Lean Manufacturing Comes to China:

A Case Study of Its Impact on Workplace Health and Safety

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Lean manufacturing, which establishes small production "cells," or teams of workers, who complete an entire product from raw material processing through final assembly and shipment, increases health and safety hazards by mixing previously separated exposures to various chemicals (with possible additive and cumulative effects) and noise. The intensification of work leads to greater ergonomic and stress-related adverse health effects, as well as increased safety hazards. The standard industrial hygiene approach of anticipation, recognition, evaluation, and hazard control is applicable to lean operations. A focus on worker participation in identifying and solving problems is critical for reducing negative impacts. A key to worker safety in lean production operations is the development of informed, empowered, and active workers with the knowledge, skills, and opportunity to act in the workplace to eliminate or reduce hazards. *Key words*: China; lean manufacturing; worker participation; workplace health and safety protections.

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Over the last 15 years, China has become the "world's factory floor," producing an ever-larger segment of the manufactured goods in the world economy. China posted a 10.7% growth in gross domestic product (GDP) in 2006, capping a decade of 10% annual growth rates. In 2005, China became the world's fourth largest economy, after the United States, Japan, and Germany, with 5.4% of global GDP. But while manufacturing represents 17% of the U.S. GDP, it constitutes 41% of China's GDP.[1–3]

Starting in 2003, China has become the world's top producer of color televisions, washing machines, DVD players, cameras, refrigerators, microwave ovens, cell phones, computer monitors, motorcycles, toys, and rechargeable batteries, among other consumer products. Chinese exports to the United States accounted for 14.8% of all U.S. imports in 2005, including 24% of textile and apparel imports (rising to 50% in 2006), 26% of electrical machinery, 31% of metal tools and cutlery, and 43% of furniture and bedding.[4–6]

In 2006, China had an overall trade surplus with the world of $177.5 billion, up from $102 billion in 2005, including a $232.5 billion trade surplus with the United States. China now has foreign currency reserves (overwhelmingly U.S. dollars) of $1 trillion, equivalent to 40% of its entire $2.4 trillion economy.[7–10]

Since the early 1980s, China has received more than $600 billion in foreign direct investment (FDI), with $63 billion coming in 2006 alone. More than 50,000 U.S.-based corporations have operations in China, and an estimated 55% of China's exports to the United States are actually intra-corporate transfers from directly owned or contracted factories.[9,11–13]

China, of course, plans to be more than just a low-cost production platform for transnational corporations. It is working to move up the value chain to design and engineer next-generation, higher-tech, higher-fashion, and higher-value products. If, or perhaps when, this happens, China will "set the pace" not only for production costs, but also for the organization of production itself.

China is also now working to transform its manufacturing base from traditional low-cost, labor-intensive "Fordist" production to higher-value, more flexible and more productive "lean" manufacturing systems. Over the last half-decade, Chinese factories have been converting from traditional forms of assembly line production to "lean manufacturing," modular teams and cell-based production. The term "lean manufacturing" is used as shorthand for a broad set of changes embodied in efforts to promote "high performance," "continuous improvement," "just-in-time," and ultimately much more efficient and profitable production.

However, because of the scale of production in these factories in China—most of the factories studied have thousands or tens of thousands of workers—these factories do not so much resemble small team-based fac-

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Figure 1—Traditional assembly production in 2000 at a sports shoe factory in Dongguan City where 2,000 women sit behind sewing machines in the fifth-floor Stitching Department assembling components of the upper shoe. The sewed parts are warehoused until they are assembled in the fourth-floor Stockfit and Assembly departments, then sent on to the third-floor inspection and packaging departments. All photo credits: Garrett Brown.

tories, but rather a new large-scale, top-down controlled version of lean manufacturing. This is "lean with Chinese characteristics" as some observers have pointed out.

In traditional production, factories are divided into various departments (often on separate floors in huge factory buildings), each generating a single part, or set of parts, of the finished product. The semi-finished parts are then sent on to another department for the next stage of processing, traveling from department to department to reach the final assembly and packaging operations. The parts are warehoused between steps in the assembly process (Figure 1).

Lean manufacturing techniques re-organize this production process. Instead of massive, single-process departments, lean manufacturing establishes small production "cells" or teams of workers who complete an entire product—for instance in shoes, from cutting raw materials, to sewing, to gluing and assembling parts, to installing eyelets and laces, to inspection and final packaging. The lean cells are often shaped in a "U" or "S" configuration so that the production process starts at one end and the final product comes out at the other end. So instead of a floor of 2,000 sewing machine operators, there might from four to 20 cells, each of which would include the full set of operations (Figures 2 and 3).

The advantages of lean production over traditional assembly lines are that it is much more efficient, has higher productivity rates, has lower rates of waste and product defects, eliminates mid-production storage needs and costs, and allows for much greater flexibility and speed in shifting production from one style or product to another. A key element of efficient lean manufacturing systems is the increased role of workers, who are "empowered" to make critical decisions—including stopping production—to adjust malfunctioning machines, remove damaged parts and materials, and modify product flows and sequences based on actual production experience within the cell.

CASE STUDY OF A LEAN FACTORY

In August 2006, a joint U.S.–Chinese research team conducted an evaluation of the impact of the transition to lean manufacturing on occupational safety and health (OSH) issues at a 13,000-worker sports shoe factory in northern Guangdong Province. The team consisted of Dr. Dara O'Rourke of the University of California at Berkeley, Garrett Brown of the Maquiladora Health and Safety Support Network, and the executive director and three staff membersof a Chinese labor rights nongovernmental organization (NGO) based in Guang-zhou. The research included several rounds of

Figure 2—Lean production cell in the studied factory in 2006 where workers sitting next to one another sew components, spray adhesive onto parts, install eyelets, and assemble and inspect the final product. The close proximity of these different operations means workers are simultaneously exposed to chemical and noise hazards.

meetings with plant managers and numerous visits to the plant floor for observation, interviews with managers and workers, and measurements of airborne concentrations of organic vapors, ambient temperature and noise levels.

The factory, established in 2003, produces sports shoes exclusively for one leading international brand. The plant is representative of the "second generation" of foreign-invested enterprises in southern China that have moved inland from the southeast coast for lower-cost land, services, and worker pay. Only 1,000 of the plant's workforce live in on-site dormitories, while the rest (92 % of the workers) live at home or in rented apartments in the surrounding communities.

Since its opening, when production was shifted from another facility in the city of Guangzhou, the plant has been configured on lean manufacturing principles. This has resulted in significant increases in labor productivity.

When the plant started, a new product would have a 90-day lead time (the time from when an order is placed by a brand to when the finished product is delivered to market). Today the factory has an average 60-day lead, with some styles having lead times as short as 30 days, 15 days, or even seven days. The factory has also significantly reduced its inventory of "semi-products" (components of the finished shoes). The factory has implemented just-in-time delivery of materials and parts, thus significantly reducing "work in process." Overall, productivity has increased, quality has improved, the factory can produce more styles and change between these styles more quickly, and profits have increased.

Positive impacts on workers' wages and hours are not as clear. In addition to the base wage for a set output goal, there are overtime payments, and production bonuses for exceeding the quota for "right first time" (essentially a measure of quality), and for on-time delivery, combined with pay deductions for quality or delivery problems. In the end, most workers were unclear whether their wages were higher or lower using lean production rather than traditional assembly lines.

Under Chinese labor law, working hours per month are restricted to 40 hours per week plus 36 hours of overtime for the month, for approximately 210 hours of work a month. At this plant a survey of two cells in different buildings for the first six months of 2006 indicated monthly work hours ranging from 174 to 247, with work hours over 210 hours per month in seven of the 11 months studied.

Also unclear, because of a lack of objective measurement criteria, is whether stress levels for workers have increased or decreased under lean manufacturing. The Chinese members of the research team conducted an individual survey and focus-group meeting with a small number of workers, described below, which indicated

Figure 3—Lean production cell where a punch-press operator installing metal eyelets wears hearing protection for noise levels in the 87–89-decibel range, but the immediately adjacent sewing machine operators are unprotected against these noise exposures.

increased production pressures and individual stress levels under lean production.

Challenges and Hazards

While substantially more productive than traditional assembly plants, the lean production plant under study has experienced many of the same organizational challenges of traditional plants, as well as all the occupational safety and health hazards associated with sports shoe production.

One of the biggest challenges for factory operators in China is a high rate of employee turnover. A constant influx of new workers, mostly young people from rural areas with limited education and experience in either urban living or industrial work, means continuous training costs, lower productivity for initial work periods, and increased accidents and safety incidents. The turnover rate at the studied plant was lower than others in the coastal areas, but still averaged 3.6% a month, or 43% a year, for the 12-month period prior to the study visit.

Production of sports shoes has a large number of well-known occupational safety and health hazards, including:

- Chemical hazards are generated by the use of polyurethane, rubber, resins, and a wide variety of solvents and organic chemicals, including methyl ethyl ketone, acetone, ethyl acetate, cyclohexane,

Figure 4—Lean production cell where a worker applying heated spray adhesive is wearing a cloth "respirator" (which offers no real protection) while immediately adjacent workers assembling parts and operating sewing machines are exposed to airborne contaminants without any ventilation or protective equipment.

and butyl acetate (Figures 4 and 5). For example, in the plant's chemical-mixing area, technicians from the Chinese Centers for Disease Control in May 2006 measured with direct-reading instruments concentrations of n-hexane at 4.5 times the Chinese eight-hour time-weighted average (446 parts per million vs. the 100-ppm limit) (Figure 7).

- Noise exposures are generated by compressed air emitted by pneumatic tools, and by punch presses and eyelet machines installing metal parts.
- Heat exposures come from heat-generating machinery such as ovens and presses used to heat and form shoe parts, stock-fit machines used to assemble parts, heaters used to singe and remove stray fibers, and from the ambient environment of southern China.
- Ergonomic hazards are generated by poorly designed work stations and chairs that do not mitigate highly repetitive assembly operations usually involving forceful motions and awkward positions (Figure 8). Long hours and piece-rate wages tied to production goals also generate highly intensive work shifts with little recovery time for workers.
- Machine-guarding hazards occur with older equipment that never had guards at the point of operation, or with newer equipment whose guards are removed to increase production or inadvertently left off following equipment repair and servicing.
- Non-ionizing radiation exposures are generated by ultraviolet (UV) lighting used to cure resins and adhesives, and by radiofrequency (RF) label machines, which use RF to adhere labels to materials. UV hazards include damage to the skin and eyes from direct exposures, while RF exposures can generate heat in somatic cells of operators using ungrounded machines.

Figure 5—Lean production cell where a local exhaust ventilation (LEV) system has been installed to control airborne solvent and adhesive vapors. Such systems must be carefully designed, maintained, and periodically tested to ensure that air flow rates actually capture vapors and remove them from workers' breathing zones. The worker here is also wearing a cloth "respirator," possibly indicating she is still exposed to discernable levels of airborne contaminants.

Lean Impact on OSH Hazards

In traditionally organized factory production, these exposures are usually in separate departments that provide economies of scale for installing, operating, and maintaining engineering controls such as local exhaust ventilation. The lean reconfiguration of work stations and product flow to increase productivity and reduce cycle time has unintended consequences affecting workplace health and safety. Processes that were formerly separate from one another, often on different floors of large factory buildings, are now mixed together in a relatively small space that includes all the assembly operations from cutting raw materials to boxing the final product.

At the factory under study, this new combination of hazards was evident in numerous locations:

- In the hot press department, skivving work stations have been located immediately adjacent to the press area. This means that skivving machine operators are now exposed to the heat and noise hazards of the hot-press department, hazards that are not created by the skivving work itself (Figure 6). A survey of the hot-press department using direct-reading instruments indicated temperatures were above 35 degrees Centigrade and noise levels were above 90 decibels, A-scale (dBA). Noise at these levels, if maintained throughout the workday, would be higher than the 85-dBA exposure limit and require implementation of a hearing-conservation program as per Chinese law. These temperature levels are also above Chinese regulatory limits.
- In both large and small cells, workers operate "hot melt" cement-spraying machines and perform hand application of adhesives and solvents immediately adjacent to other workers operating sewing machines. This means that stitchers are exposed to chemical hazards that did not exist in previous all-stitching departments (Figure 4). A survey using a direct-reading instrument indicated "hot spots" where organic vapor concentrations were above 200

Figure 6—Workers in the Hot Press Department, where operators of "skiving" machines (foreground) trimming rubber soles are immediately adjacent to hot presses generating noise exposures above 90 decibels and temperatures above 35 degrees Centigrade.

parts per million, especially near curing ovens integrated into the assembly line;

- In both large and small cells, workers operate punch presses and eyelet-installation machines immediately adjacent to workers operating sewing machines or applying adhesives and solvents. This means that stitchers and chemical applicators are exposed to the noise hazards generated by metal-on-metal punch-press operations (Figure 3). A survey with a sound-level meter indicated punch presses and eyelet machines generated noise levels in the 87–89 dBA range (potentially above the eight-hour 85-dBA exposure limit and threshold requiring annual worker audiograms and training); and
- In both large and small cells, equipment is frequently moved or rearranged to reconfigure the line for different products. This means that the hazards of moving heavy pieces of equipment—such as pinch and crush injuries—now occur more frequently than previously. A review of the plant's log of injuries and illnesses for the last year indicated at least three serious accidents—resulting in worker days away from work—involved falling machinery.

In addition, the reorganization of production along lean principles generally leads to an intensification of work. This higher productivity carries with it the greater risk of ergonomic hazards and injuries arising from increased repetitive motions, shortened cycle times, and increased awkward postures and forceful actions in frequently changing work stations. Chinese workers in both traditional and lean factories work very long hours with little rest, often more than 11 hours a day, six or seven days a week, for weeks at a time. Some departments in this factory worked employees up to 274 hours a month during the first half of 2006.

Greater intensification of work and use of group-goal pay systems also increase the stress generated by work operations as workers take fewer breaks to maximize production and are also tied to the work pace and rhythm of their co-workers rather than their own schedules.

Lean manufacturing depends on employees being able to perform numerous distinct tasks and operate multiple types of equipment in a frequently changing environment where different products are produced by the same cell. With different products comes the need for increased employee training relative to the hazards of different equipment and exposures to both chemical and physical agents. Inadequate training increases the hazards to workers in the lean manufacturing environment.

Worker Survey and Focus Group Results

The Chinese labor rights NGO conducted a small survey of 27 workers from various departments during the research visit. The 49-question survey was developed by the NGO and administered by their members of the research team in private interviews with workers on the factory floor and with 20 workers who participated in a three-hour focus group meeting conducted privately on site.

Responses to questions about general conditions in the facility indicated its "model factory" status. Sixteen of 27 workers said this plant was better than other factories they had worked in; and 24 of 27 production-line employees indicated that conditions had improved in the preceding year.

At the same time, the survey reflected the impact of lean manufacturing processes on workers. Nineteen of 27 characterized their own stress levels in the plant as either "very nervous" (1) or "a little bit nervous" (18).

Figure 7—Chemical mixing department of the factory's chemical warehouse, where adhesives and solvents are mixed in open processes without any controls. In May 2006 technicians from the Chinese Center for Disease Control conducted direct-reading instrument screening of the area and found concentrations of n-hexane to be 4.5 times the Chinese eight-hour time-weighted average exposure limit (446 parts per million vs. the 100 ppm limit).

The source of the stress was identified as "concerned about not reaching the target" (13), "too rapid line speed" (6), and "too much work" (4).

The workers also selected the following as causes of stress for workers at the facility: "unrealistic output targets" (7); "unfair treatment by supervisors" (4); "no control over work decisions" (3); and "unrealistic deadlines," "performance constantly monitored," "poor communication between workers and management" (2 each).

Over all, the interviewed workers were split between preferences for an individual or group piece-rate bonus system—seven workers preferred a group bonus system while 11 preferred an individual bonus system.

KEY ELEMENTS FOR WORKER PROTECTION IN LEAN OPERATIONS

To fully protect workers in a lean manufacturing environment, it is necessary to combine a traditional industrial hygiene approach and a greatly expanded role for workers themselves. The traditional industrial hygiene approach involves the recognition, evaluation, and control of workplace hazards. Given the combination of previously separated hazards in lean manufacturing, as well as the frequent changes in production, occupational safety and health professionals at these plants must increase their hazard identification, evaluation, and control activities.

For example, the workers sitting immediately adjacent to punch-press operators may, or may not—depending on the measured level of noise exposure—need to wear hearing protection and be enrolled in a hearing-conservation program (annual audiogram and training) like the punch operators themselves. Workers operating sewing machines immediately adjacent to cement-spraying operations need to be evaluated for exposures to airborne chemicals. Similarly, workers immediately adjacent to hand applicators of chemicals need to be evaluated for chemical exposures, like the applicators themselves.

The use of small enclosures and local exhaust ventilation (LEV) systems are important to control exposures. Such LEV systems, however, are required on a more widespread, if smaller, scale. Moreover, these systems need to be tested periodically to ensure they are effective and are operating as intended (Figure 5).

In addition, there must be an increase in the amount and types of occupational safety and health training provided to employees so that they are aware of all the hazards generated by frequently changing lean production processes.

Worker Participation

Because of the decentralization inherent in lean manufacturing, as well as the massive scale of factories in China, a critical element of an effective occupational safety and health program in lean production is an expanded role for workers. Theoretically, workers are empowered in lean manufacturing to make key production decisions, such as stopping production to adjust machines or tools causing problems or undermining quality. The occupational safety and health arena similarly needs empowered workers able to identify, evaluate, and suggest controls for hazards arising in their work areas that have frequently changing materials, machinery, and related hazards.

A network of employees trained to identify and evaluate hazards in their work cells—such as chemical

Figure 8—Non-adjustable stools used throughout the 13,000-worker factory, which provide no support or protection against ergonomic hazards.

exposures, malfunctioning ventilation systems, unguarded equipment, and excessive noise and heat levels—would significantly expand the reach and impact of the plant's health and safety program.[14–19]

It is in the area of employee training that large-scale worker participation can have the most positive impact. Under Chinese national law, international conventions and standards, and the corporate "code of conduct" of its transnational customer, this factory is required to provide virtually all of its 13,000 workers with training in one or more occupational safety and health topics. It is not possible for the plant's small occupational safety and health department and management safety committee to conduct worker training meeting the requirements of these laws and norms. As a result, the factory is not in compliance with these regulations.

Experiences from other large factories indicates that a group of 100–200 production-line employees could be given a series of training sessions and appropriate written materials to become "peer trainers" conducting "tool box" safety briefings to 50–100 of their co-workers on the hazards present in their work areas and the control measures designed to prevent injuries and disease. Given the high employee turnover rates in China's export factories, this kind of training needs to be an ongoing activity.

The workplace safety and health topics about which workers at this and similar plants need training include hazards from chemical exposures; adverse health effects of noise, heat, and non-ionizing radiation; ergonomic hazards and controls; machine guarding and "lockout/tagout" procedures; electrical hazards; and emergency action and fire-prevention plans.

Over all, China has an adequate set of formal workplace health and safety regulations, including the Prevention and Control of Occupational Diseases Law and the Production Safety Law, both implemented in 2002. China has also ratified key workplace safety conventions of the International Labor Organization (ILO), including Convention 155 (Occupational Safety and Health), Convention 167 (Safety and Health in Construction), and Convention 170 (Chemicals). But while these laws requiring worker participation are on the books, actual employer compliance and government enforcement are highly variable and generally poor.

Obstacles to Worker Participation

Our research at this plant and in other foreign invested enterprises in China indicates that there are a number of significant obstacles to implementing large-scale, meaningful participation by workers in plant-wide health and safety programs. These include:

1. lack of political will and/or inadequate allocation of resources by executive management;
2. a "command and control" management approach that prohibits ceding any authority and power to non-management employees, such as production-line workers;
3. opposition from the government-controlled All China Federation of Trade Unions to genuine worker participation in factory-level decision making, and to any real forms of worker representation;
4. opposition from first-line supervisors and department managers, whose ability to meet production goals may be threatened by time lost to occupation training sessions, safety measures that slow production, and the absence of workers performing safety-related tasks;
5. lack of volunteers among workers, who may feel they are inadequately prepared or insufficiently supported to perform safety tasks; or feel that they, or their production team, will lose pay while worker health and safety volunteers perform safety tasks rather than production activities; and
6. high turnover rates of employees that trigger repeated training sessions for both production-line workers and members of the safety program.

In our experience in China, one or more of these obstacles has prevented large-scale participation of workers in plant-wide health and safety programs in the sports shoe, garment, toy, and electronics industries. These challenges can be overcome, but to do so will require a conscious policy decision and allocation of sufficient human and financial resources by both the transnational corporate customer and the actual contract factory owner.

Effective health and safety programs are not possible—in either traditional or lean factories—without genuine management commitment, a well-developed program and structure, the necessary resources to implement the program, and large-scale, meaningful participation by workers.

Given the lack of any independent, member-controlled unions in China, national and international NGOs have played a key role in focusing attention on dangerous working conditions, employer noncompliance and government inaction. A critical objective of the international "anti-sweatshop" campaigns directed at China has been precisely to create space for workers on the plant floor to speak and act on their own behalf in addressing and correcting unsafe and unhealthy working conditions in both national and foreign-owned factories.

CONCLUSION

The transition from traditional assembly-line production to lean manufacturing techniques is proceeding at a very fast pace. This is true not only in advanced industrialized countries but also in low-wage countries such as China, as all workplaces in the global economy are now competing with one another for the lowest production costs and the most nimble, productive and efficient operations.

While lean production is often more efficient than "Fordist" assembly lines, lean manufacturing does not in itself eliminate occupational safety and health hazards. In fact, in addition to long-recognized hazards of traditional production processes, lean production can actually *increase* hazards by mixing previously separated exposures, with additive and cumulative effects. The intensification of work leads both to higher plant productivity and to greater adverse ergonomic and stress-related health effects for workers. Lean production can also lead to increased safety hazards with frequently moving machinery and equipment.

The standard industrial hygiene approach of anticipation, recognition, evaluation, and control of hazards continues to be applicable to lean operations, but more intensive efforts are required to evaluate combined and mixed hazards, and then to implement flexible and effective controls. A key for both maximum productivity and optimal worker safety in lean production operations is informed, empowered, and active workers with the knowledge, skills, and opportunity to act in the workplace to eliminate or reduce hazards. In theory, lean manufacturing should open the door to and institutionalize meaningful worker participation on the shop floor. Experience to date in China indicates that several major obstacles to effective worker participation must be overcome if the promise of improved worker safety under lean manufacturing is to be realized.

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