# The [Shapeless] Shape of Automation:

# Moments of Constructing Factory Robots in East Asia

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Creation brings transformation and also destruction, but in what shape? When robots and automation gradually penetrate into factory life in East Asia, what will the micro production landscape look like?

At the transitioning moment of constructing and using assembly robots, changes are never linear and straightforward. When new robotic species are made, one by one, by their human creators, long-term human practices are segmented, analyzed, rationalized, and then mechanized. It is not the whole body, but anatomized parts and functions that are replaced. Furthermore, they bring equally shocking effects to those who work with the replaced core. With new functions and potentially new divisions of labor, robots start to compete and co-evolve with (parts of) humans and their practices, although usually with overwhelming power over their competitors.

***Laptop Production Landscape***

East Asia has been a major production base for global consumer electronics and computer products for a few decades, in particular after the 1980s. In the laptop industry, annually around 50-90% of worldwide products were made by Taiwanese contract manufacturers with their factories in China after 2001, including Quanta Computer, Compal Electronics, Wistron Corpration and Foxconn Technology, producing brand products for Apple, Dell, Hewlett Packard, Acer, Asus and so on.

The emerging usage of assembly robots in computer factories is a watershed and provides us with an excellent opportunity to explore the inner social world of producers since all elements have to react to this changing moment. Situating robots in their social and historical context will help us understand the intertwining relations among humans, robots, and society.

I explore the new measures of adopting robots and more automation technologies since 2013 in the largest laptop producer, Quanta Computer. The adoption of automation was aimed both at lowering the dependence on local Chinese workers and at preventing another round of factory relocations. However, the implementation and impact of using robots in assembly lines have triggered unexpected results.

In particular, my study focuses on a few essential questions: (1) the competition between humans and robots, (2) the resistance from the design engineers, and the new epistemic culture in the producers, (3) using robots to fight against geopolitics, and (4) the more complex transformative expectations of the so-called Industry 4.0 in the East Asian context. Overall, new concerns about the power struggle and knowledge hierarchy among different groups of the producers have arisen.

### *The Moment before the Final Assembly Automation: The Conveyor Line as a Calculating Boundary that Manipulates Workers, Space, Time, and Material*

Laptops are a high-priced and high volume globalized commodity (the global shipment of laptops reached its peak in 2011, with a volume of around 200 million units, and in 2015, the number dropped to around 150 million units).[1] In 2000, around 50% of laptops worldwide were still made in Taiwan. By 2005, however, 80% of laptops worldwide came to be made in China, due to Taiwan's open industrial policy of investing in China. Nevertheless, these Chinese factories were under Taiwanese control and ownership, and many design and engineering jobs were still kept in Taiwan. A major

[1] See http://www.digitimes.com/news/a20160121RS400.html.

transitional year for laptops occurred in 2001-- the year after the Democratic Progressive Party (DPP) became the ruling party of Taiwan -- when the Taiwanese government officially lifted the ban on laptop investment in China.[2] As early as the 1990s, due to a shortage of low-wage workers, Taiwanese laptop companies had been importing foreign labor, primarily from several Southeast Asian countries.[3] But after 2000, they considered that rather than importing more foreign laborers, it might be better to export their own factories to China. The official lifting of the ban in 2001 initiated what became a collective movement of laptop factories. The collective move brought not only laptop factories and machines, but also numerous supply chains from Taiwan, factory managers and engineers, as well as a life of long-term commuting for trans-border design teams.[4]

After moving to China in 2001, the production capacity of these Taiwanese producers enlarged enormously, and the global production was further consolidated into a single space. Quanta Shanghai had several huge factories that produced laptops for many well-known brands: including Apple, Dell; Toshiba, Sony, and NEC, in 2012. Another big customer, Hewlett Packard, had already moved to Quanta's Chongqing base. Acer and Asus were also moving to Chongqing.

The single Quanta Shanghai base produced more than 50 million laptops in 2011,

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[2] This new openness from Taiwan was initiated by multiple factors: in addition to China's open policy after 1978, there were Taiwan's domestic political changes, a global economic recession, further cost reductions sought by the laptop brands, and Taiwan's lack of human and land resources needed for the ever-increasing large-scale production.

[3] Taiwan officially opened the policy of importing foreign workers for the manufacturing industries in 1992 due to the shortage of fundamental workers in Taiwan and the increasing wages and land costs. Within three years, the number of foreigner workers surpassed 150,000. The number doubled in 2000. Between 1994 and 1999, the workers came mainly from several different countries from Southeast Asia, including Thailand, the Philippines, Indonesia, and Malaysia. See a research project done for Council for Economic Planning and Development, Executive Yuan, Taiwan at http://www.ndc.gov.tw/dn.aspx?uid=4416 (Chinese).

[4] "Moving Factory to China," Ling-Fei Lin, in her doctoral dissertation, *The Dynamics of Design-Manufacturing Laptops*, 2015, Cornell, or a same-name article under preparation.

which was about 25% of the total shipment worldwide that year; a figure that did not yet include Quanta's production in Chongqing.[5] Given the scale of Taiwan's laptop industry, a tiny difference in the process of product development and production could lead to a large profit discrepancy. Scale-sensitive knowledge thus became much more crucial than it had been in Taiwan: this involved not only disparate requirements of production equipment and arrangement, but also the extremely detailed management of workers and materials, and special attentions were also needed for the efficient practices within the design-manufacturing process.

Scale-sensitive knowledge and efficient practices were made up by many elements, and one of the most direct ones was the new combination of shop-floor laborers and material configurations in their factories that could achieve a maximum constant flow in a global speed.

The opportunity to use the vast supply of inexpensive and "flexible" labor in China was a major attraction for many foreign companies.[6] Domestic or internal migrant workers have compromised the dominant labor body in the special economic zones. In 2009, there were 145 million rural-urban migrants in China, which accounted for about 11 percent of the total population.[7] This was no exception for the laptop manufacturing.

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[5] The total laptop shipment of Quanta in 2011 was 55.2 million units. With cheap labor and land at that time, all the major players kept expanding their Chinese factories in the first few years, including purchasing land and built factory buildings themselves. This race of factory production capacity in China indeed led to larger product orders, but unfortunately this overcapacity also enabled brand-name firms to further squeeze the manufacturers' profits.

[6] For example, one Apple executive described how the company relied upon a Chinese factory to revamp iPhone manufacturing just weeks before the device was due on shelves. Apple had redesigned the iPhone's screen at the last minute, forcing an assembly line overhaul. New screens began arriving at the plant near midnight. According to an executive, a foreman immediately roused 8,000 workers inside the company's dormitories. Each employee was given a biscuit and a cup of tea, guided to a workstation, and within half an hour started a 12-hour shift, fitting glass screens into beveled frames. Within 96 hours, the plant was producing over 10,000 iPhones per day. "The speed and flexibility is breathtaking," the executive said. "There's no American plant that can match that." See "How the U.S. Lost Out on iPhone Work." By Charles Duhigg and Keith Bradsher, *New York Times,* 21 Jan. 2012.

[7] See

For example, Quanta Shanghai hired around 80,000 employees in 2012, including several thousand Chinese engineers and more than three hundred engineers and managers from Taiwan, but the majority of the Chinese laborers were temporarily migrant workers (called *mingong* or *nongminggon)*. The basic-wage shop-floor operators were young and relocated, and thus mainly lived in the dormitories provided by the companies, and many of them arrived with a dream to experience the life in/near an urban city and planned to go back to their hometowns after a few years.[8] Their daily life was almost all with the company, and thus, they were tightly regulated and disciplined by the organization (see Figures 1). The following section addresses the relations between the shop floor operators and the material configuration that the Taiwanese engineers and managers planned and built. The boundary between the workers and the objects was especially explored.

https://www.migrationpolicy.org/article/chinas-young-rural-urban-migrants-search-fortune-happiness-and-independence.

[8] Author's interview with shop floor workers "Kang" and "Joy" from Quanta (24 Jul. 2013, Shanghai, China). It involves the cycle of leaving the village, following others, helping family, exploring the wide world, building their careers, returning home, and getting married. See https://www.migrationpolicy.org/article/chinas-young-rural-urban-migrants-search-fortune-happiness-and-independence.

**Figure 1**. Workers swiping ID cards when going in or out of the dorm, Jul. 2012 (photograph by author).

Figure 2. Operators and the flowing “run-in carousel” system in Quanta, Shanghai, 2007. It refers to the three moving levels of laptops up in front of the workers (Courtesy of Quanta).

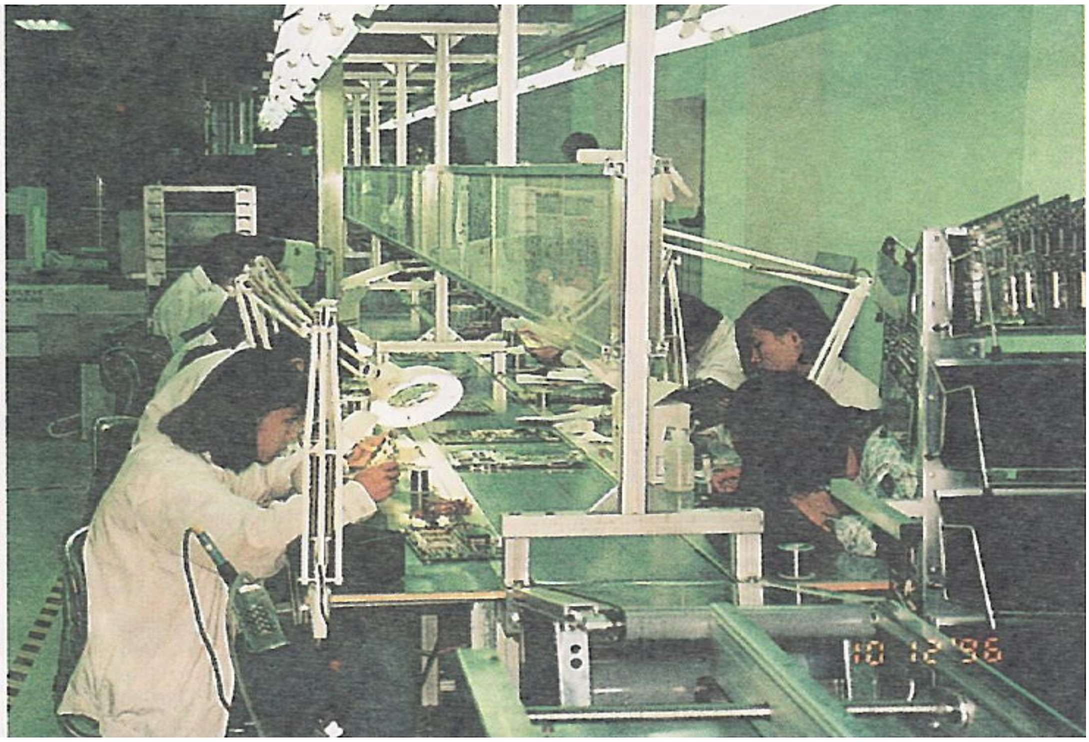


Figure 3. Quanta's early factory in Taiwan in 1996 (Source: Quanta's, December 1998, p.35). It shows a very static picture about the scale and flow of materials and assembly.

Inside a laptop factory, there are two main types of production line: the first is the surface mount technology line (the SMT line, for for building motherboards), which has been highly automated since Taiwan entered the laptop business. The SMT machines have been the most expensive equipment in laptop factories. They help "mount" thousands of small components, including integrated circuits, onto the motherboard. The SMT line also needs workers to monitor the machines and do various jobs, but as it is highly automated, it requires relatively few workers. The second line is the final product assembly line, which was labor-intensive and was fundamentally composed by conveyor lines at that time.

The mechanical conveying system represents the rational calculation and facilitate the efficiency that a modern production system demands. In 1913, the Ford Motor Company introduced its first moving assembly lines based on Chicago's and

Cincinnati “disassembly” lines in slaughterhouses (where the workers cut out different parts of cows or pigs at different stations) and on the conveyor systems in milling, brewing, and canning factories.[9] Today, conveyor lines are seen everywhere in our society: in airports for reclaiming luggage and moving passengers on automated sidewalks, in stores at check-out counters, in ski resorts for transporting skiers up the slopes, and in sushi bars for delivering food to customers. These lines are examples of an automated transportation and distribution tool that is widely used in warehouse, wholesale, transportation, manufacturing, and retail sectors. We can see their operations in production, distribution, and consumption.

One common feature of the conveyor lines is moving things or people from one point to another, that is, making a shift in location, but another feature in factory assembly lines also concerns the time dimension. One possible interpretation of the moving assembly line is that it is a time calculator. The operators need to readjust themselves to get “into the flow” and are supposed to maintain the continuity between the global production and consumption systems. In the final assembly lines of laptop manufacture, they typically had several tens to more than one hundred of operators in each line, each of whom was responsible for assembling, testing, checking, or packaging. A product would be materially born after flowing from one end of the belt to the other.

The three factories (Quanta, Compal, and Wistron, three laptop contract manufacturers) that I visited in 2012 had different designs for their final assembly and packaging lines. Wistron asked their operators to stand, while the workers in the other two companies were seated. Also, while Quanta and Compal both used conveyor belts, Wistron did not. Instead, Wistron adopted an inching system, in which each plate

[9] See Hounshell (1985:10, 241), and Chapter 6 on the Ford Motor Company.

surface in front of a worker kept still for about 20 seconds, and then suddenly, the lower roller flipped, creating a temporary flow for the product to be sent to the next station or next person. A factory manager at Wistron explained that the conveyor line would be shaky if it kept moving, so the inching system had the advantage of stability when workers were assembling products.[10] However, there was no set agreement about using the more stable flip-flow system or using the continuous flow of a conveyor belt.

A Compal factory manager told me that the traditional conveyor belt might make novice operators *linesick* (like carsick or seasick), since many things were moving in front of them. The novice then would have to gradually adapt to the line speed either by training at an initially slowed-down speed or just by observing the conveyor line first.[11]

The line speeds varied for different phases and products. In Quanta, if it was a pilot run, the speed could be as slow as around 30 seconds, but if it was in the mass production phase, and for standard notebooks, the line speed was usually 12 seconds. That is, a worker needed to finish the assigned job in 12 seconds when the product was moving in front of him/her, i.e., from a worker's left-hand side to the right-hand side, it would take 12 seconds. The direction can also be from the right to the left-hand side, but according to calculations, this direction would take one to two more seconds for a right-handed worker than the other direction. For thin ultrabooks, it was about 14 seconds. For tablet PCs, it was 14.6 seconds. Quanta once tried to set the flow speed to 9 seconds for some products, but it failed because too many errors occurred at that speed. For Apple's notebook products, the flow speed for the mass production phase was usually slower—20-some seconds.[12]

With such a tense working time schedule in mass production, repetition and

[10] Author's interview with "Ryan" (18 Jul. 2012, Kunshan, China).
[11] Author's interview with "Howard" (18 Jul. 2012, Kunshan, China).
[12] The information was from the Quanta managers who accompanied me to visit the production line in the factory.

alienation were the most serious problems, as the Marxists had claimed. For both the filmmaker, Charlie Chaplin, and the artist, Diego Rivera, the insanity-inducing assembly line was always their focus for the American factories in the 1920s and 1930s, because they both were far more interested in the pace and process of mass production than in the product itself (Hounshell, Chapter 6). “The ‘real, inner truth’ of mass production was what took place in the factory, not its product,” as David Hounshell (1984: 323-324) summarizes. This situation remained true in the twenty-first century factories in China.

An industrial engineer at Compal highlighted the pace of the workers, saying that if an operator worked for 8 hours (if not overworked), it would mean that the same motion would be repeated about 1920 times when that time period was divided into 15-second intervals. If the operator’s motion happened to be installing the screws, they usually had to put in five screws in that station because placing one screw with an automatic screwdriver would take only about 3 seconds, so they would screw in 5 screws at a time, 2400 times a day, which means that an operator would have to put in almost 10,000 screws in total, in a day.[13] Within the small space bounded by the operators’ two arms, their lives are disciplined and measured by the conveyors day by day, second by second.

In addition to being a marker of time, the conveyor line was also a transformer and a flowing boundary between ideas and artifacts, and partially reflected how assembly knowledge and practice in the industry were produced. Along the spectrum for making a new machine from design to assembly, the final step was the only one done by operators. In other words, the conveyor line was the final boundary through which ideas changed to material products. It was also a boundary that changed a spatial scale to a

[13] Author’s interview with “Lila” (18 Jul. 2012). She is one of the few female engineer-managers I interviewed, and she is Chinese. The intolerable repetition of a same motion is also well presented in Charlie Chaplin’s classic film *Modern Times* (1936), also cited in Hounshell (1984).

temporal scale in accordance with precisely calculated and arranged relations among humans' motions, numbers of workers, line lengths, and line speeds.

During the last steps of the detailed division of labor in their laptop factories, it was IEs (industrial engineers) or PEs (production engineers)[14] who translated and allocated the assembly motions for workers. Although the knowledge and design of assembly motions of workers were co-produced by the characteristics of the human body and the quest for industrial efficiency, the latter was usually privileged, so that it ended up pushing the human body's potential to its limits, as Taylorism aims to do.

The ideal motions designed for workers resulted from many earlier levels of design-engineering effort. At the final level, a Compal industrial engineer, "Lila," who was a female Chinese engineer, said that the design team would come to teach the IEs how to assemble the product, and then together they would try to assemble it. After that, the IEs would prepare two to three sets of standard operating procedures (SOPs) to be discussed at meetings attended by different departments in order to make the final decision about the assembly motions to be assigned to workers. It required a great deal of experience to design an excellent SOP that both could save time, make best use of workers, and assure quality assembly.

For "Lila," the most important thing for SOPs was "balancing," which meant assigning equal time for all stations (each station was responsible for different motions from the beginning to the end of the product assembly).[15] That is, when assembly motions were dissected, the ideal was for each worker to finish the assigned assembly task (such as inserting the hard disk, screwing on the cover, or mounting the keyboard), test the product, and even package it in just those set time, say, 14 seconds. If one

[14] For Compal and Wistron, IEs were the primary people who played the role, but in Quanta, it was the PEs. Interviews from multiple sources.

[15] Author's interview with "Lila" (18 Jul. 2012, Kunshan, China).

station could finish its action in 10 seconds, but another needed 14 seconds, it was not "balanced" since some workers would have to wait for others to finish. As a result, if the assembly jobs were not balanced, the IE team would adjust the SOPs. IEs needed to stay on site every day in the factory to see what was going on in the assembly line and adjust or re-design operators' assigned motions according to the situations they observed.

In terms of process innovation, tools like conveyor lines bear many social meanings. Just like a sushi conveyor line, which helps stimulate the customers to consume sushi immediately after it is freshly made behind the line by the chef, conveyor lines or the Carousel system in Quanta are also important for moving things between boundaries. They are themselves flowing boundaries that facilitate efficiency and represent rational calculation. They mark and mediate boundaries between humans and machines, between ideas and materiality, between design and assembly, and between time and space. They are boundary flows that are transformative.

Due to economies of scale, cost-saving, and efficiency-enhancing issues, the boundaries are both calculated (mainly by engineers) and calculating (of workers' output). They are calculated and calculating boundaries, and also time calculators and communication devices between managers and workers. The assembly of the products is precisely calculated and controlled by the various material configurations through the effort of layers of engineers, who intentionally or unintentionally helped realize the shift of control over production from workers to managers (Braverman 1974, Noble 1984). As requirements for increased speed and precision are imposed on the workers, their lives inevitably bear the extreme boredom and burden of the ever-faster global production system.

***Relocation, Again: Robots vs. Geopolitics***

The year 2009 was another transitional moment for the laptop producers. In 2009, to accommodate the Chinese state's Western Development Drive and with the end of ten-year tax incentives (the first five years free of taxation, the second five years 50% off) for the producers, along with the plan for the basic wage in Shanghai to go up to double in five years from 2011, thus the laptop producers were semi-forced to move their coastal factories to inland China. One interviewee said that by shrinking the preferential incentives and continuing to raise the basic salary in coastal areas, as well as offering attractive incentives inland both to brand-name companies and contract manufacturers, few companies would refuse to move to Western China.[16]

This new move to inland China was not only designed to boost economic growth in the Western part, but also aimed at solving its social problems. In addition to environmental policy and industrial upgrading considerations, other goals were to reduce the urban-rural gap and to enable numerous workers from inland or rural areas to stay near or in their hometowns, instead of migrating to distant economic zones.[17] The new initiatives to pull back the migration by moving part of the production base inland were designed to disperse them spatially and partially solve the social problems caused by the current heavy population influx to the coastal zones.

This second major move (in 2009) was quite different from the first one (in 2001), in many ways— Taiwan's producers did not buy land or build the factories themselves as

[16] "Eli, " Compal manager, interviewed by author via Skype (4 Dec. 2011) Also, Eric Chiu, author's Skype interview on 8 Nov. 2016. Chiu was a top factory manager in Quanta, who retired in 2017.

[17] Most of the special economic zones were concentrated in the coastal areas of China before 2010, so a huge amount of migrant workers from far away were mobilized to join "the factory of the world." However, this temporary migration not only generated an outflow of young people from rural areas, their lack of social welfare from the state due to the rigid household system, but it also caused problems in the cities, as well as the unbearable transportation burden during long holidays, such as May 1st, October 1st, and especially during the Chinese New Year, when most workers wanted to go home at the same time.

they had done before,[18] thus making things or factories more “disposable” (Stalk 2008). Also, the Taiwanese supply chain began to dissipate except for a few larger suppliers. It was gradually replaced by the so called “red supply chain” (China’s local companies), in particular after 2014.[19] More importantly, the laptop employees showed stronger resistance this time. In 2011, when Quanta’s top factory manager Eric Chiu discussed the automation plan with its CEO Barry Lam, Lam said that automation could possibly bring the factory back to Taiwan [Quanta’s headquarters]. The comment made Chiu conduct even more actively the implementation of automation. For him, there was no hope in just continuing to move factories: “Moving [factories] to Chongqing is just transitional; Where should we move next? India? And how about our supply chain?” “What is the benefit of relocation? We do not gain any benefits.”[20] For Chiu, it is only the brand-name companies who will gain the benefit, and he urges that everyone just not move again. Stay, rather than keeping investing in different places.[21]

“We don’t want to move anymore,” a former Quanta factory manager said, instead of continuing to chase after and move to lower-cost places, living like a nomadic people, they wanted to develop new approaches to avoid further movement: including using robots and other automation technologies.[22] So now, robots are competing not only with humans, but also with places and nations.

### *The Shape of Automation: Replacing Workers’ Fingers, Eyes, and Skills with Machine Sensing and Communicating*

The global market of laptops reached its peak in 2011, and began to shrink

[18] Author’s Skype interview with Eric Chiu (4 Mar. 2017)
[19] ibid.
[20] Author’s interview with Eric Chiu (13. Dec. 2016) in Taoyuan, Taiwan.
[21] ibid, p. 5.
[22] Author’s Skype interview with “Christopher” (16 Apr. 2013) who was a top manager in Quanta’s factory and retired in 2017.

thereafter. Around this market peak time, the utilization of Chinese operators also reached an extreme mechanized status-- the inhumane speed of global production, the strictly time-disciplined and high-intensity repetition of actions that are characteristic of modern factories are not easy for human beings to bear. As early as 2009, a series of suicides at Foxconn (Apple is one of Foxconn's major clients) illustrated these social problems and drew international publicity to the high-pressure demands in China's factories.[23] As a result of these tragedies, one "solution" that Foxconn offered was to adopt robots. It announced in 2010 that it would incorporate the use of one million robots in 2013. Although in the beginning years, the progress of automation in Foxconn was not as it anticipated, currently, the speed of adopting more robots and automation technologies is only accelerating.

Similar to Foxconn's move, facing the new central policy, increasing wages, shortage of labor, and re-relocation pressure, Quanta and Wistron in 2013 also indicated that they were studying new automation plans on the final assembly line [[and would begin with simple jobs, such as inserting screws. Although using a robot that cost about twenty thousand US dollars to screw in screws was still too expensive then.[24] But by

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[23] In 2009 at Foxconn, a young worker committed suicide due to being accused of being responsible for losing a prototype of the iPhone 4. In 2010, fourteen more employees committed suicide in different Foxconn factories in China. Different accusations were aired; some accused Foxconn of being a modern sweatshop, and some accused Apple of indirectly exploiting Chinese workers. Other interpretations were also given. The tragedies and pressures from the public pushed both the brand-name companies and the contract manufacturers to make the whole production process more transparent and accountable. For example, Apple makes public the information about their top 200 suppliers and their eighteen final assembly facilities online (see http://www.apple.com/supplier-responsibility/our-suppliers/), issues annual reports with the results of the previous year's audits and corrective actions on suppliers (for the progress report of 2014, see http://www.apple.com/supplier-responsibility/highlights-2014/), and constructs a more systematic way to assure their suppliers' responsibility related to the welfares of workers, labor and human rights, health and safety, and environmental issues.(http://www.apple.com/supplier-responsibility/).

[24] The laptop's mainboard production was already automated by SMT (surface mount technology) machines a very long time ago, so it was the possibility of using robots and other automated machines in the final assembly that was under discussion at that time. Interviews conducted on 14-17 Apr. 2013 with "Christopher," through multiple emails and Skype.

2017, the price and technical issue of screw robots was largely gone, and almost all screw-inserting jobs in Quanta had been replaced by robotic arms. Many other final assembly jobs were automated as well, including testing, labeling, and packaging. Several thousands of related jobs in Quanta were delegated to machines within only a few years.[25]

The shift, thus, brings us a perception of direct competition between robots and laborers. Indeed, robotic figures supersede human workers in their precise and indefatigable motions, and in their separation of body and "mind." Also, robots are more a comrade of the capitalist than that of the laborer. Yet, robots do not always win the war. For example, Toyota once "fired" robots because they found that using human workers was still a better bargain.[26] Furthermore, humans and robots could collaborate with each other under suitable design and arrangements, and new types of jobs could emerge (the so-called "re-skilling," Zuboff 1988) such as maintaining and fixing robots and their systems. Therefore, it does not show a simple linear image of progression in this robots-or-laborers tension.

Also, what part of jobs to replace is not clear. In fact, no one in Quanta could clearly tell them what "the shape of automation" would look like. The vague image of automation futures partially resulted from the unstructured environments of assembling laptops, which is also the basic difference between robots today and a few decades ago: [27] Most fine assembly tasks (e.g. in the electronics, food, shoes industries) are still out

[25] Author's interview with Eric Chiu (8 and 15 Nov. 2016 Skype interview, 13 Dec 2016, Taoyuan, Taiwan) and "Jack" (13 July 2017, Skype interview, Taoyuan, Taiwan). Chiu was a top factory manager, now retired; Huang is a factory manager now working with Taiwan's R&D division.

[26] https://qz.com/196200/toyota-is-becoming-more-efficient-by-replacing-robots-with-humans/.

[27] Author's interview with Pham Quang Cuong, an assistant professor and the leader of industrial robots in the Robots Research Center of Nanyang Technological University in Singapore (14 Nov. 2016).

of the reach of today's industrial robots Because they belong to the so-called "unstructured" environment, which is completely different from the "structured" environment of the automotive industry for a few decades. In the structured environment, the robots "don't have to see, everything is precise and fixed well, and the investment in automation is huge."

In the unstructured environment, it seems not practical to invest as much as that in the automobile, since hiring shop floor workers is cheaper and works better in many industries; after 2010s, it was more feasible to use more intelligent robots that have visual and learning abilities and are inexpensive. , Although there is still a major gap between laboratory products and real applications for industrial robots, the latter requires an "extensive engineering effort" to make robots robust and reliable.[28]

In 2013 when Quanta started its automaton plan, this "extensive engineering effort" was what confronted Quanta. To achieve the automation of the final product assembly, Quanta in 2013 asked their long-time business partners in Japan, Matsushita (Panasonic) and Fujitsu, to examine how to conduct automation in Quanta's factory. However, after scrutinizing the product and production process, station by station, both partners gave up. They said that it was just too difficult to implement automation in Quanta's final assembly line due to the "irregularity" of laptop assembly-- unless Quanta changed the product design of laptops.[29]

From another perspective, the difficulty also came from the short life cycle of the laptop market. The life cycle time was as short as four months which was much less than

[28] "If it takes about 3 months to produce a 90% workable machine in a research lab, it will take about 3 years of engineering effort to make the other 10% perfect," he added. Author's interview with Pham (14 Nov. 2016), p.1.

[29] Eric Chiu (8 Nov. 2016, Skype interview, he was in Taoyuan, Taiwan). Note that Quanta offered both design and production services, and for many Wintel-laptop orders, Quanta was also the designer of the product. Quanta also talked with MIT, but the latter's product was too expensive and needed to wait further for the degree of precision modified from 2mm to 0.02-0.05 mm, so Quanta did not adopt. Chiu (15 Nov. 2016, skype).

the implementation time for a well-planned automation line Quanta knew. The message they gained from partners was that automation could be conducted since all automation lines would be "customized." Yet it would take a long time and fit only one model each time, which was basically useless for the laptop industry, since the industry changed models very frequently.[30] Therefore, Quanta turned to planning and implementing their automation by themselves.

The company began to analyze which segments of their production process could be automated. "We ourselves designed what our automation should look like."[31] Facing obstacles in automating the final assembly, Quanta decided to experiment with automating the final testing, packaging, and labeling, which belonged to the second part of a production line, so it was called semi-automation in such a case. With great effort from factory engineers managers and local partners, by November, 2016, all production lines in Quanta had become semi-automated.[32]

In addition to testing, packaging and labeling, Quanta also strove to set up a few automation lines for final assembly, except for those undoubtedly hard motions for machines—such as assembling cables, since the material was soft in texture and needed to penetrate to different places in the laptop. That is, Quanta crafted their own robots that could conduct regular work, such as putting in the hard disk drive, optical disk drives, LCD modules, member cards, and screws.[33] In the end, the length of each production line was shortened from 220 meters to around 90 meters, and the number of human operators was reduced from 150 to 90 some for semi-automated lines, and to only 40 some for automated lines; that is, it was a reduction of labor to merely one-half to

[30] Author's interview with "Jack" and "Zach" (13 Dec. 2017) in Taoyuan, Taiwan. Both were senior factory engineers in Quanta, and then became managers who were responsible for bridging the design and factory teams during automation transition, p.3.

[31] Ibid, p.3.

[32] Eric Chiu (8 Nov. 2016, Skype interview), p.4.

[33] Eric Chiu (8 Nov. 2016, Skype interview).

one-third. Simultaneously, the number of automation machines increased from zero to around 15 units (semi-automated) and 35 units (automated).[34] The factory presented a new human-machine configuration on the production line.

Enormous engineering effort from factory led the road to Quanta's automation. As long as they are robotic stations, we will craft them almost one hundred percent by ourselves"[35] For Quanta, a robot was just like "one of the components or parts." Purchasing a robot was just a beginning. the company designed the base support and the control board for it, wrote the software of the automation control, added CCD cameras, and crafted the optical sensing, as well as connecting the input/output, linking with the peripheral devices, and designing its fixtures for assembly.[36] Since there were no ready or easy solutions on the market or available from experienced partners, Quanta preferred to work out their own way of automation and to protect it from being copied by other companies—although they also considered that Industry 4.0 was very hard to copy, because each producer had its own way of transforming old practices into new ones based on their distinctive factory culture. [37]

Although a great effort was required and the number of automation lines was not yet high, things were moving in an acceptable direction for Quanta, in particular, when the price of robotic arms decreased around 30-40%, and the basic wage in Shanghai increased 70% within three to four years.[38] The trend was just too obvious to refuse. Even an internal company in Quanta Group was dedicated to making robotic arms.

[34] The laptop output for a 12-hour shift was different in different lines: 3300 (with all humans), 2500-2700 (semi-automated), and 2000 units (automated) respectively.[34] Although there seemed to be higher output for the first type of line, the length of it (the all-human line) was more than double the other two, so it does not mean the first was more effective in production.

[35] Author's interview with "Jack" and "Zach" (13 Dec. 2017), p.3.

[36] ibid.

[37] Eric Chiu (15 Nov. 2016, Skype interview, he was in Taoyuan, Taiwan). p.2

[38] Eric Chiu (15 Nov. 2016, Skype interview, he was in Taoyuan, Taiwan).

A few major impacts on production-line operators were: neighboring colleagues gradually changed from the human to the mechanized species, so there was no way to "chat" with the neighbors. After some curiosity in the very beginning, later the operators would treat the robots as just equipment. But a major thing is that the line speed had to be adjusted to favor the robots. Since the robot's performance was quite stable, the human counterpart felt more stressful, as they could not show lag when collaborating with the machine.

Strictly speaking, shop floor workers were not replaced by machines in a whole-body sense. Machines only replaced parts of their bodies: their eyes, fingers, hands, and arms, or a combination of them, usually departing from the angle of practical functions. For example, in the testing of the quality of touch panels, Quanta used an air cylinder to mimic the human finger for the testing. In the past, there were thirteen operators in the testing section, but with automation, it required merely one member by 2017.

The other example in the testing section was to greatly use CCD (charged coupled device) cameras to replace the eyes of the worker. An example concerns the screen color testing. To see if the color or pixels of an LCD screen has any defects, instead of humans' inspection and feedback, the factory used a tablet computer with a camera as the testing tool to go through the just assembled laptop, and afterwards, the camera on this tablet would send signals back to the embedded camera of the laptop, telling the latter what to do. So machines not only produce machines, they also use visual communication ("eye contact" in another meaning) to talk with each other in this daily production of a global goods. This testing with communication application alone took seven to eight engineers a year of time in Quanta factories to finish. There were also other examples in testing that were full of communicating functions, such as wi-fi function testing. In total, each production line required thirteen operators to conduct testing in the past, but it required merely one member by 2017. Communicating and feedback have been the important features in cybernetics (Wiener 1954), and as Don Norman (1989) argues, there was no “overautomation,” but only inappropriate feedback and interaction.


Figure 4. A new laptop assembly line comprised with robotic devices at many stations (those with metal frames) in Quanta, Chongqing in 2016 (Courtesy of Quanta). Thousands of assembly workers have been replaced by robotic arms and other automation devices.

***Design for Automation: Centering around Robots, or the Impact on and Resistance from the Design Team***

Although robots perform the jobs of assembly workers, they do not simply “replace” those workers and keep other elements in the product-making process intact. In a micro-level analysis, the smooth speedy flow in the assembly conveyor line (composed of human operators) that the laptop factories had built was heavily disrupted due to the coming of the robotic colleague. Since robotic arms do not act just like the nimble and versatile hands of the human workers, the working procedures, time intervals, assembly orders and so on (or the SOPs, the standard operating procedures) have to be re-designed. Thus, the industrial engineers, factory managers, and laborers' work content are all affected. For example, the job of production engineer (or industrial engineer in other companies) was transformed. In the past, in addition to arranging SOPs, reviewing product quality and keeping line balance, one major work was to observe and manage production line operators, but with the coming of automation machines, this part of job was gone. Instead, they learned new software, fixture design, and learned to maintain the emotionless automation equipment.[39]

More importantly, transformations also reached the design team, resulting partially from the intertwining relation between design and factory in the laptop industry. The traditional image of a hierarchical knowledge division between design and manufacturing is problematized and flattened, and there has been strong feedback from manufacturing to design or intensive communication in the whole product-making process.[40]

The primary difficulty in automating laptop final assembly, as discussed, results from the fact that there is no standardized design of laptops. Between 2013-2016, the number of Quanta's automated lines was unstable. Some of the automated lines changed back to human-worker lines again. The main reason was the difficulty to modify automated lines for different laptop models, in particular when the market required small-volume large-variety products. Robotic machines were hard to change, and fixtures needed to be re-designed or re-adjusted. "Every time when we need to change

39 Author's interview with "Jack" and "Zach" (13 Dec. 2017).
40 Ling-Fei Lin, Dissertation, 2015.

the line [for different models], it is so painful."[41]

Therefore, instead of merely effort within the factory, the factory team thought of a way to incorporate the other party-- pushing for the simplification and standardization of product design from the R&D team. "R&D is the key to success [for automation]," Chiu considered.[42] But he found that it seemed so painful for the R&D to change their design practices, "just like asking you to change from being right-handed to left-handed." To make this feasible, a group of engineers and managers who had rich factory experience were asked to move back to Taiwan to help bridge the gap between design and factory for automation.[43] They worked with both parties, and product designs had to be reviewed by both the design and factory teams to see if the design followed the DfA (design for automation) concepts. By 2017, Chiu observed that the R&D team could already accept the idea of helping more automation, but it was the doing that was the hard part. "It is harder [to push the R&D for automation] than pushing a factory['s automation]." [44]

Although, using robots in the unstructured computer final assembly line is much more possible now (thanks to the enhanced sensing, communication, and calculating capabilities), they are still quite dull and unskillful compared to their human counterparts, so their adoption in the final assembly line is still fragmented and challenging. Thus, in such "unstructured" environments, the burdens that "dumb" robots bring about fall onto the shoulders of other groups. One such group is the design team. They have to accommodate and adapt themselves for their robotic colleagues— making final assembly easier for automation. That is, the designers have to "design for automation"

[41] Eric Chiu (8 Nov. 2016, Skype interview). P.2.
[42] Eric Chiu (8 Nov. 2016, Skype interview, he was in Taoyuan, Taiwan). P.6.
[43] ibid.
[44] ibid..

(DfA).[45]

DfA did not exist before 2013 in Quanta. But its ancestor DfX had existing for many years and has been an important principle in the firm. The X means everything that the design team needs to pay attention to, such as DfM (design for manufacturing), DfQ (design for quality), and DfC (design for cost).

To meet the aims of design for manufacture, Quanta's factory team generated the DfM guidelines more than twenty years ago, requesting that the design team follow basic rules from the factory. These documents included "musts" (for example, there must be a certain distance between a screw and a part) and "must-nots" (for example, certain kinds of materials must not be used). The guidelines were a result of a long-term accumulation of experience and reflected important practical know-how as well as a database in Quanta, according to "Taiwanese Laborer." When I asked if I could take a look at the documents, he said it was not possible, because it was one of their competitive resources. He said,

> "Although it concerns only 'small knowledge,' the collection of small knowledge is a company's competitiveness."[46]

It is interesting that it was the factory team members who generated important rules for the designers, rather than the other way round. Due to mass production being at a later stage in making products, the producer believed that instead of getting endless feedback from and quarrels with the factory later that would delay the time of shipment, it was better to initially inform and tame the design team. Accumulated know-how, experience from factory engineers, team leaders, and shop floor workers were then

[45] Author's interview with "Jack" and "Zach" (13 Dec. 2017) in Taoyuan, Taiwan. Both were senior factory engineers in Quanta, then became managers who were responsible to bridge the design and factory teams during automation transition.

[46] Author's interview with "Taiwanese Laborer" (11/17/2010,), p.10, who was a senior project manager at Quanta. This is a pseudonym he wanted me to use to express that he were like an foreign laborer who did not receive enough benefits and credits.

translated and encapsulated in the guidelines to the design teams. This practice further demonstrates that a myth of a traditional knowledge hierarchy between design and manufacturing.

The emergence of DfA a few years ago thus reflected a new trend in the producer. Like the early days in DfX, the design team was resistant to accept the "rules" from the factory to regulate their design freedom, DfA has a similar fate. The factory and the design teams solved the early dispute of DfX by negotiating and reached a consensus about what rules from factories could be accepted by the design team, it is now the same turn for DfA.[47]

The impact of factory automation on upper stream of design work was also the main reason why Matsushita Panasonic and Fujitsu gave up the automation plan work for Quanta, unless Quanta could persuade the design team and change their computer product design. In the meantime, the Japanese partners warned Quanta that there would be a great deal of resistance from R&D teams, because the R&D would have to change their long-time experience and design practices so that they could work well with the robotic "colleagues." [48] In a word, it was too hard to change automation technology, so the producer asked the humans to change in order to fit with the technology first. Unlike there are more than two hundred rules in the long-term DfM (design for manufacturing), the DfA has now only a few major design guidelines: including: parts should be designed to be able to be put directly up and down rather than in a bent angle [so that it will be easier for robotic arms to assemble]; and same working procedures such as inserting screws should happen at the same time as possible as they can [so that the robotic machines could perform the same type of job at the same station]. These

[47] Author's interview with "Jack" and "Zach" (13 Dec. 2017) in Taoyuan, Taiwan.

[48] Author's interview with Eric Chiu (Taoyuan, Taiwan, 13 Dec. 2017), and author's Skype interview with "Christopher" (16 Apr. 2013)

rule look simple, but they need a lot of changes in design practices and are quite challenging to the design team, in particular when the "art" of laptop design is "to squeeze as many components as possible in ever-thinner and even curved space" without sacrificing excellent quality.[49]

Quanta let one of its brand-name customers Acer try the automated production first, who was very satisfied with the stable quality of laptops with automated assembly, because machines "have no emotional issues."[50] To do so, Quanta changed certain inner product designs for Acer (as Quanta did both design and production work for Acer's products). Yet some other brand-name customers did not want to modify their product design. For example, Asus, which designed their own laptops, showed very strong resistance to changing their design merely for assembly automation conducted in Quanta.[51] As Eric Chiu from Quanta indicated, the design team considered that when automation required simplification and standardization of design, it would surely shrink their space of thinking, making them resemble "technicians who lost their freedom."[52] This also shows how entangled design and manufacturing were. Design cannot do whatever design wants. This move from user-centered or worker-centered design to robot-centered design seems to further exacerbate their "design freedom," and makes the total automation of design work also very possible in the near future.

The power and epistemic relations within laptop contract manufacturers have been tricky. Although design teams usually enjoy a higher hierarchy in the power relations and epistemic order compared to factory teams, it is not always so. After adopting robots, design teams have been deeply affected. They showed certain

[49] Author's Skype interview with Alex Chu and Elvis Chuang, Quanta's RD technical manager (10 Mar. 2017), p.3.

[50] Eric Chiu (8 Nov. 2016, Skype interview, he was in Taoyuan, Taiwan). P.2.
[51] Author's skype interview with Eric Chiu (15 Nov. 2016).
[52] Eric Chiu (15 Nov. 2016, Skype interview, he was in Taoyuan, Taiwan). p.6.

resistance because in order to accommodate the less flexible robots (compared to humans), design engineers had to adopt new design guidelines or “design rules” to design their products.

These robot-incurred or robot-centered design rules not only set new limits on the designers’ possible innovations but also disrupt their existing design practices and experiences that have accumulated over the past twenty-some years (note that these contract manufacturers provide both design and manufacturing services, which is especially so for the Wintel computer). Thus, the transition from manual to automatic assembly creates new tensions between the factory and the design communities.

## *Conclusion*

The robotization of a factory concerns not only technologies and industries, but also geopolitics and global manufacturing order. The laptop factory has evolved from an early short production line that did not stress efficiency in Taiwan, to a factory full of highly-disciplined Chinese female workers in the early 2000s, and then to a 2016 factory with male operators, robots, and other automation machines dominating the space. The changing production landscape and the new contest of “robots vs. geopolitics” are involved with complex political and economic wrestling globally. It is a chronological series of picture painted by the wrists of workers, robots, societies, and states.

New concerns about the power struggle and knowledge hierarchy among different groups within the producers have arisen. Robotic developers have said that in the future they will make the industrial robot more “social.” But I would argue that the industrial robot today is not less social than the so-called social or service robot, just that the social effect is at different levels. It looks as if the robot is just replacing some jobs that no one desires to do and rescues conveyor operators from alienating work. Yet, on the one hand, while phasing out a large group of front-line workers who are on the edge in turning ideas into objects and the reskilling prospect of them is in unclear, since on the other, the robot also drags other groups to tune into the machines' tone and flow, since the robot is not a perfect replacement of humans with its awkward motions and reactions when compared to humans'. As a non-human actor,[53] paradoxically, the robot has formed a new "social" group which seems to have more power and agency over the assembly workers, engineers, managers, and designers in shaping the direction of the sociotechnical world.

In routine practices, the long spectrum from design to assembly in the laptop has to get through various levels of designers and engineers and then into the hands of workers; however, among each of the steps, their relations are highly interactive and iterative, in aiming at getting feedback and new thoughts on (endlessly) improving product and process (which I call "knowledge from iterative interaction" in a paper, to distinguish it from other forms of knowledge in STS such as tacit knowledge, local knowledge, and situated knowledge)[54] in the fast-changing industry. Thus, when a non-human actor is inserted and prioritized, it could trigger readjustment and restructuring of employees across all sectors and numerous changes of the long supply chain and other partners' work.

The robot's inferiority to humans in its dexterity and flexibility in part comes from the gap between the internal digital order and the external analog action it has to

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[53] In Michel Callon's (1986) and Bruno Latour's (1987, 1993) Actor Network Theory, they lift the capacity of non-human actors/actants in acting or participating in the network in their analysis, which has been a controversial theory in STS.

[54] "Turning "High Tech" Ideas into "Low Tech" Practices? Creating Knowledge through Iterative Interaction in Taiwan's Laptop Contract Manufacturing," *Technology and Culture* (under review). For tacit knowledge, see Michael Polany (1958), Thomas Kuhn (1962), and Harry Collins (1985). For local knowledge, see Clifford Geertz (1983), Bruno Latour (1987), *and* Brian Wynne (1992). For situated knowledge or standpoint theory, see Donna Haraway (1991), Sandra Harding (1987).

perform. It is the struggle between bits and bones, analog and digital, new knowledge and old knowledge modes that disrupts the once fast and smooth flow of global production. New knowledge sets are generated, but in the meantime, a great portion of old knowledge will undergo destruction and will be found mainly in history. When more new knowledge sets and modes are created, the flow might go back to being streamlined again and reach a new balance. It is merely that, in the new scenery, the protagonists inside factories will shift to be robots rather than humans, with the former never getting linesick, no matter how fast the new global production flow is.

We usually think that modern factory workers have been reduced to being like machines, but when real machines arrive, it is other groups of people who will know how docile shop-floor workers were [and how “undocile” robotic colleagues are, who in turn require the other groups of employees to become also docile]. Depending on each producer’s own culture and accumulated practices, they will go on different journeys to automation. The moment of their transitions provides us a unique opportunity to explore the shape, texture, and reflection of the turmoil in between.

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