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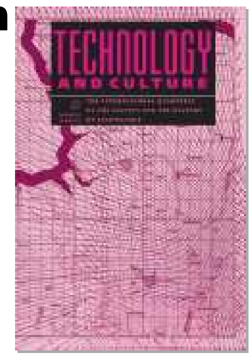

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Radical Innovation as a Multilevel Process

Introducing Floating Grain Elevators in the Port of Rotterdam

HUGO VAN DRIEL and JOHAN SCHOT

In August 1901 a delegation of the Verein deutscher Handelsmüller, an association of German grain mill owners, visited Rotterdam, the Dutch seaport that handled the largest share of continental Europe's grain imports, to promote the use of floating pneumatic grain elevators.[1] The delegates stressed

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1. On the introduction of the grain elevators in the port of Rotterdam, see Dick van Lente, "Machines and the Order of the Harbour: The Debate about the Introduction of Grain Unloaders in Rotterdam, 1905–1907," *International Review of Social History* 43 (1998): 79–110; A. Voogd, *De graanelevators en de gisting in het havenbedrijf te Rotterdam* (Rotterdam, 1907); and Ch. A. Cocheret, *Het elevator-bedrijf in de Rotterdamsche haven 1908–1933* (Rotterdam, 1933). In this article we have cited the records of the Graan Elevator Maatschappij (Grain Elevator Company, GEM) directly only when the information they contain is not (or not correctly) mentioned in Cocheret, who was able to consult certain reports of discussions that can no longer be found in the GEM archives.

the elevators' important advantages: unloading a ship by vacuuming the grain out of its hold was several times faster than unloading by hand, and pneumatic elevators also incorporated automatic weighing and cleaning functions. But the mill owners met with a lukewarm response; the traders considered the speed of the existing system high enough. A committee of the Rotterdam Chamber of Commerce said that the traders would much rather take their time in receiving grain from the seagoing vessels, and that "the forwarding trade does not desire a quicker dispatch either."[2] Only one of the many middlemen in the Rotterdam grain business, J. C. Smalt, perceived a future for pneumatic unloading, and he would become the moving spirit behind the introduction of the new elevators into the port.

In April 1904 Smalt founded a company that ordered two elevators from Germany, the first of which went into operation in August 1905. Unfortunately, its built-in scale malfunctioned, which created a credibility problem. Smalt returned the elevators to the factory and asked that the automatic scales be replaced with manually operated equipment. In the meantime, the workers who weighed the grain, whose jobs were endangered by this new development, organized and went on strike. Because the German grain importers were largely dependent on the port of Rotterdam, they settled with the strikers and promised not to receive grain from the elevators. After more than a year and a half of indecision, Smalt's company put the two elevators into operation again in March 1907. This time the dockworkers began a guerrilla war against the elevators that culminated in such violence against strikebreakers that in July 1907 the Dutch army had to restore order. Following that episode, the traders, ship agents, and stevedore firms joined forces against the workers, and within a couple of years they had managed to introduce the grain elevators in Rotterdam on a massive scale. In 1913 a fleet of floating pneumatic elevators unloaded 96 percent of the grain in Rotterdam.[3] The elevators used in Rotterdam became the standard for continental European ports, although not all of them—Rotterdam's main competitor, Antwerp, was the most important exception—mechanized as rapidly. A new technological regime, as we will call it in this article, had emerged through a process of radical innovation.[4]

2. Report of a committee of the Rotterdam Chamber of Commerce (Kamer van Koophandel Rotterdam) concerning the visit of the Verein deutscher Handelsmüller of 29 October 1901, Rotterdam Chamber of Commerce Archives (RCCA), inventory number (inv. no.) 113, no. 165, Rotterdam Municipal Archives (RMA).

3. Directie van den Arbeid, *Verslag over het Haventoezicht uitgeoefend in 1913* (Report of the port inspection of 1913) (The Hague, 1914), 62.

4. A radical innovation can be defined by contrasting it with incremental innovation. The latter is a small step that improves the existing dominant practice (regime). Incremental innovations are continuous, cumulative, and adaptive. In contrast, a radical innovation is a departure from the existing path, a new direction creating a discontinuity. Drawing an analogy with evolutionary theory, Joel Mokyr suggests that radical innovation is like the emergence of a new species. See Joel Mokyr, "Evolution and Tech-

In this article we will set out to explain this remarkably quick and complete mechanization process in the port of Rotterdam. Why did it happen when it did? Rotterdam had become the most important grain port in continental Europe without any significant technological innovations in cargo handling, and it appears that when pneumatic elevators were introduced there ships carrying grain could still have been unloaded manually without major problems.

Because of the drama involved—the fierce resistance, the swift and radical transformation of the handling regime—this is a fascinating story in itself. The port of Rotterdam is a rich research site for bringing together labor and entrepreneurial perspectives. Moreover, port technologies are crucially important for any transport history and in a broader sense for any history of regional and world markets. Ports are local spaces where various streams of people and goods come together, needing to be coordinated and linked to each other. Global markets are coproduced and materialized in local harbor layouts, cranes, and other cargo-handling equipment. Yet the main reason to tell this story is methodological. This revealing case study will demonstrate how to combine macro-, meso-, and microlevel developments into one multilevel model, and we will argue that such an approach is necessary for explaining radical technological change.[5]

The Multilevel Perspective

The rise of Rotterdam as a major port has been explained by several macrolevel factors, such as German industrialization, the superb location of the city at the mouth of the Rhine, and the emergent global economy of the second half of the nineteenth century, made possible by the development of steam technology, especially in rail transport and shipping.[6] One

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nological Change: A New Metaphor for Economic History?" in *Technological Change: Methods and Themes in the History of Technology*, ed. Robert Fox (London, 1996), 63–84, esp. 69–73.

5. This multilevel model has been developed at the University of Twente in the Netherlands by Arie Rip, René Kemp, and Johan Schot, and further advanced by Frank Geels in his dissertation, supervised by Schot and Rip. See A. Rip and R. Kemp, "Technological Change," in *Human Choice and Climate Change*, vol. 2, ed. Steve Rayner and Elizabeth L. Malone (Columbus, Ohio, 1998), 327–99; J. W. Schot, A. Rip, and H. W. Lintsen, "Methode en opzet van het onderzoek," in *Techniek in Nederland in de twintigste eeuw*, vol. 1, ed. J. W. Schot et al. (Eindhoven, 1998), 37–52; R. Kemp, J. W. Schot, and R. Hoogma, "Regime-Shifts to Sustainability through Processes of Niche Formation: The Approach of Strategic Niche Management," *Technology Analysis and Strategic Management* 10 (1998): 175–96; and Frank Geels, *Technological Transitions and Systems Innovations: A Co-Evolutionary Perspective and Socio-Technical Analysis* (Cheltenham, 2004).

6. See Brian Hoyle and David Pinder, "Cities and the Sea: Change and Development in Contemporary Europe," in *European Port Cities in Transition*, ed. B. S. Hoyle and D. A. Pinder (London, 1992), 1–19. They assume that the location, design, structure, and oper-

might argue that the introduction of the elevators resulted largely from these macrolevel factors, which created new opportunities to be seized by Rotterdam entrepreneurs. Yet this argument leaves unexplained why the change should have happened between 1901 and 1907, why it took place so rapidly, and why so many traders opposed it initially. Was it just a conservative attitude that needed to be crushed by the innovative spirit of Smalt?

We think not. Macrolevel factors such as changing trade patterns are important because they constitute the background for technical change; they provide windows of opportunity and a set of barriers for development. There are three kinds of macrolevel factors: first, rapid external shocks, such as wars or fluctuations in the price of oil; second, long-term changes, such as German industrialization; and third, factors that do not change or that change only slowly, such as climate. This is a highly varied set of factors that can be combined into a single category because they form an external context that the actors cannot influence in the short run. The ensemble of all relevant macrolevel factors is part of what we refer to as a sociotechnical landscape. This metaphor seems appropriate because it refers to the background nature of the ensemble and to both technological and social developments. The components of the landscape are determined by the chosen unit of analysis—in our case, grain handling in the port of Rotterdam. By their nature these background developments cannot sufficiently explain the timing and nature of radical change.[7]

To explain why the mechanization of grain handling in Rotterdam took place when it did and how it did, we need to follow the actors at the microlevel and study how they carved out and negotiated a particular course. We need to find out how groups involved in this controversy redefined the problems in such a way that elevators became the appropriate path for grain handling. Radically new technologies are what Joel Mokyr calls "hopeful monstrosities."[8] Their performance is usually low as measured against dominant performance criteria such as productivity (speed),

ations of ports are primarily determined by trade patterns. Seaport technology is following global trends. See also these earlier studies on Rotterdam: Petrus Serton, *Rotterdam als haven van massale goederen* (Nijmegen, 1919), 10–11, and J. Ph. Backx, *De haven van Rotterdam: Een onderzoek naar de oorzaken van haar economische betekenis in vergelijking met die van Hamburg en Antwerpen* (Rotterdam, 1929). A recent study on the history of Rotterdam stresses the importance of changes in the social structure of the city's elite; see Paul van de Laar, *Stad van formaat: Geschiedenis van Rotterdam in de negentiende en twintigste eeuw* (Zwolle, 2000).

7. See also Eda Kranakis, *Constructing a Bridge: An Exploration of Engineering Culture, Design, and Research in Nineteenth-Century France and America* (Cambridge, Mass., 1997), 1–5. Kranakis argues that the influence of larger structures, such as democracy, cannot be researched directly, because they are mediated by lower-level structures in the immediate environment of a specific technology.

8. Joel Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress* (New York, 1990), 291.

cost, and versatility. Institutional and regulatory forces may also hinder implementation. Finally, actors may not believe that an emerging technology will be an improvement, and so focus on optimizing dominant solutions. Hence, actors who push for radical innovations have to operate in niches where the technology is protected from immediate market and regulatory pressures and from the negative attitude of the larger constituency behind the dominant technology.[9] In these niches specific selection criteria operate that make a new technology attractive for users who have particular demands and are prepared to accept certain disadvantages.

The first applications of electricity were, for example, targeted at the niche markets of world fairs, theaters, and public events. High costs were traded against excitement.[10] How do niche technologies become dominant solutions? Through a process of branching out. Electricity moved on to niches in the transport, household, and factory markets, and eventually became more widely diffused and partially displaced oil and gas technologies. Of course, many niche technologies have difficulty spreading beyond their initial small market, where they flourish because of special circumstances. Radically new technologies require a host of changes that usually take time and meet much resistance.

The concept of niches alone does not suffice to explain the emergence and diffusion of radical innovation. We need to capture the environment that restricts entry of radical new technological options. We propose to call this environment a technological regime and to position it at what might be called the mesolevel, because of the influence it has on actor choices and preferences.[11] We define the notion of regime as the grammar or rule set embodied in engineering search heuristics, user preferences, expectations,

9. For this argument and an elaboration of the importance of niche development for understanding technical change, see J. W. Schot, "The Usefulness of Evolutionary Models for Explaining Innovation: The Case of the Netherlands in the Nineteenth Century," *History and Technology* 14 (1998): 173–200. See also D. A. Levinthal, "The Slow Pace of Rapid Technological Change: Gradualism and Punctuation in Technological Change," *Industrial and Corporate Change* 7 (1998): 217–47.

10. See David Nye, *Electrifying America: Social Meanings of a New Technology* (Cambridge, Mass., 1990), chap. 2.

11. See also the work of Thomas Misa, who points to the importance of a mesolevel analysis. In his view, a macrolevel study is prone to technological determinism, while a microlevel study will not allow for drawing broader conclusions about the technological construction of society. Misa's solution is to focus on a midlevel (or mesolevel) methodology that directs attention to networks that mediate between the macro and the micro. Our definition of the mesolevel differs in that we focus on rules. However, our multilevel analysis can be used to answer his call to study both the social construction of technology and the technological construction of society while avoiding a technologically deterministic approach. This article can be read as an attempt to move beyond a typical social constructivist focus on actors shaping new technologies, since we pay attention to how technologies become regimes and, over the long term, change the landscape. See Thomas J. Misa, "Retrieving Sociotechnical Change from Technological Determinism," in *Does*

technological practices, design characteristics, skills, regulations, and standards.[12] This definition clarifies our notion of actors: people, groups, or organizations whose perceptions and behaviors are guided by rules.[13] In 1901, the dominant manual regime for grain handling endured because the entrepreneurs involved did not perceive a need to introduce elevators to secure an acceptable performance level. They were trying to optimize the existing regime. Twelve years later, another vision dominated: without elevators the port would fail to compete in the future. This shows that a regime shift had occurred.

Technology Drive History? The Dilemma of Technological Determinism, ed. Merritt Roe Smith and Leo Marx (Cambridge, Mass., 1994), 115–42.

12. For a further discussion of this concept, see the works cited in note 5. The notion of a technological regime was first used by R. R. Nelson and S. G. Winter, in "In Search of a Useful Theory of Innovation," *Research Policy* 6 (1977): 36–76, and became popular in evolutionary theories of technical change advanced by economists; for an overview, see Giovanni Dosi et al., eds., *Technical Change and Economic Theory* (London, 1988). Historians also have adopted evolutionary theories; see, for example, Mokyr, *Lever of Riches*, and George Basalla, *The Evolution of Technology* (Cambridge, 1988). In these formulations, the generation of variations is either random or directed by a technological regime, but it is independent of the selection process that determines the ultimate fate of those emerging variations. In our approach, both variation and selection are guided by a technological regime and thus are coordinated: the variation process is tuned to the subsequent selection. Gabrielle Hecht employs a similar concept in *The Radiance of France: Nuclear Power and National Identity after World War II* (Cambridge, Mass., 1998), in which she uses the idea of technopolitical regimes that govern technological development to stress the presence of purposeful policies prescribed by a regime. We put less emphasis on purposeful agency and highlight the importance of rules, which are often applied on a routine basis, but our conception comes close to hers. The notion of a regime differs from the Hughesian idea of technological systems because such systems are not assumed to prescribe behavior, an idea that is central to the concept of regime; see Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore, 1983).

13. This view of agency is congruent with the work of leading sociologists, especially Anthony Giddens. In Giddens's structuration theory, the duality of structure is central. In his view, actors are guided by rules and resources that make up social structures, while these structures are themselves the product of knowledgeable human actors. We call such a structure internal because it directly guides the actions of the actor, who has internalized the rules. However, actors always have the option to act against the structures. See Anthony Giddens, *The Constitution of Society: Outline of the Theory of Structuration* (Berkeley and Los Angeles, 1979); for an illuminating discussion and application, see Kevin Borg, "The 'Chauffeur Problem' in the Early Auto Era: Structuration Theory and the Users of Technology," *Technology and Culture* 40 (1999): 797–832. Our notion of actor differs from that proposed by actor-network theorists such as Bruno Latour and Madeleine Akrich. They assume that technologies should also be called actors because objects constrain and enable specific actions. We emphasize the importance of perceptions and the decisions of actors (assumed to be knowledgeable) to be guided by rules or not, and by doing this we exclude nonhuman actors. See, for example, Madeleine Akrich, "The De-Scription of Technical Objects," in *Shaping Technology/Building Society: Studies in Sociotechnical Change*, ed. Wiebe E. Bijker and John Law (Cambridge, Mass., 1992), 205–24.

In our model, explanation is a question neither of identifying a set of causal factors in the context nor of following the actors in a microconstructivist study. Explanations are located in the coincidence of developments at several levels. At the macrolevel, windows of opportunity and barriers arise that do not influence actor behavior in any direct way but form an external background. However, they do make it easier for actors to follow certain paths rather than others. The practice, perceptions, and actions of actors are not only influenced by external factors, they are also guided by the internalized rules of a technological regime (the mesolevel). An important feature of this multilevel model is that agency matters and must not be conceived as antistructural. Here we differ from Fernand Braudel, who defined agency ("events") mainly as a superficial disturbance of structural change.[14] We contend, however, that history is, to borrow a felicitous phrase from Andrew Abbott, a contingent narrative. The multilevel model asserts the indeterminate nature of historical processes while claiming that, given the narrative unfolding at several levels, certain developments become more probable than others.[15] We have developed this model to contribute to the elaboration of the contextualist paradigm that has emerged in the history of technology over recent decades.[16] The case study of the introduction of the elevator serves to demonstrate the usefulness of our approach.

What is the contingent narrative, then, of the introduction of the elevator to the port of Rotterdam in the early decades of the twentieth century? Which sequence of actions located in which technological regime led to a process of niche formation and regime shift? Which role can be allocated to the sociotechnical landscape in the narrative? To this story we now turn, leaving a further theoretical, empirically informed discussion to the concluding section.

Windows of Opportunity

Around 1900 grain was exported to northwestern Europe from several regions: the Black Sea, the Baltic, and North and South America. Importers resold this grain to other traders or directly to millers in the hinterland. (We will follow the practice current in Rotterdam at the time of using the

14. Fernand Braudel, *On History* (Chicago, 1980), 10–11 and 27. Braudel never theorized the relationships between event, conjuncture, and structure (*longue durée*), while the multilevel model is built on the idea that microchanges can build up to structural changes.

15. See Andrew Abbott, "From Causes to Events: Notes on Narrative Positivism," *Sociological Methods and Research* 20 (1992): 428–55.

16. John M. Staudenmaier, *Technology's Storytellers: Reweaving the Human Fabric* (Cambridge, Mass., 1985), and "Rationality, Agency, Contingency: Recent Trends in the History of Technology," *Reviews in American History* 30 (2002): 168–81.

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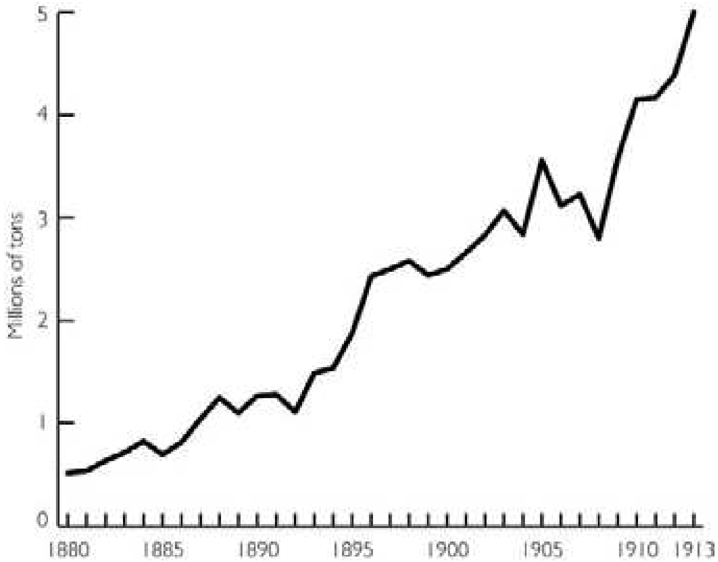

FIG. 1 Volume of grain arriving in the port of Rotterdam, 1880–1913, in millions of tons. (See http://www.fhk.eur.nl/websites/ra/, sheet 3.) Note that the volumes given contain a small amount of grain (probably less than 1 percent) that was transported to Rotterdam by barge or train instead of by sea. (See http://www.fhk.eur.nl/websites/ra/, sheet 5, data on incoming cargo in 1896 and 1904.)

terms "trader" and "importer" interchangeably. End users—that is, mill owners—sometimes dealt directly with exporters and might therefore be called importers too, which adds somewhat to the confusion.) In 1900 grain was one of the most important products shipped from overseas into Rotterdam, and the volume of grain imports there had grown significantly since 1893 (fig. 1). The grain was usually carried by tramp steamers, and a full cargo would consist of several consignments.[17] Only in the North and South American trade did regularly scheduled freighters play an important role in grain transport.

Grain was traditionally transported in bags, but around 1870 the United States began bulk shipments of grain to Europe. This practice was particularly encouraged by the advent in the United States, around 1850, of grain elevators, storage silos equipped with mechanical means to move grain.[18] By the turn of the century practically all American grain exports to

17. Serton (n. 6 above), 30–32.

18. See William Cronon, *Nature's Metropolis: Chicago and the Great West* (New York, 1991), 106–47, and Adrian Jarvis, "The Nineteenth-Century Roots of Globalization: Some Technological Considerations," in *Global Markets: The Internationalization of the Sea Transport Industries since 1850*, ed. David J. Starkey and Gelina Harlaftis (St. John's, Newfoundland, 1998), 217–37, especially 227–28.

European ports were bulk shipments. At the time, the Black Sea region was the main grain supplier of Rotterdam, and we may assume that a significant proportion of the grain from that region also arrived in bulk, and that the same was true of imports from the Baltic countries as well.[19] By 1913 virtually all Black Sea and Baltic grain came to Rotterdam in bulk.[20]

Many different parties were involved in grain handling in the port of Rotterdam.[21] Dockworkers employed by stevedore firms unloaded the ships, employing baskets and winches—the only mechanical devices used—to bring the bags up from the hold onto the deck (fig. 2). There the grain was weighed, using small, manually operated scales. Eighty kilograms was about the maximum weight of a bag of grain, though the exact weight depended on the type of grain. Specialist weighers were employed by importers through the mediation of factors (cargo superintendents), who played a central coordinating role. Often both exporters and shipowners had their own middlemen to check the weighing (the shipping companies had an interest in accuracy because their freight revenues depended on weight). Then the grain was transferred, either bagged or in bulk, to barges for transportation into the interior.[22] The factors made sure that the barges

19. In 1904, 70 percent of Rotterdam grain imports originated in the Black Sea region, 13 percent in the Baltic countries, 12 percent in South America, and 5 percent in North America. The shares for the full period 1904–13 were 58 percent, 17 percent, 12 percent, and 13 percent, respectively. Calculated on the basis of V. van Peski and D. L. Uyttenboogaart, *Le Marché des Céréales de Rotterdam* (Rome, 1918), 16–17. One German study suggests that shipping grain in bulk had become the rule by the end of the nineteenth century; Walter Borgius, *Mannheim und die Entwicklung des südwestdeutschen Getreidehandels*, vol. 2 (Freiburg, 1899), 76. Furthermore, between roughly 1890 and 1910 the transport of grain in bulk became a rather common practice in Russia; most domestic grain shipments went by rail. This grain must have been shipped to overseas destinations in bulk, too. Elevators and other warehousing facilities were poorly developed in Russia, where their capacity amounted to no more than 10 percent of annual grain exports. Often the grain was stored in bulk in the open air, which of course could be very detrimental to its quality. See Leo Jurowsky, *Der Russische Getreideexport: Seine Entwicklung und Organisation* (Stuttgart, 1910), 124 and 133–35; D. P. Ssemenov and W. J. Kasperow, *Russlands Landwirtschaft und Getreidehandel* (Munich, 1901), 69–70.

20. Serton, 32–33. Twenty-five percent of the grain from Argentina, another important point of origin for Rotterdam grain, still arrived in bags on the eve of the First World War.

21. This paragraph is mainly based on D. Uyttenboogaart, "Het graantransportbedrijf," in *Gedenkboek uitgegeven ter gelegenheid van het 600-jarig bestaan van de stad Rotterdam, 1328–1928*, ed. E. O. H. M. Ruempol (Rotterdam, 1928), 277–97; Serton, 35–39; and personal communication of the authors with K. K. Vervelde, who, besides his research in archives and literature (K. K. Vervelde, *De Rotterdamse graanhandel bemonsterd en gewogen: 125 jaar Koninklijke Vereniging het Comité van Graanhandelaren 1872–1997* [Rotterdam, 1997]), can call on his own experiences in the Rotterdam grain trade and on tradition passed on to him, mainly through his father, who was also active as a grain trader. See also Van Lente (n. 1 above), 82–84.

22. Rail and road transport played a minor role in grain shipments from Rotterdam

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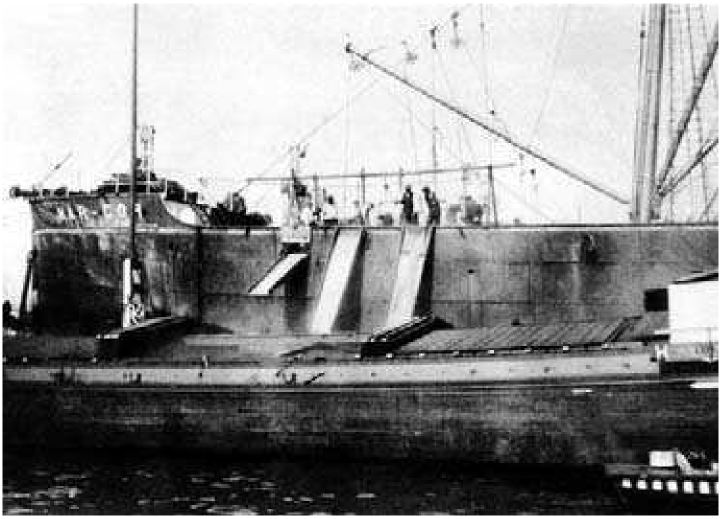

FIG. 2 A grain ship being manually unloaded, date unknown. The winch in the background is being used to bring baskets of grain from the hold onto the deck of the ship. After the grain had been weighed on deck it was taken to the ship's rail, and from there the bags were slid down a chute to a waiting barge or—as this photograph shows—were emptied into the chute onto the barge for bulk transport. (European Bulk Services Photo Archives, box no. 14, Rotterdam Municipal Archives.)

arrived alongside at the proper time. The weighers and other men hired by the factors were also involved in checking the quality of the grain by sampling it and by measuring its specific gravity. In short, quite a number of intermediaries were involved in grain handling. When we realize, moreover, that each ship carried cargoes for several importers, each with its own factor leading a group of workers, the observation "that in the beginning of the twentieth century a discharging grain ship gave the impression of a teeming ant hill" surely seems apt.[23]

This regime of manual cargo handling, laborious and complex as it appears, presented no serious productivity or control problems at the time. The traders considered the prevailing handling rate of 10 tons per hour per shift fast enough.[24] They also appreciated the system's flexibility; for example, when the importers had not yet resold their grain, or when barges were

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to the hinterland. Note that the term "factors" has a very specific meaning in the context of the Rotterdam grain trade; these were cargo superintendents, not commission agents or sales agents or the like.

23. Uyttenboogaart, 284.

24. See the report of the RCCA committee on the visit of the Verein deutscher Handelsmüller (n. 2 above).

unavailable or too expensive, unloading slowly saved on storage costs. Manual grain handling permitted the speed of unloading a ship to vary; one could shrink or expand the number of workers, for instance, as they were not employed on a regular basis. The use of expensive machinery, by contrast, favored unloading at the highest possible speed. Similarly, mechanization tended to infringe on the traders' preference for flexibility; several protested vigorously when the Holland America Line, which had begun to use bucket elevators in 1896, forced them to receive their grain in consignments of at least 60 tons.[25]

The complex nature of the grain trade also provided those involved in it with other opportunities for wheeling and dealing—or even cheating. By manipulating the scales, placed on a ship's deck that was always in motion, the weighers tried to benefit their principals—the importers—by recording short weights. The exporters' checkers tried to prevent them. Russian exporters were repeatedly accused of adulterating the grain with sand or other substances. Eventually these exporters and the German and Dutch importers agreed on a method of arbitration. The so-called German-Dutch contract, the first version of which was drawn up in 1904, more or less resolved this issue.[26] Rotterdam entrepreneurs actually played down the problem of theft: in 1900 a committee of the Rotterdam Chamber of Commerce concluded that the quantities stolen in the port itself were small, and that most thefts occurred after the grain had left the port—that is, as it was transported into the interior.[27] In all, while those involved in the grain trade at Rotterdam were eager to regulate, they valued the control they had over aspects of grain handling in the port under the existing system.[28] It is therefore doubtful that the entrepreneurs involved perceived a "crisis of control" that triggered mechanization, as Dick van Lente has argued.[29] On the contrary, the traders believed they could effectively

25. Minutes of the meeting of the Comité van Graanhandelaren, 7 April 1898, notulenboek-4, Koninklijke Vereniging Het Comité van Graanhandelaren Archives (CGA), Rotterdam. The minimum consignment was 30 *last*; one *last* equaled 1.5 to 2.5 tons, depending on the type of grain.

26. J. C. Everwijn, *Beschrijving van handel en nijverheid in Nederland*, vol. 2 (The Hague, 1912), 643–53, and Jurowsky (n. 20 above), 69–70, 98–118, and 156–64.

27. Kamer van Koophandel Rotterdam, *Verslag van de Kamer van Koophandel en Fabrieken te Rotterdam over 1899* (Report of the Chamber of Commerce and Factories in Rotterdam on 1899) (Rotterdam, 1900), 92–93. For a study of changing views on the legitimacy of thefts by workers in preindustrial England, see John Styles, "Embezzlement, Industry and the Law in England, 1500–1800," in *Manufacture in Town and Country before the Factory*, ed. Maxine Berg, Pat Hudson, and Michael Sonenscher (Cambridge, 1983), 173–210.

28. Mechanization leading to a loss of space for negotiation is a broader trend in the twentieth-century history of technology; see John Staudenmaier, "The Politics of Successful Technologies," in *In Context: History and the History of Technology*, ed. Stephen H. Cutcliffe and Robert C. Post (Bethlehem, Pa., 1989), 150–71, esp. 157–61.

29. Van Lente (n. 1 above). He borrows the phrase "crisis of control" from Richard

respond to perceived problems by regulation, and hence optimize the existing—in their view, stable—technological regime.

Nevertheless, developments at the landscape level—continuously rising grain imports, shipped ever more frequently in bulk—offered a window of opportunity for innovators in handling technology. As early as 1882 a company attempted to introduce a bucket elevator for loading grain into the port of Rotterdam. (A bucket elevator works like a dredging machine, digging cargo out of a ship's hold by means of buckets or skips.) It was a primitive device and quickly suffered a sad fate; outraged by the threat to their employment, in 1883 the dockworkers set fire to it.[30] This event so traumatized the port companies that when the Holland America Line (HAL) installed a bucket grain elevator in 1896, so that its large, new, regularly scheduled liner could be discharged on time, they decided to retain all of their workers, regardless of the elevator's laborsaving potential. (A crew of dockworkers could unload only 10 tons per hour by the usual manual method, in comparison to the bucket elevator's 60 tons per hour).[31] In this way, the new technology was fitted into the existing regime.

The use of bucket elevators in Rotterdam (the HAL put two more into operation before 1900) remained restricted to the niche created by the Holland America Line, and the new technology did not diffuse into the less time-sensitive market of nonscheduled tramp ships. That pattern changed, however, with the introduction of a new type of elevator.

A Producer-Initiated Introduction

In 1907 the floating pneumatic elevator (fig. 3) initiated a radical change in the technological regime of the port of Rotterdam. The first pneumatic elevators had a maximum capacity of 150 tons per hour. Later it was calculated that under the manual regime 126 dockworkers, weighers, and bag holders took seven to eight days to unload a ship with a cargo

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Edwards, *Contested Terrain: The Transformation of the Workplace in the Twentieth Century* (New York, 1979), and James R. Beniger, *The Control Revolution: Technological and Economic Origins of the Information Society* (Cambridge, Mass., 1986).

30. Boek Comité kladnotities Graswinckel periode 1877–1914, p. 19, box Graancomité Geschiedenis 1872–1962, CGA. D. P. M. Graswinckel and Leo Ott, *100 jaar 'in granen': Handel en wandel van het Comité van Graanhandelaren* (Rotterdam, 1972), 48 (the story as related by one Mr. Teeuwen, whose father supposedly built the elevator and who as a child played amid the wreckage). Minutes of the meetings of the Comité van Graanhandelaren, 19 August 1882, 30 September 1882, 11 January 1883, 21 February 1883, 11 March 1883, and 31 March 1883, notulenboek-3, CGA. W. A. H. Crol, *Een tak van de familie Van Stolk honderd jaar in de graanhandel, 1847–1947* (Rotterdam, 1947), 25.

31. Minutes of the meetings of the Board of Supervisory Directors, 3 February 1896 and 10 October 1896, Holland-Amerika-Lijn Archives, inv. no. 3, RMA; M. G. de Boer, *De Holland-Amerika Lijn, 1873–1923* (Amsterdam, 1923), 39. The official name of HAL at that time was Nederlandsch-Amerikaansche Stoomvaart Maatschappij.

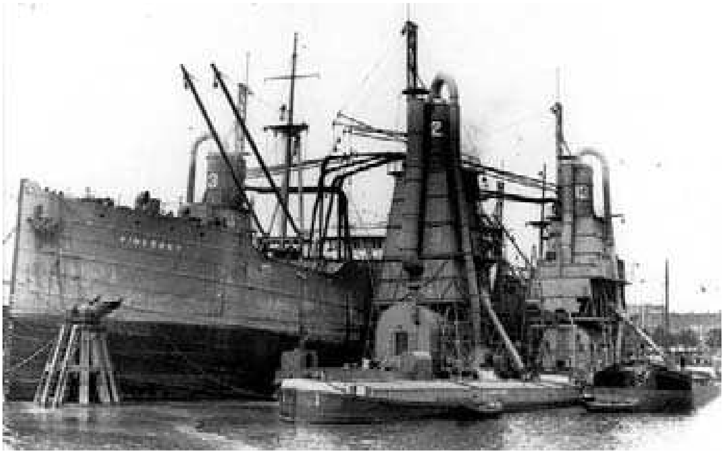

FIG. 3 Floating grain elevators discharging a ship in the Rotterdam Maashaven basin, 1926. As the picture shows, the elevators could operate on both sides of the vessel simultaneously. (Stichting Historie der Techniek, Eindhoven.)

capacity of 6,000 tons of grain. If two pneumatic elevators were used, with a crew of fourteen on each one, the job was done in two days.[32] This was a reduction in labor input of 94 percent.

How did the pneumatic elevators work? The grain was vacuumed from the ship's hold and discharged into a reservoir at the top of the elevator tower, using a steam-driven pump to create the vacuum. From the reservoir it fell by gravitational force into an upper bunker, from where it could be poured onto the scales. A lock between the reservoir and the bunker preserved the vacuum. From the scales the grain flowed to a lower bunker, and from there it was discharged into a barge, again by gravity (fig. 4).

The technique employed had been understood long before 1901. The first experiments with lifting grain by means of airflows had taken place around 1863.[33] In Liverpool in 1893 the Millwall Dock Company put into operation the first floating grain elevator that worked properly, designed by Frederick L. Duckham.[34] In 1896 the firm G. Luther AG in Braunschweig, a company specializing in grain-milling equipment, acquired the right to man-

32. Serton (n. 6 above), 42.

33. George F. Zimmer, *The Mechanical Handling of Material* (London, 1905), 207.

34. For the general technological history of the grain elevators, see M. Buhle, *Technische Hülfsmittel zur Beförderung und Lagerung von Sammelkörpern (Massengütern)*, vol. 1 (Berlin, 1901), 1–13; Carl A. E. Müller, "Die Entwicklung der schwimmenden pneumatischen Getreideheber," *Jahrbuch der Hafenbautechnischen Gesellschaft* 20 (1937): 163–82; and Chr. Klock, "Die Förderung von Körnergut im Luftstrom und ihre Bedeutung für die Schiffahrt," *Jahrbuch der Schiffbautechnischen Gesellschaft* 19 (1918): 173–217.

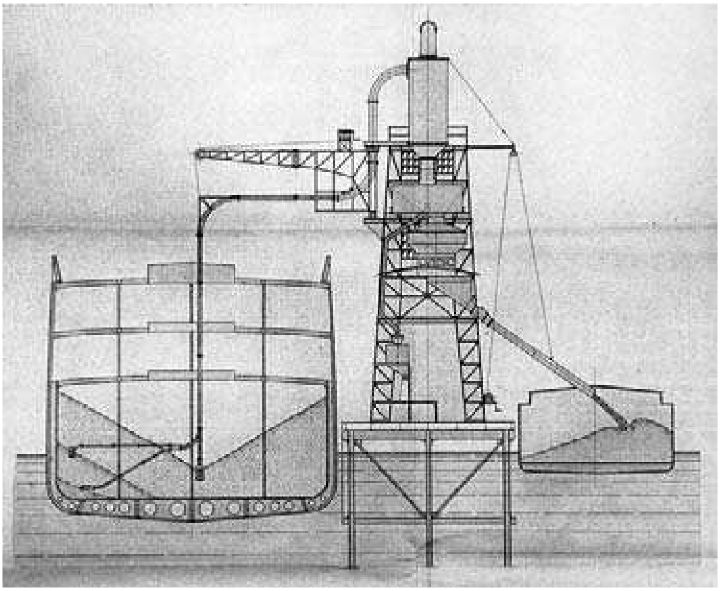

FIG. 4 One of the plans J. C. Smalt developed after the first niche strategy had failed consisted of a series of pneumatic grain elevators placed on a jetty. This plan was not realized (Rotterdam would get a shore-based installation of grain elevators only in 1964), but the drawing nicely illustrates the working of pneumatic elevators, floating or not. The grain was vacuumed from the ship's hold (left) and discharged into a reservoir high up in the elevator tower (middle). From there it fell onto the scales, via a few intermediate steps, and after weighing was discharged into the barge (right). (GEM Archives, box no. 1, inventory no. 3, Rotterdam Municipal Archives.)

ufacture Duckham elevators under license for the European continent. On the basis of this license, in 1896 Luther supplied the German shipping companies Hamburg-Amerikanische Packetfahrt-Actien-Gesellschaft (HAPAG) and Norddeutscher Lloyd with elevators for unloading grain in their respective home ports of Hamburg and Bremen.

In August 1901 the delegation of the Verein deutscher Handelsmüller mentioned at the beginning of this article visited the port of Rotterdam in an attempt to pave the way for the introduction of pneumatic elevators there as well.[35] The German mill owners probably came to the Netherlands

35. The Verein deutscher Handelsmüller was the association of German mill owners who bought grain, milled it, and traded flour at their own risk. In contrast, so-called *Lohnmüller* milled grain for third parties without taking title to the grain. Unlike *Lohnmüller*, most *Handelsmüller* owned large mills and operated on a national or even international scale (both buying grain and selling flour). The Verein deutscher Handelsmüller was founded in 1898 to represent the interests of this group of mill owners in particular.

mainly to promote Luther's interests.[36] F. W. Meyer, head of the delegation, was not only the Verein's chairman but also a supervisory director at Luther. Meyer's son Willy, an engineer, worked for the company as well.

So it was actually the machine builder who, indirectly, pushed for the application of the new technology. Meyer's arguments met with a skeptical reception except from J. C. Smalt, delegated supervisory director of the N.V. "Het Nederlandsche Veem," a Rotterdam warehousing, grain forwarding, and grain factor company. Smalt, an entrepreneur with many years of experience in the grain trade, had been appointed only a couple of months before to save the failing business, and he became the moving spirit behind the introduction of elevators in the port of Rotterdam.[37] For Nederlandsche Veem the grain factor department was vital, and Smalt worried that the company might lose much if not all of this business to an elevator company. During a board meeting on 12 September 1901, Smalt reported on his trip to Hamburg and Bremen, where he had seen the elevators in operation. The visit had convinced him "that the floating elevators will come to Rotterdam; if we don't introduce them, it will certainly be done by others."[38]

Nederlandsche Veem was in dire straits financially, so Smalt had to look for partners to get an elevator company off the ground. Several potential partners showed little or no interest. The grain traders considered the existing handling speed high enough. A Rotterdam Chamber of Commerce committee, set up in October 1901 following the visit by the Verein deutscher Handelsmüller, expressed this sentiment forcefully. The traders also ob-

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The general association of German (grain) mill owners, the Verein deutscher Müller, dates from 1867; see Gerhard Luther, *Die technische und wirtschaftliche Entwicklung des deutschen Mühlengewerbes im 19. Jahrhundert* (Leipzig, 1909).

36. A brochure attached to an undated circular distributed by the delegation of the Verein deutscher Handelsmüller during their visit to Rotterdam contains passages that are practically identical to parts of the content of a presentation by Albert Lemmer, director of Luther AG in the same period. See GEM Archives (GEMA), box no. 508, RMA, and *Zeitschrift des Vereins Deutschen Ingenieure* 45 (24 August 1901): 1217–18.

37. In 1898 the N.V. "Het Nederlandsche Veem," formed by the amalgamation of three old warehouse companies in Amsterdam in 1896–97, took over the Rotterdam forwarding and grain factor business Borleffs and Company and built a grain silo with a warehouse, called the "Eersteling," in the port of Rotterdam. For those days it was a huge building, with conveyor belts and a bucket elevator on the quay on which it fronted. The idea probably was to discharge grain directly from the ships into the building. But the new company was not able to fill the warehouse—it was not common then to store grain that way in seaports—and from the beginning the Eersteling was regarded as a failure. See H. van Driel, "De ontwikkeling van de vemen in Nederland, 1600–1967," Management Report Series 194, Erasmus Universiteit Rotterdam, Faculteit Bedrijfskunde, Rotterdam, 1994, 49–55. There seems to have been no relationship between the Eersteling, with its bucket elevator, and the interest that Smalt took in the floating pneumatic elevators. See also Smalt's obituary in the *Nieuwe Rotterdamsche Courant*, 23 February 1918.

38. Minutes of the meetings of the "Het Nederlandsche Veem" board of managing directors, 8 August 1901, 12 September 1901, 15 June 1903, 23 June 1903, and 30 July 1903, Directievergaderingen januari 1901–juni 1915, Koninklijke Vopak Archives, Rotterdam.

served that unloading by elevator made it difficult, or even impossible, to receive grain in bags even when that was desirable; in February 1904, for instance, a trader wrote Smalt noting that the elevator was impractical for the fine-gridded distribution of grain in bags within the Netherlands.[39] Nor did the elevator's cleaning function fit in with the existing technological regime. The Verein deutscher Handelsmüller emphasized the advantage of separating the grain from the dust and other dirt, arguing that since the grain in the elevator was cleaned before weighing the receivers had to pay import duties only on the weight of the pure grain, which would save about twenty million German marks on a yearly basis.[40] The Chamber of Commerce committee noted, however, that the sellers would simply raise prices if cleaning the grain at the port proved financially unfavorable to them.[41]

The committee did see one important advantage in the elevator: the cost savings it conferred could attract additional cargo to the port. Whether this mattered remained to be seen, for Rotterdam was already the largest grain port in continental Europe. At any rate, the committee was careful to modulate its reaction; the memory of the destruction of the bucket elevator in 1883 was still vivid. Although rapid unloading, which enabled more round trips per ship per year, would benefit shipowners greatly, the Rotterdam ship agents gave Smalt's initiative only a lukewarm welcome.

Failed Niche Formation

Eventually Smalt managed to convince the leading Rotterdam ship agents of the merits of pneumatic unloading. Exploring the technological features of the elevators was a vital step in this process. Smalt acquainted himself with the construction of elevators from different manufacturers.[42] Between 1901 and 1904 elevator design developed rapidly, so that it became possible to discharge larger ships ever more efficiently. The company mainly responsible for this rapid development was the leading continental elevator manufacturer, Luther AG, which adapted, through trial and error, the orig-

39. For the Chamber of Commerce report, see note 2. J. van Rede en Zonen to Smalt, 9 February 1904, GEMA, box no. 508, RMA.

40. This separation occurred because the grain lost speed as it entered the reservoir and settled on the bottom, whereas the lighter dust and (some of) the dirt kept swirling and could thus be collected separately.

41. It became common practice in Rotterdam, as in most other ports, to add back to the grain, prior to weighing, the dust that had been separately collected—in the eyes of some cargo-handling experts, an almost ridiculously inefficient practice; see Brysson Cunningham, *Cargo Handling at Ports* (London, 1923), 134, and T. J. Noordraven and C. A. G. van der Boom, *Het beladen: Een handboek over het beladen van zeeschepen, het stuwen van lading, de vrachtberekening en de beginselen van de stabiliteitsleer*, 3rd ed. (Amsterdam, 1928), 469.

42. For Smalt's activities and investigations, see the correspondence in GEMA, box no. 508, RMA, and Cocheret (n. 1 above).

inal British elevator design to circumstances in continental ports.[43] Finally, Smalt decided to take his chance with Luther. In March 1904, nearly three years after the visit of the Verein deutscher Handelsmüller, several parties joined together to found the Maatschappij tot Exploitatie van Drijvende Elevatoren (hereinafter the Elevator Company, for simplicity). Together with his fellow director of Nederlandsche Veem, D. L. Uyttenboogaart, Smalt took on the management of the Elevator Company. Besides Nederlandsche Veem, the main participants in the Elevator Company were five leading Rotterdam ship agents. Two smaller ship agents, three factors, one stevedore firm (Thomsen), Max Münzel (director of Luther AG at the time), Smalt, and some other individuals bought smaller numbers of shares. In this way a network was formed to support the niche in which the manufacturer and various groups of users participated. In vain Smalt tried to persuade the German importers to participate in the company, given their apparent interest three years earlier. In hindsight, we can see that the visit in August 1901 by the German mill owners gave a misleading impression concerning the attitude of German importers toward the grain elevator.

In April 1904, the company ordered two grain elevators from Luther, which together could handle no more than about 10 percent of Rotterdam's annual grain throughput. Besides lack of capital (each elevator cost about 185,000 Dutch guilders; the hourly wage of a dockworker was around 0.25 guilders at that time), the innovators had a strategic consideration for this niche focus: they did not want to upset the dockworkers and middlemen too much, for without supporting measures existing relations would be adversely affected. In contrast to the HAL's installation of a bucket elevator or the use of pneumatic elevators in foreign ports, which served only the needs of individual liner shipping companies, these elevators were being

43. On elevator design developments, see Müller (n. 35 above), who was probably an engineer at Luther AG. Unfortunately, his article entirely lacks source citations. The first English elevators were equipped with several towers, with the idea being to unload a ship through several hatches at once, but in practice this proved awkward. Moreover, these Duckham elevators had a much squatter shape, which was well adapted to the small river barges of London but not very suitable for larger ships. Unloading these entailed bending the suction pipes—which the elevator builders did not perceive as a problem until the turn of the century because they labored under the faulty idea that transportation of material via airflows was the same as transportation of liquids, which failed to take into account the considerable loss in speed of the grain when it struck the walls in the bends of the pipes. Based on its discussions with Smalt and other customers, Luther implemented design changes step by step. Finally, the company decided to build an elevator for Rotterdam with a single tower almost 20 meters high (including the reservoir), much taller than the first elevators, which were based on the Duckham patent. See Kosten-Anschlag über einen schwimmenden pneumatische Getreideheber von 150 tons stündlicher Leistung mit später einzubauender Getreidereinigungsanlage, 18 July 1903 and 10 November 1903, GEMA, box no. 1, inv. no. 2b, RMA. The first two Luther elevators for the port of Rotterdam became, according to Müller, the standard for German elevator construction.

introduced for general use in the port of Rotterdam.[44] This threatened not only various dockworkers' jobs but also the stevedore firms and factors. In a report dated 1 February 1904, written for the planned elevator company, a committee of the five leading ship agents sought to clear the air in advance. Grain handling by elevators, the committee recommended, would be organized so as to leave the stevedore firms and factors unaffected.[45] The report further emphasized that the coming of elevators would lead to an increase in grain traffic to Rotterdam, moderating the loss of jobs. In fact, Smalt later maintained that the limited setup, with only two elevators, able to handle just 10 percent of the grain arrivals in Rotterdam, was mainly meant to spare the workers as much as possible.[46]

In July 1905, well over a year after the founding of the Elevator Company, the elevators were ready for use. In August, just as they went into operation, a serious flaw came to light. Each elevator was equipped with two automatic scales, each of which could weigh up to 78 tons per hour (this roughly corresponded to the elevator's unloading capacity of 150 tons per hour).[47] But the scales were inaccurate; Luther had not taken into account the "live weight" of the grain falling onto the scales, which caused them to register too heavy a weight.[48]

44. This is confirmed by an observation in a Dutch newspaper: "In Hamburg, Bremen, and London such machines were already in operation, although in the ports first mentioned they were operated exclusively by the transatlantic steam-shipping companies themselves, which saw the advantages of applying these machines for a quicker dispatch. Rotterdam, however, is the first continental port where a company provides the elevator to 'traders,' to ships arriving and leaving at irregular times." "De graan-elevators in Rotterdam," *De Maasbode*, 12 November 1905.

45. GEMA, box no. 1, inv. no. 2a, RMA.

46. Minutes of the meeting of the supervisory directors of the Elevator Company, 15 December 1905, GEMA, box no. 501, RMA.

47. Luther to Smalt, 17 September 1904, GEMA, box no. 508, RMA.

48. Directie (N.V. Nederlandsche Veem), Nml. Mij. tot Exploitatie van Drijvende Elevators, Verslag over de periode van 28 april 1904 tot 31 Dec 1905 (annual report, typewritten, in the minute book of shareholders' meetings), GEMA, box no. 507, RMA. Uyttenboogaart (n. 22 above, 285) and Cocheret (n. 1 above, 28) offer different explanations for the flaw, both related to a faulty adjustment between grain lock and scales, but, inexplicably, neither takes into account the presence of the upper bunker between grain lock and scales. Luther had made it clear that the company had sufficient experience with automatic weighing. The Chronos scales used in the elevators were manufactured by the Hennefer Maschinenfabrik C. Reuther & Reisert m.b.H., which could show an impressive list of satisfied customers from various countries; Hennefer Maschinenfabrik C. Reuther & Reisert m.b.H., Hennef a.d. Sieg (Rheinprovinz), Zeugnisse über unsere patentirte, aichfaehige, automatische Waage "Chronos" als Absack- und als Elevatorwaage in Lagerhaeusern, Silo-Speichern, Elevatoren, Verzoll- und Umladestationen, Muehlen etc., n.d., GEMA, box no. 1, inv. no. 1, RMA. One of those customers was Norddeutscher Lloyd, in Bremen. However, at the request of the local merchants in Hamburg the elevators Luther delivered were equipped with hand-operated decimal scales instead

Although the management of the Elevator Company thought that a simple adjustment—installing a screen to break the grain's fall—might solve the problem, it opted instead to replace the automatic scales with manually operated scales of similar hourly capacity.[49] Two considerations influenced the company's decision: fear of further lawsuits over incorrect weights and, possibly more important, a desire to restore its credibility, for the failure had confirmed distrust of automatic scales. One of the technical possibilities of the new elevator was thus sacrificed to accommodate the traders' existing preferences.

The incident considerably retarded the introduction of elevators into the port of Rotterdam and had significant consequences for the innovation process. It took a month and a half to install the manual scales, during which time the opposition organized. The stevedore firms and factors joined forces to frustrate the Elevator Company, or at least to extract concessions on handling rates. The strongest opposition came from the weighers, elite dockworkers whose livelihood was immediately threatened. On 4 November 1905, all 450 weighers working in the port went on strike, seeking a guarantee that they would remain employed.

This strike, supported by the checkers and other dockworkers, particularly affected the German importers, because import duties on grain shipped to Germany were to be raised in March 1906. In the intervening few months they understandably wanted to import as much as possible, and in the depths of winter the Rhine would be difficult or impossible to navigate. To settle the strike, the importers promised not to accept grain from the elevators until May 1906.[50] As a result, at the end of 1905 the Elevator Company was forced to close down the elevators.

During the lull that followed, the traders' objections to the elevators arose again, and more emphatically. To be sure, there were dissenters in their ranks. Smalt himself was active in the grain trade and he was greatly respected by his colleagues.[51] Another prominent trader, P. W. Schilthuis, spoke favorably of the elevators in a meeting of the Comité van Graanhan-

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of automatic scales, which shows that there was precedent for the Rotterdam traders' concerns; Luther to Smalt, 11 September 1902, GEMA, box no. 508. The traders' fear that automatic weighing on a floating elevator was not reliable enough is quite understandable, as the elevator would move under the impact of the grain. Luther must have known about this, but the company's aim apparently was a standard machine in which as many functions as possible were mechanized.

49. Minutes of the meeting of the supervisory directors of the Elevator Company, 5 October 1905, GEMA, box no. 501, RMA.

50. To be precise, the German importers promised only to accept grain weighed in the conventional manner, bag by bag; in practice this meant that unloading by the elevators made no sense.

51. Graswinckel and Ott (n. 30 above), 48; K. K. Vervelde, personal communication.

delaren (Committee of Grain Traders, the central association in Rotterdam) in November 1905.[52] Nevertheless, opposition was widespread enough and deep enough to cause the Comité to adopt a neutral attitude toward the elevators, shading to negative. In February 1906 a special committee, set up by the Comité and chaired by antielevator man F. C. Hoyack, concluded: "Discharge by means of the elevators is not in our interest."[53]

As we have already noted, fast unloading indeed often was not in the interests of the traders—when they had not yet sold the grain, for example. Furthermore, receiving grain from the elevators would remain just as expensive for the traders as it had been, thanks to the Elevator Company's decision not to underbid the stevedore firms.[54] Some traders particularly objected to the impossibility, when an elevator was in use, of receiving grain in bags and small consignments.[55] But the most active opposition came from the German importers, who were little concerned with this issue.[56] In the beginning of 1906 they extended their contract with the weighers to 1 May 1907. The leader of the German opposition, secretary of the Rhenish-Westphalian grain importers' association Levi Rosenthal, claimed that the quality of the grain was adversely affected by the elevators, that the elevators unloaded "too fast," and that short weights were detected at the Rhine ports.[57] In sum, many traders were afraid of mechanization; they felt it threatened their control of their grain-handling business, their ability to negotiate a given situation, and their operational flexibility. Prestige also played a role. The German grain importers, who had outstripped the Dutch traders in the decades preceding the elevator conflict, did not like to be told how to receive their grain by some local Rotterdam company.[58]

52. Minutes of the meeting of the Comité van Graanhandelaren, 8 November 1905, notulenboek-5, CGA.

53. Minutes of the meeting of the Comité van Graanhandelaren, 9 February 1906, notulenboek-5, CGA.

54. "De Graanelevators," *Rotterdamsch Weekblad*, 24 March 1906.

55. Several observers suspected that the importers saw another disadvantage to the idea of weighing the grain in bulk. When the grain was weighed bag by bag, the importers usually received a certain overweight, which added up, whereas weighing grain by the ton would bring them a negligible advantage, if any at all; Van Lente (n. 1 above), 91–92.

56. Even large grain-processing installations in Germany were often not equipped to receive grain in bulk; Eugen Fridrichowicz, *Die Technik des internationalen Getreidehandels* (Berlin, 1908), 197–98. However, the grain was normally shipped in bulk from Rotterdam to a Rhine port, such as Mannheim, then bagged for transport by rail to the industrial processor; Borgius (n. 20 above), 76–79.

57. Minutes of a meeting of the Comité van Graanhandelaren and the German importers, 20 March 1906, notulenboek-5, CGA.

58. Borgius, 13; Everwijn (n. 27 above), 639–40. A publication coauthored by one of the directors of the Elevator Company attributed the dip in Rotterdam grain traffic in 1908 to the German traders' continued annoyance after the battle had been fought, suggesting that they imported much more grain through Antwerp than usual that year; Van

A New Regime

During the entire year of 1906 the Elevator Company did not use the elevators, though it did not remain idle.[59] From the company's point of view, the elevators had proven themselves technically as well as economically in the brief period during which they had operated. Based on data from November 1905, when the elevators handled 28,000 tons of grain, and taking into account the special circumstances of that month, the Elevator Company projected a net annual profit of forty-eight thousand Dutch guilders, for a return on sales of 29 percent.[60] It therefore made sense to continue the fight, although with a new strategy. By the end of 1905, Smalt had come to the conclusion that his gradualist approach had been wrong; in fact, paradoxically, one of the traders' objections was that the company had not ordered enough elevators.[61] Smalt now developed plans for an all-or-nothing attack, ordering six or more new elevators. He would no longer build a small niche, but would try to capture a large part of the market all at once.

To succeed, the company first needed to build a wider and stronger network. In April 1907 it managed, by means of guarantees and attractive rates, to persuade the nine most prominent Rotterdam grain importers to work with elevators. How to explain the traders' change of attitude? The weighers' strike had precipitated an extensive debate in Dutch society on the "elevator question." It turned out that not only liberal and religious politicians and other opinion leaders but also most socialist intellectuals (including labor union officials) shared the prevailing view that resisting modern technologies was irrational and antimodern.[62] At the macrolevel,

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Peski and Uyttenboogaart (n. 19 above), 15 and 18. On the other hand, Van Lente suggests that during the elevator conflict the Rotterdam employers wanted to "show the powerful German importers who was the boss in the harbour"; Van Lente, 108.

59. The stevedore firm Thomsen and Company leased the elevators for half a year, but labor resistance prevented their operation.

60. Minutes of the meeting of the supervisory directors of the Elevator Company, 7 December 1905 and 15 December 1905, GEMA, box no. 501, RMA (net return calculated by authors).

61. Minutes of the meeting of the supervisory directors of the Elevator Company, 18 November 1905, GEMA, box no. 501, RMA; undated drafts of prospectuses, GEMA, box no. 508, RMA; drawings of shore-based pneumatic elevators, GEMA, box no. 1, inv. no 3, RMA.

62. Van Lente (n. 1 above), 93–109. After the nine Dutch traders had signed the agreement with the Elevator Company, they published a proelevator letter in a leading Rotterdam newspaper, in reply to an antielevator article by F. C. Hoyack of the Comité van Graanhandelaren in the same paper the day before. Their argument reflected the general view in Dutch society concerning the irrationality of obstructing technological progress: "One notices with surprise that there are still many workers, and not only they, who even in the twentieth century believe that they have to take the battle of the handicrafts against the progress of history. But the history of the last hundred years teaches us

then, technology had become an icon of progress, which provided a dominant cultural orientation.[63] Other developments reinforced the idea that technological change would go on no matter what. Beginning in March 1905, the leading Rotterdam coal trading company had put into operation several floating coal loaders, which made obsolete many workers who had loaded coal by hand into ships' bunkers and considerably reduced the amount of time needed to coal a ship (the analogy with grain handling is apparent).[64] And in 1907 a new company had installed five pneumatic grain elevators of the Rotterdam type for general use in Hamburg, working in close cooperation with the local factors.

The crucial change, however, occurred within the grain-handling regime: the conflict over the elevator had turned into a conflict over power in the port. By April 1907 the effect of the elevator technology on the process of unloading ships was no longer the main issue. Rather, control of labor had become the focal point. Initially the traders had blamed the Elevator Company for creating labor unrest, but eventually the fierce resistance of the workers produced an alliance among the various groups of entrepreneurs. In the eyes of the traders, the elevator conflict had ignited a struggle for power between them and the workers. On 7 May 1907, A. C. van Eyk, a subtle voice among the Rotterdam grain traders, noted that "no one is in favor of the elevator, but the aim is to remain in charge."[65] The struggle over the elevator, rather than problems within the existing regime, had stimulated a desire to become independent of the workers.

To break the dockworkers' resistance, the Elevator Company offered the stevedore firms a lucrative contract, which was signed in May 1907. Besides its own group of weighers, recruited after the deal with the traders, the Elevator Company could now also employ strikebreakers to unload ships, either using the two elevators or by the conventional method. The dock-

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that a machine that performs a job better, quicker and cheaper than a handicraft inexorably replaces that craft. On the other hand, the growth of commerce creates new jobs. Therefore we have to teach the worker to adapt to technological change." P. W. Schilthuis, *Nieuwe Rotterdamsche Courant*, 12 May 1907, trans. Van Lente, 101.

63. See Leo Marx, "The Idea of 'Technology' and Postmodern Pessimism," in Smith and Marx (n. 11 above), 237–58. See also Johan Schot, "The Contested Rise of a Modernist Technology Politics," in *Modernity and Technology*, ed. Thomas J. Misa, Philip Brey, and Arie Rip (Cambridge, Mass., 2003), 257–78.

64. D. G. van Beuningen, the managing director of the Rotterdam branch of the coal trading company involved, Steenkolen-Handelsvereeniging, had even made an agreement with Smalt to introduce the coal loader and the grain elevator simultaneously and to face the expected labor resistance all at once. After repeated delays on Smalt's part, Van Beuningen decided to introduce the coal loader on his own. See Van Beuningen, Memoirs, Handschriften, no. 326, RMA, and Harry van Wijnen, *Grootvorst aan de Maas: D. G. van Beuningen 1877–1955* (Amsterdam, 2004), 130–35.

65. Minutes of the meeting of the Comité van Graanhandelaren, 7 May 1907, notulenboek-5, CGA.

workers responded with violence against the strikebreakers, in effect doing the dirty work for the weighers, whose agreement with the German importers bound them not to strike. After a brutal confrontation on 5 July 1907, the army became involved: Rotterdam was in a state of siege. At that point the patience of the German importers reached its limit. Earlier in the year they had extended their contract with the weighers by three years, to 1 May 1910, but in mid-July they expressed their desire to reach an agreement with the Elevator Company.

The workers now constituted the only remaining obstacle. The Elevator Company remained prepared to restrict itself to 10 percent of the grain traffic in the port for a period of three years. The workers did not want to give in, very likely because they suspected that after three years that self-imposed restriction would be lifted and probably also because they felt overconfident after the success of the weighers' strike. The importers eventually were able to appease the weighers by offering them a pay raise. On 23 September 1907 the workers called a general dock strike, which the weighers did not join. With the employers having joined forces, the strike had little chance of success. It ended after nine weeks and the only thing the dockworkers got out of it was a pay raise.

The day after the dock strike began the Elevator Company issued a prospectus for eight (later reduced to six) additional elevators. This time there was no difficulty in raising the required capital. The traders thought they should be rewarded for supporting the introduction of the elevator, which still supposedly was not in their own interest. In 1908 the Elevator Company was replaced by a new firm, the Graan Elevator Maatschappij (GEM). Equal shares in GEM were given to two groups: the ship agents, shipping companies, and stevedore firms (group A), and the traders (Dutch and German), forwarders, and factors (group B). Each group received fifty percent of the shares and each provided an equal number of supervisory directors.

In addition, measures were taken to permit the receiving of grain in bags.[66] Several alternative and smaller elevator designs were proposed in discussions between GEM and the traders, to be built by Dutch producers, but investigations repeatedly confirmed the technical superiority of the

66. By mid-1907 Smalt had already become more willing to do something about this crucial technical disadvantage of the pneumatic elevator for the traders. For this and the following, see Wijnmalen and Hausmann (a Rotterdam technical trading company) to Smalt, 31 May 1907, GEMA, box no. 1, inv. no. 2b, RMA; minutes of the meetings of the supervisory directors of the Elevator Company, 17 July 1907, 1 August 1907, 10 September 1907, and 27 October 1907, GEMA, box no. 501, RMA; N.V. Machinefabriek "Hoogenlande" v/h Firma Pannevis en Zoon, Utrecht (a Dutch factory), September 1907, Beschrijving eener Drijvende Pneumatische Graan Elevator Capaciteit 60–80 ton per uur ten dienst eventueel der Haven Rotterdam (description of an alternative elevator), GEMA, box no. 1, inv. no. 1, RMA; Pannevis to J. van Rede en Zonen, 2 September 1907, and H. A. van IJsselstein (vice director of the Rotterdam municipal works and

Luther model. From 1911 to 1919, GEM operated several Luther elevators equipped with bagging installations, but this was uneconomical and, moreover, still too fast in the eyes of the traders. The solution of the problem proved to be the so-called double manipulation, introduced by GEM in 1910. The grain to be bagged was first dumped, unweighed, into a lighter, taken to an installation onshore, then bagged and reloaded onto the barge or a railroad car. This represented quite a concession by GEM to the receivers, because it did not fully charge them the costs of the extra handling. But although the radical new elevator technology was thus adapted to accommodate preferences stemming from an earlier regime, the key technology remained unchanged, and the traders had to accept that ships would be unloaded many times faster than before. The number of new elevators grew, and before the outbreak of the First World War the manual unloading of grain had virtually disappeared, and grain elevators dominated the harbor scene.

The Multilevel Model Revisited

With respect to grain handling, in 1900 no serious bottleneck existed within the technological regime that prevailed in the port of Rotterdam. Problems that did arise could be handled within this regime, by adopting trade regulations, for example. Nevertheless, a radical innovation in handling technology took place within a few years, which had an enormous effect on both labor requirements and the division of labor among the companies involved in the trade. How can we explain this?

We have shown it to be the result of a number of developments coming together at several levels. There was no strong pressure to innovate from the sociotechnical landscape, though it offered prospective innovators a window of opportunity. Grain traffic in the port increased every year, and would-be innovators could make a case, referring to this broader trend, that mechanization of the handling process was necessary to cope with the increasing flow of grain. Also, grain was increasingly shipped in bulk, which lowered the cost barriers for mechanical handling.

This window of opportunity was first exploited by the leading builder of pneumatic grain elevators, Luther AG. This "producer push" is an indi-

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technical advisor to the Elevator Company) to Smalt, 28 October 1907, GEMA, box no. 1, inv. no. 1, RMA; Advice by the delegates of group B, A. van Rede en Boecking (traders), 22 May 1908, and Report of Engelbrecht and Van Hasselt (ship agents), probably dated 23 May 1908, GEMA, box no. 2, inv. no. 4b, RMA; Rapport der commissie benoemd door den Raad van Commissarissen in zijn vergadering van 2 juni 1908 ter behandeling der zakgoedkwestie, 11 December 1908 (report), GEMA, inv. no. 4a3, RMA; minutes of the meetings of the supervisory directors of GEM, 17 February 1911 and 20 December 1911, GEMA, box no. 480, RMA; GEM annual and quarterly reports 1911–1920, GEMA, boxes no. 458–60, RMA.

cation that no strong need for radical innovation was perceived within the Rotterdam grain-handling regime (the mesolevel). The traders were satisfied with the existing unloading speed and appreciated the room for maneuver that the manual regime of handling grain afforded them. They worked on optimizing the regime by organizational measures, such as standard trade contracts. But Luther did find a partner to work with in J. C. Smalt. He in turn managed to persuade a number of leading ship agents (representing the shipowners' interests) of the prospects of the elevators, but he could not persuade the traders. Nevertheless, he founded a new elevator company.

This company opted at first to develop a niche, so as to reduce the threat to the existing regime. To appease the workers, the company explicitly expressed its initial intention to cover no more than 10 percent of the market, a market that was growing strongly at that time. In addition, the innovators assured the middlemen (stevedore firms and factors) that they would not lose their positions, even though the new technology would render them largely or completely superfluous. Finally, the grain elevator as originally designed by the producer was stripped of devices that were not in the interest of the traders.

However, due to contingencies at both the micro- and the macrolevel, the cautious strategy of embedding the innovation in the existing regime and introducing it gradually had a counterproductive effect. The unexpected failure of the weighing apparatus of the first elevator fueled distrust and opposition among major customers of the elevator company, the grain importers/traders. Until then they had been lukewarm toward the new technique. Although they were not blind to possible economic advantages, they deplored the loss of flexibility that would result from a sector-wide application of the new technology. Unexpectedly, one segment of the grain traders, the German importers, allied themselves with the Rotterdam grain weighers who had gone on strike after the weighing apparatus failed. Because the elevator company had agreed to cover only 10 percent of the grain-handling market, the German importers remained dependent on the weighers. Moreover, a vital element of the landscape (external context) came into play: duties on grain were about to increase, motivating the German importers to bring in large quantities of grain before winter came and the Rhine became less easily navigable. Therefore, they promised the weighers not to receive grain from the two elevators. The niche strategy had failed.

This specific configuration of contingent elements reveals the weakness of the network carrying the niche that the innovators had built. In particular, the trading community was strikingly absent. This was a pressing issue, since coordination was not easy to attain in the grain trade. Unlike the other main dry bulk businesses of coal and ore, the grain trade was fragmented into numerous relatively small buyers and sellers. And unlike the general cargo business, the grain trade was dominated by tramp shipping, where market niches to build on were much less easy to select than in liner shipping. In other words, due to a combination of contingent factors and characteristics of the grain trade, radical innovation by niche formation was very difficult to achieve.

Still, and this was of vital importance, the elevator quickly demonstrated its economic viability. This convinced the innovators that they were betting on the right horse. Smalt and his collaborators continued their efforts, but with another strategy. Abandoning their cautious approach, they sought to conquer a larger part of the market in one fell swoop. Again, dynamics and contingencies played a crucial role, this time in favor of the Elevator Company. In the first half of 1907 the conflict escalated, with persistent violence from the workers' side. The traders (and the other employers, such as the stevedore firms) now redefined their attitude toward the existing regime. Their objections to the new technology became less important than the question of who controlled in the port. Unlike before, the entrepreneurs now perceived a control problem in grain handling: the prevailing regime was redefined as outdated and one that would not allow Rotterdam to compete in the future. This redefinition was reinforced by a debate in Dutch society on the elevator question, in which resistance to the elevator (a specific technology) was equated with resistance to Technology in general. The redefinition was also supported by successful examples of mechanization, for example, of coal handling in Rotterdam and grain handling in Hamburg. In 1908 the Elevator Company was restructured into a new company in which the traders and their middlemen had a 50 percent stake. Moreover, the elevators themselves were embedded into the traditional regime through the installation of a special facility for receiving grain in bags. Now the way was clear for massive investments in the new technology. In 1913 the grain elevator company was operating twenty-four elevators, which unloaded 96 percent of the grain shipped through the port of Rotterdam. By that time it was hard to argue that the manual unloading of grain had been a viable alternative. Yet our narrative shows that the Rotterdam grain-handling regime could easily have looked very different.