the Bataafsche Petroleum Maatschappij, the Dutch branch of Shell. After this first ship, Werkspoor received other orders for diesel engines for large ships, including one for the cargo-vessel of the Royal Packet Company (Koninklijke Pakketvaart Maatschappij [KPM]) and another tanker (Juno) of 4300 brt. The Werkspoor diesel engines were innovative and of such quality that foreign companies signed a license contract with Werkspoor. Furthermore, other Dutch electronic companies, especially after the introduction of the patent law in 1912, had an increasing interest in acquiring knowledge by foreign licenses as well as in-house research.[20]

From the 1920s onwards, shipbuilders increasingly used diesel engines, pushing other propulsion techniques aside. Of the nineteen largest Dutch trading-vessels, eight (often the newest) had a diesel engine, seven a turbine, and four (the oldest) a steam engine. The transition from steam to diesel is also illustrated by the following figures: in 1915 the Dutch merchant service had only 15 motor ships compared to 345 steam

[20] Guthrie, *A History*, 198-200; *Gedenkboek Werkspoor*, 50-52; Jasper Faber, *Kennisverwerving in de Nederlandse industrie 1870-1970* (Amsterdam, 2001), Ph.D. dissertation VU Amsterdam. For a study of the co-evolution of patent laws and the industry see Johann Peter Murmann, *Knowledge and Competitive Advantage: The Coevolution of Firms, Technology, and National Institutions* (New York, 2003). There has been no research on this field, however, in the Netherlands.

ships (inclusive of turbine steamers), while at the end of 1938 those figures numbered 488 to 319.[21]

It is clear that the navy strongly stimulated the introduction of steam turbines in Dutch shipbuilding. Dutch machine factories, however, did not become players in this field. The situation was different for diesel engines. The Dutch machine company Werkspoor played an innovative role and stimulated the application of diesel engines at Dutch shipyards.

The Suppliers of Steel

The innovations in propulsion techniques were partly due to the availability of new sorts of steel, such as that produced by Siemens-Martin, which was strong, cheap, and increasingly used for shipbuilding. In 1908, Lloyd's also prescribed the use of Siemens-Martin steel in shipbuilding. Its toughness and flexibility compared with iron, made steel easier to process. Metal sheets, for example, could be bent without heating. Moreover, steel was easier to dent, which contributed to the safety of the ships in case of collision or running aground. Steel only gradually replaced iron in ships: boilers were first, then machines, and later plating.[22]

The Dutch shipyards imported steel (as well as iron) from foreign blast furnaces and steelworks. Although some yards such as the large Amsterdam shipyard NSM imported steel from Belgium and England, Germany was the main supplier. Because of German steelworks' policy of trying to keep prices high for German customers and dumping their remains on the markets of neighboring countries, steel prices were relatively low for Dutch shipbuilding.

It was a long time before it was considered profitable to establish a blast furnace and steelwork in the Netherlands, due mostly to the absence of coal and iron ore and the supply of cheap foreign, mostly German, iron and steel. During World War I, there was an initiative to start a national blast furnace and steelwork to deal with the seriously threatened supply situation. The shipbuilders and ship-owners supported this plan.[23] Moreover, financial revenues had increased due to the War, making the establishment of a blast furnace financially possible. The government supported the plan for this basic industry. Strategic reasons, namely a reduction of the dependence on foreign iron and steel help explain why state intervention become more normal and accepted during World War I.

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[21] *Gedenkboek Werkspoor*, 53-59; De Klerk, "*Klink Los!,*" 214-19; H. J. de Keuning, *De Nederlandsche zeescheepvart* (Gorkum, 1944), 17-19.

[22] S. Visser and A. Roos, *Scheepsbouw. Met 131 figuren tusschen den tekst* (Den Helder, 1921), 3rd edition, 2-4.

[23] This is comparable with the situation in Sweden, where the shipyards urged there be more domestic production of ship material. Lars O. Olsson, "System Builders, National Systems and the Rise of the Swedish Shipbuilding Industry in the First Half of the 20th Century," *Polhem: Tidskrift för teknikhistoria* 15, no. 3 (1997) 250-81, there 260-61.

In 1918 financial support from the government helped establish the first Dutch blast furnace (the Nederlandsche Hoogovens en Staalfabrieken N.V.) in IJmuiden at the North-Sea coast. It took another 6 years before the first blast furnace came into operation. The expansion to a steel factory was postponed because of Hoogovens' financial losses during the recession in the 1930s. Moreover, steel production was not attractive in a period when the Dutch were spoiled by access to cheap foreign steel. The positive results for Hoogovens at the end of the 1930s as well as increasing prices for steel led to the decision to establish a Martin-steel factory, which started production in 1939. The management of Hoogovens also developed plans to invest in a rolling mill to make sheets for shipbuilding. The war situation delayed its establishment until 1947.

Therefore, although shipbuilders and shipping companies played a role in the start of the Hoogovens company, the "supply relationship" between the shipyards and Hoogovens was not very close. The shipyards during the 1920s and 1930s continued to import most steel from Germany where it was still cheap. Hoogovens exported most of the pig iron it produced to other countries. At the end of the 1940s, due to severe foreign competition, the export position of pig iron declined. Hoogovens increasingly used the pig iron itself to make steel products, like thick steel sheets (3-60 mm). With the new rolling mill, it was possible to produce 120,000 tons a year. For these sheets, Hoogovens considered the Dutch shipyards their main customers.

The weak relationship between Hoogovens and the shipbuilding companies became complicated in the years after the war. There were two reasons for this tension: price level and conflicting views on mutual protection and support. The shipbuilders, supported by the ship owners, urged low prices to strengthen the international position of the Dutch yards. Hoogovens, however, refused to lower its prices for shipping steel. However, it wanted the Dutch shipyards to be obliged to purchase shipping steel from Hoogovens. The shipyards, having formed a purchasing cooperative (Coöperatieve Inkoopvereniging van Metaalindustriëlen [Coopra]), strongly opposed having to buy from Hoogovens; once again, the shipping companies supported them. The Directorate for Shipbuilding and Repair (Directoraat voor Scheepsbouw en Reparatie), responsible for the distribution of steel output among the shipyards, signed a long-term contract with a steel company in Austria because it offered a lower steel price.[24] Moreover, it was not until March 1948 that Lloyd's, soon followed by the French Bureau Veritas, certified the quality of the Hoogoven steel sheets. Before that certification, use of Hoogovens' steel was limited to repairs and inland shipping. This put Hoogovens in a weak competitive position. To improve its position Hoogovens also signed a contract with the British Iron & Steel Corporation for the exchange of pig iron for shipping profiles, allowing them to offer

[24] It was part of the Dutch ministry of Economic Affairs.

the shipyards a more complete assortment. The first substantial order for shipping plates came from the NSDM in Amsterdam for the construction of a Norwegian motor ship.

Hoogovens, however, never became the "preferred supplier" of the Dutch shipbuilders. Both the tense relationship between Hoogovens and the Coopra and the long lasting relationship of Dutch shipbuilders with foreign steelworks contributed to this situation. Hoogovens increasingly found export markets for its shipping steel, especially in the United States. In the 1950s, however, the situation drastically changed. By that time, it had become difficult to meet the ever-increasing demand for metal sheets. Hoogovens, which did not want to give up its export markets, protested when confronted with an export restriction on metal sheets in 1951. It saw no reason to favor the Dutch shipbuilders, which now asked Hoogovens for help.

In short, a close cooperation between the shipbuilding companies and Hoogovens did not materialize. Arguments for mutual dependence in a national context only played a role in the founding of the company; in practice, the international market situation was more important for supplier-customer relations. Exclusivity was desirable only when there were shortages.[25]

Shipbuilding and Scientific Research: The Ideal Shape

In addition to engines and shipping material, the shape of the ship and its propeller also contributed to more speed and efficiency. Although an early initiative, it took several decades to establish a national tank for experiments with ship models in the Netherlands.

The Briton William Froude was the first to scientifically test ship models around 1870. Within 2 years a Dutch naval engineer, Bruno Tideman, who worked at the national naval yard in Amsterdam (Amsterdamse Rijkswerf), followed his example and started an experimental tank. They received orders, even from abroad, for testing the ideal shape for warships as well as merchant vessels.[26] With the death of Tideman in 1888, the tank fell into disrepair and closed shortly after 1900.

After closure of the tank, all testing of models occurred abroad. Most shipyards, shipping companies, and the navy went to Austria. The

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[25] Joost J. Dankers and Jaap Verheul, *Hoogovens 1945-1993: Van staalbedrijf tot twee-metalenconcern. Een studie in industriële strategie* (Den Haag, 1993), 19-33, 106-11; Mila Davids and Jan Luiten van Zanden, "State-owned Enterprises in the Netherlands" in Pier Angelo Toninelli, *The Rise and Fall of State-Owned Enterprise in the Western World* (Cambridge, U.K., 2000), 253-72; Jan de Vries, *Hoogovens IJmuiden 1918-1968* (Ijmuiden, 1968), 35; J. W. F. Werumeus Buning, *Gedenkboek NV Nederlandsche Scheepsbouw Maatschappij*, (Haarlem, 1934), 59, 60.

[26] Dirkzwager, *Dr. B. J. Tideman. Grondlegger van de moderne scheepsbouw in Nederland* (Amsterdam 1970) 185; Dirkzwager, *Schepen*, 46.

establishment of a new towing tank was too expensive. Although the department of shipbuilding at the Technical Polytechnic in Delft regretted the loss of testing capability, their position was not strong enough to change the situation. The department at Delft, established in 1864, was quite small with relatively few students and graduates. Until 1900, there were no more than two graduates a year, a number that increased to eight in the period 1920-1940. The first full-time professor was assigned in 1905. The study society William Froude (established in 1903) tried in vain to get a new experimental tank established in 1906.[27]

It took more than 10 years before the idea of a research institute for model testing reappeared on the agenda. This time the initiative came from A. van Driel, an employee of the shipping inspectorate. The government was convinced of the importance and set up a commission. The estimated costs for such an institute exceeded the available budget and the plan was postponed.[28] Van Driel followed another route and looked for the cooperation of the Royal Academy of Engineers (Koninklijk Instituut van Ingenieurs (KIVI)). Finally, in 1927, the director of the Austrian naval architectural experimental station, Dr. B. Gevers, was invited to give a lecture on the possibilities for realizing an experimental tank in the Netherlands. As a result, another study commission investigated and proposed establishing a smaller, cheaper tank, for testing of only standard models. Experiments with large ship models or torpedoes still would be done abroad.[29]

This time the seed of the plan fell on fertile soil and in 1929, they set up an experimental station "De Stichting Nederlandsch Scheepsbouwkundig Proefstation" (NSP) with a towing tank. It is important to note that attention to scientific research had grown considerably in the Netherlands. The large number of established industrial laboratories contributed to this increasing scientific orientation. There were also National initiatives to promote applied scientific research in Dutch industry, and an organization for applied natural scientific research (Toegepast Natuurwetenschappelijk Onderzoek [TNO]) set up to coordinate these activities. Cooperation between the various actors in the shipbuilding complex was also important for the establishment of the NSP. The board of the NSP, which consisted of representatives of the shipping companies, the government, KIVI, and the department of Shipbuilding from the Polytechnic in Delft, also illustrated this growing cooperative

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[27] H. Baudet, *De lange weg naar Technische Universiteit Delft* (Den Haag, 1992) 472; Frieda de Jong, "De moeizame introductie van wetenschap en technologie in de scheepsbouw tot 1940", *Jaarboek voor de geschiedenis van bedrijf en techniek* 1 (1984), 311-27, there 316-18.

[28] The costs were estimated at 1.8 million Dutch guilders.

[29] M. W. C. Overveld, "MARIN, Moving to Higher Technology," in *Hydrodynamics: Computations, Model Tests, and Reality,* Developments in Marine Technology, 10, ed. H. J. J. van den Boom (Amsterdam, 1992), 1, 2.

attitude. The NSP director came from the navy; the government as well as the shipping-owners and shipbuilders all contributed financially.[30]

The growing attention to research in shipbuilding positively affected various actors in the shipbuilding industry. One of the largest suppliers of propellers, the Lips company, established in 1928 in Den Bosch, soon worked together with the NSP to improve its propellers. Lips, the main—almost monopolistic—supplier of large propellers in the Netherlands, was also active on the international market. In the mid-1950s, Lips had branches in Belgium, France, Spain, and Italy and produced one-sixth of the world's large propellers.[31]

Despite these activities, a more scientific interest in Dutch shipbuilding developed rather late, as illustrated by the limited number of naval architects who were working in shipyards. Moreover, scientific articles in this field were scarce and the general scientific journal, *The Engineer* (*de Ingenieur*) included only a few articles on shipbuilding.[32]

For modifications of ships themselves (for example, the enlargement of the capacity, new propulsion techniques, the use of new shipping material, the shape of the ship, and the propeller), relations with various actors and institutional changes proved to be important. Specific actors (customers and suppliers such as the navy and Werkspoor) and the existing relations and institutions (the building rules from the classification societies) were important for the adoption and diffusion of these innovations. However, these innovations also produced new organizations and institutional changes, for example, the establishment of the Hoogovens company, as well as the start of the NSP.

Closely related to the improvements of the ship itself are changes in the process of shipbuilding. Daily practices changed considerably during the first half of the twentieth century. Technological as well as organizational changes were important. Here we focus on three aspects: the changes at the shipyard, the emergence of separate design departments, and the change from riveting to welding, and describe these developments in relation to the involved and the changing institutional setting.

Modernization of the Shipyards

The prosperity in the market as well as the enlargement of the ships contributed to a metamorphosis of the shipyards. Most yards in the nineteenth century were small, with unpaved paths, and no systematic organization, located near city centers. When the ships increased in size, low bridges and small canals became serious obstacles. It became rather

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[30] Ibid.

[31] J. M. Hartogh, *Lips NV 25 Jaar Drunen* (Drunen, 1965), 5-53.

[32] De Jong, "De moeizame introductie van wetenschap en technologie in de scheepsbouw tot 1940."

complicated, for example, to transport the new ships from the shipyards in the center of Amsterdam (such as the NSM and the Rijkswerf [National Yard]) to the IJ, because the lock through which they had to pass and the rail bridge were far too small. The growing capacity of the ships not only complicated the transportation, but made it necessary to enlarge the yards, partly as a result of the need for larger slipways. In the city center, however, this was often difficult.[33] From 1900 onwards, shipyards were transferred or built outside the city centers. In Amsterdam, for example, the NSM moved parts of its yard to the other side of the IJ and in Rotterdam new yards were built along the Nieuwe Waterweg (New Waterway), which was nearer to the sea.

The establishment of large modernized shipyards also began in 1900. The shipping companies played an important role in this process; often partially financing the yards. Two shipping companies, the Steamboot Maatschappij Nederland, and the Java-China-Japanline co-financed a new NSM yard in Amsterdam in 1916. We already mentioned RDM. Also, the extension of the NV Wilton's Machine Factory and Shipyard in Schiedam was built at the instigation, and with the financial help, of the Holland-America Line (Holland-Amerika Lijn [HAL]).

The shipping companies played an important role in establishing the RDM as the first shipyard along the Nieuwe Waterweg in 1902. Several companies that wanted a yard especially for repair invested in the new shipyard. The builders introduced new elements in the large RDM yard, which was partially a continuation of the existing De Maas yard. They paid substantial attention to the layout of the yard, providing a logic order of the various processing steps, and good facilities for moving intermediate products. They built larger slipways and bought various cranes and new machines, for example a hydraulic riveter for manufacturing boilers. Electricity generated by the yard's own power station drove the machines. During the first decades of the twentieth century the RDM yard was one of the most modern yards in the Netherlands. Students of the faculty of mechanical engineering and naval architecture often visited it from Delft and other universities.

Soon other shipbuilders also enlarged their capacity, introduced electrification, and reorganized and rationalized the layout of their yards. Various factors stimulated the gradual replacement of steam by electricity. The extensiveness of the yards favored the use of small electric motors, which could operate on a "stand alone" basis. Belts and wires were no longer necessary. Until the First World War, most large shipyards had their own power stations, because it was not easy to purchase electricity. This became much easier in the 1920s when the number of municipal and provincial electricity companies increased.

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[33] C. P. P. van Romburgh and E. K. Spits, *De Nederlandsche Dok en Scheepsbouw Maatschappij* (Rotterdam, 1996), 14-15.

The transition to electricity, however, was gradual. In a single yard, it was possible to use various sources of energy (steam, electricity, and hand power) at the same time. In 1916, for example, in the of the Dutch Shipping Company (NSM) yard, hand power was used for some lifting equipment, next to electric cranes and electric motors for the processing of metal sheets and in the carpenters workshop. We also have to keep in mind that in smaller shipyards, electricity and the use of machinery was less important. The medium-sized shipyard of Boele in Bolnes near Dordrecht, which built smaller ships and did a lot of repair work, for example, used a lot of steam power and the ships were manually lifted onto the repair slipway. Electrical lifting was not done until the 1920s.[34]

Organizational Changes in Shipbuilding

The enlargement of the ships and shipyards and increasing complexity accompanied an increasingly planned production process and growing division of labor. Existing ideas of scientific management influenced these developments. The various processing steps were split up, and clustered on specific locations. This was not only the case with the production tasks. Preparations for the actual building process (the purchasing of material, the planning of the process, and the design) became increasingly important and divided among new departments. While the purchasing bureau was responsible for the presence of the needed material, a planning department had the responsibility to plan and coordinate the various tasks and workforce in various shifts. The planning department also had to organize the large amount of work done by sub-contractors (for example, painters, electricians, and installers). Separate departments were also set up for design work, which became more complex due, among others factors, to technical improvements and growing legal and insurance requirements.

The changes in the design process were quite striking because in the 1920s and 1930s it was physically separate from the shipbuilding companies. Design of new ships typically occurred in the shipyard as part of the total shipbuilding process to conform to the wishes and demands of the shipping company. From the second decade of the twentieth century onwards, however, large shipping companies started their own design departments. This development resulted from the growing number of wealthy shipping companies desiring special ships. Mail boats for shipping to the Dutch Indies required different designs than passenger ships to North America. Tramp shipping, which came up in 1910, needed special equipment to load and unload, while for tankers security was

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[34] De Nederlandsche Scheepsbouwmaatschappij van Amsterdam, in *In- en Uitvoer* (5 Jan. 1916), 11-13; J. van Beek, *Boele Bolnes*, (Ridderkerk 1996), 14, 15, 20-22; G. Blijham and W. Kerkmeijer, *Nieuwe van de bijl* (Hoogezand-Sappemeer, 1999), 139-40.

essential. The number of naval architects educated in Delft also contributed to the shipping companies' growing interest in ship. These engineers started working for ship-owners as well as for engineering firms.[35] Consequently, external design departments increasingly determined the shipyard building process from the 1920s onwards.

The growing division and complexity of tasks led to the introduction of more formal directive mechanisms. For example, design departments used technical drawings to communicate specifications to the shop floor. Therefore, laborers had to learn to "read" these drawings. In the technical schools, where most of the shipyard personnel received their education, "reading of drawings" and sometimes also the making of drawings was added to the curriculum. Some larger shipyards (De Schelde, RDM, NDSM, and Fijenoord) had their own training programs to provide these courses.[36] Increasing mechanization and division of tasks did not lead to a deskilling of workers.[37] However, due to new production techniques, specific skills became outdated, requiring acquisition of new skills. This was, for instance, the case with electric welding.

New Production Techniques: Welding

One of the major innovations in the production process was the replacement of riveting by welding. Until the end of the nineteenth century, workers connected sheets (among other parts) with rivets by hand. From the end of the century, rivet machines increasingly replaced riveting hammers, especially in large yards. The production principles remained the same, however.[38]

The first electric welding experiments were done at the turn of the century. The quality of the weld improved substantially when the Swedish engineer Oscar Kjellberg devised a new method in 1904. This new technique protected the molten metal from contamination by air with the layer of slag produced when the heat of the welding arc melted an electrode coated with a flux. Previously, the absorption of nitrogen and oxygen from the air had a negative influence on the quality of the weld.[39] A company was established (Elektriska Svetsningsaktiebolaget [ESAB]) and 2 years later, patented this electric welding method (also called electric arc welding).

Welding had several advantages. The workers involved could work with less noise. Shipbuilding by riveting was extremely loud and most

[35] Bonebakker, *Rede* 18, appendix 2.

[36] Goudappel, *Machinefabriek en Scheepswerf* 27; Van Hooff, *Vulcanus*, 164-68.

[37] Olsson, "System Builders," 263-64.

[38] *Marin*, 5,6. For a detailed description of the NSP-research, see W.P.A. van Lammeren, *Weerstand en voortstuwing van schepen* (Amsterdam, 1944).

[39] W. H. Drukker, *Electrisch lasschen en klinknagelverwarming* (Amsterdam, 1923), 6-12, A. J. Nooijens, De lastechniek in historisch perspectief, in *Lastechniek* 50 (Sept. 1984): 161-62; Olson, "System Builders."

riveters suffered hearing damage. Moreover, working with red-hot rivets was dangerous and unpleasant. Welding was less labor intensive. American research in 1929 estimated saving 18 percent on labor.[40] The supporters of electric welding also stressed the potential advantages of welded ships. First, the ships would be lighter, thereby needing less fuel. The weight saving was estimated at 12-15 percent for larger ships, and an even more impressive 25-30 percent for smaller ships. The decrease in weight would make a greater payload (or more arms if the ship were a naval vessel) possible. Water resistance would decrease due to an improved streamline of the ship's plating. Finally, welded connections would be less pervious to water and oil. This aspect made welding especially appropriate for oil tankers.[41]

Despite these advantages, the use of electric welding at the shipyards increased slowly. The method was typically used in repair work. Exceptions were the building of the first welded towed vessel in 1915 in the United States and some smaller ships in Great Britain and France. However, until the 1930s welding was scarcely used for building new ships. In most cases, only certain parts were welded, not the whole ship.

A variety of circumstances explains the slow introduction of welding. The high temperature needed for welding (3,700 degrees Celsius) caused tensions in the material, which sometimes led to cracks and deformations. Moreover, initially quality control was not possible. The only way for shipbuilding companies to minimize risk was by using the most experienced welders. By the 1930s, using roentgen could better control the welds, but during the early years, this was very expensive.[42]

Due to these uncertainties, the classification societies adopted a "wait-and-see" attitude. By 1918, the Swedish Lloyd's Register had formulated the first regulations concerning repair of ships by welding; they labeled it as "experimental." The classification societies' regulations, which were very important for the diffusion of innovation in production processes, clearly slowed the use of welding in the building process.[43]

One sector, however, was especially interested in electric welding: the navy. The Washington arms reduction agreement of 1922 had placed restrictions on the weight of naval vessels. The use of electric welding made it possible to build large, heavily armed, and fast naval vessels. In Germany, for example, from 1925 onwards, various cruisers with as many welded connections as possible were made, including the "Deutschland" and the "Graf Spee." The navies also had an easier time using welding because they did not have to bother with the classification societies'

[40] De Klerk, *Klink Los!*, 86-104.
[41] Ibid.
[42] Nooyens, *De Lastechniek*, 163; De Klerk, *Klink Los!* 119.
[43] Nooijens, *De lastechniek*, 162; Olson, "System Builders."

regulations. Finally, their sound financial foundation made it possible to invest in roentgen facilities to control the quality of the welds.[44]

The Dutch navy followed the examples of the foreign navies. In building the cruiser "De Ruyter" in 1935, a "substantial" number of connections were welded, although most were still riveted. In the Dutch navy, one of the head engineers, G. de Rooij, especially propagandized the use of welding. In cooperation with the company Willem Smit & Co Transformer, a manufacturer of equipment for electric welding, he developed special steel for welding ("staal 52") and electrodes. As a result, the Dutch navy increasingly used welding for submarines and light cruisers. In 1937, workers used roentgen technology to control the welds.

The use of electric welding by the navy contributed to the dissemination of welding expertise to other ships. The building of naval vessels was concentrated in the four Dutch yards (RDM, Wilton-Fijenoord, De Schelde and the Nederlandsche Scheepsbouw Maatschappij), which combined their knowledge on welding.[45]

The shortage of welders was a serious problem that increased as orders grew for welded ships (and merchant vessels). Welding education was not much of a priority. The "bad" image of welding likely contributed to this situation for a long time. Although yards sometimes initiated welding education, this hampered the dissemination of electric welding. When in 1937, for example, during the building of the passenger vessel the "Oranje" in the NSM in Amsterdam many of the connections still had to be riveted because of a shortage of welders.[46] The actual breakthrough in electric welding came during World War II, when the United States started to mass-produce standardized all-welded merchant vessels, among which were the Liberty ships.[47]

Conclusion

We can conclude that during the first decades of the twentieth century most innovations in Dutch shipbuilding were foreign in origin. An exception was the Dutch company Werkspoor's leadership in developing diesel engines for large ships. The Dutch capacity for innovation primarily manifested itself in the adoption and adaptation of foreign innovations in the Netherlands.

Our focus on the entire constellation of actors in Dutch shipbuilding, their relations, interactions, and interdependence, as well as

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[44] Ibid.

[45] The four yards co-operated in the Nevesbu. G. de Rooy, "Moderne laschconstructies bij den bouw van onderzeebooten," in *Schip en Werf*, (5), 18 Feb. 1938; "De flottieljeleider Tromp," *Schip en Werf* (1938), 155-56; H. V. Quispel, *The Job and the Tools* (Rotterdam, 1960), 134-37.

[46] Van Romburgh, Spits, *Nederlandsche Dok en Scheepsbouw Maatschappij*, 84; Nooyens, *De lastechniek*, 168.

[47] Olson, "System Builders."

on the institutional setting clearly contributes to gaining a better understanding of innovation processes. The role and importance of these actors and institutions differed widely, however.

Customers were very important for the introduction of innovations in shipbuilding, especially the Dutch navy. The role of the navy was comparable to that in other countries. Application to navy vessels stimulated dissemination of the steam turbine and the welding process. Consequently, merchant ships as well as naval vessels were using this technology. The navy's substantial budget made it possible to invest in research capacity. Without the use of roentgen, for example, welding would not have been safe enough.

The development of a public knowledge infrastructure in Dutch shipbuilding was a slow process. The establishment of the Dutch Scheepsbouwkundig Proefstation with an experimental tank to investigate the optimal shaping of ships did not occur until 1929, despite the early expertise available in the navy. This example illustrates that other parts of the shipbuilding system did not always quickly adopt naval expertise. However, it also clearly demonstrates the importance of extending the general national knowledge infrastructure. Only when general attention to industrial research increased efforts to establish a center of expertise did the idea of an experimental tank become a reality. The cooperation between the academic world, shipbuilding companies, and shipping owners was also important in this respect. The shipbuilding complex was not very scientifically oriented. The limited number of engineers who found a career in shipbuilding companies also illustrates this. The international orientation of the shipbuilders and shipping companies also slowed down the process. For a long time designers used foreign centers for experiments, because this was cheaper than jointly building a tank in the Netherlands.

This international orientation and "cost saving" attitude also came to the fore in the relationship between the shipyards and the steelworks. Despite the fact that the shipbuilders and shipping companies had supported the establishment of a national blast furnace and steelwork, it was only from the end of the 1940s onwards that Hoogovens started to deliver metal to the Dutch shipyards. Hoogovens never became the sole supplier, which we cannot explain solely by the late start Hoogovens got in producing metal sheets. The shipbuilding companies preferred foreign metal. The long existing foreign contacts and the low price played a role in the international orientation. We can conclude that within the shipbuilding system the relations between the shipbuilding companies and national suppliers varied considerably. There was, for instance, a loose relationship with the Hoogovens, while a close cooperation existed with the Dutch machine factories.

Besides the navy, the shipping companies were also important customers for the shipbuilders. Due to their financial involvement, their influence on the modernization of the larger shipyards was substantial.

The close relationship between the shipbuilders and the shipping companies also had disadvantages for the shipbuilding companies. The establishment of design departments within the shipping companies led to a situation in which more and more expertise was lost at the shipyards.

We have seen the importance of the classification societies in the process of innovation in the shipbuilding industry. They established the building regulations for shipbuilding and therefore contributed to the diffusion of innovations. The question remains how important the lack of a national classification society was for the Netherlands. Did the lack of its own classification society (such as Norway's) hamper the building of a strong national innovation system? This remains an interesting question for further research.

For the educational system, it is important to integrate new developments into curricula. We have seen in the case of welding, that an inadequate response to new developments directly hampered the diffusion of this process innovation.

The importance of the institutional setting for innovation processes in shipbuilding varied considerably. Regulations, mostly set by the classification societies, stimulated but sometimes also hampered technical developments. They positively stimulated the use of steel, while their caution with regard to electric welding slowed down the spread of this new technology. We cannot separate this from a general resentment in the sector against this new production technique. More generally, we can state that although not always clearly visible, these kinds of general sentiments always play a role in innovation processes. Patents were another institutional factor that had an impact in the field of electrical engineering, where knowledge-building became increasingly important from 1912 onwards.

By focusing on organizations, institutions, and their interaction, we have a better understanding of the innovation process in Dutch shipbuilding, including their incentives and constraints. We can conclude that the "systems of innovation approach" is a fruitful analytical framework for historical research. The decision to focus on many levels, rather than just the national, regional, or local level proved to be helpful, especially in a very internationally-oriented sector like shipbuilding. Some relationships proved to be international, while others were national or regional in nature. Moreover, the relations between important actors change over time. Studying these possible shifts provides an important framework for further research on innovations in Dutch shipbuilding.