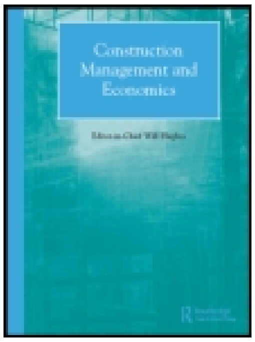

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Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan

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In Japan, similar management practices in product development, design, supply-chain coordination, marketing and sales have been used to produce very different products: industrialized housing and automobiles. Manufacturing principles derived from the car industry have been successfully used to produce attractive, customized and affordable homes. But there are limits to which such techniques can be applied to manage the assembly of wide varieties of component parts needed to produce complex customized products. Managers must trade off the need to achieve economies of scale in the production of standardized factory parts with economies of scope in various stages of assembly in order to provide flexibility to satisfy consumer choices. The housing industries can benefit by learning more about the use of advanced manufacturing techniques developed in car production. At the same time, automobile makers may learn more about the management of customization from the way in which housing firms organize sales, design and final assembly. The paper suggests that wider ranges of choice can be delivered through managing the whole production system, balancing the use of standard components with flexibility in assembly, rather than by solely attempting to optimize control in discrete parts of the system.

Keywords: Innovation, manufacturing processes, Japanese industrialized housing, car production, technological learning, economies of scale.

Introduction

This paper explores the extent to which technological learning has occurred between two industrial sectors in Japan: industrialized housing and car production. The scope and purpose of the paper is to investigate the influence of manufacturing techniques on Japanese industrialized housing.

Fruin (1992) argues that Japan's enterprises are involved in an interactive, dynamic learning system in which companies continually adapt and change in response to learning from past experiences, competitors, suppliers, other sectors and from overseas. This enterprise system is an interorganizational structure of business management and coordination in which there are many interdependences between factories, firms and interfirm networks. The adoption of advanced factory production methods by industrialized housing firms provides new examples of the learning and transfer of expertise between industrial sectors. It demonstrates the possibility of two-way learning between sectors and not merely a one-way diffusion process from car production, often perceived as the leader in management practices, and housing production, traditionally viewed as a slow-to-change, craft industry. The benefits of cross-industry learning are clearly demonstrated in the case of Toyota, one of the world's three largest car manufacturers, which also produces several thousand factory-made houses a year.

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But Toyota may still have lessons to learn from other housing producers in how to manage the production of a wider range of customized products in which the use of automated techniques is limited by the degree of complexity of the product associated with the number and range of component parts.

The paper draws upon research carried out during eight study visits to Japan between 1990 and 1995 together with ongoing collaborative research between UK and Japanese researchers on innovation in the construction sector. The work included a UK Government Trade and Industry Expert Mission to assess innovation in Japanese prefabricated housebuilding industries (Bottom *et al.*, 1994). Data were gathered through a series of detailed semi-structured interviews in Japanese housing companies and during site visits. More than 30 organizations were visited, and in many cases an interpreter was used. Some organizations, such as Toyota, were visited on a number of different occasions, and in many cases managers from several departments within each organization were interviewed. In addition, the Housing Corporation of Japan, Ministry of Construction and Ministry for International Trade and Industry were helpful in supplying and interpreting official statistics.

The paper is divided into four sections. The first explains the main principles underlying performance improvements in manufacturing, and illustrates a long history of attempts at utilizing these in housing production in Europe and the USA. The next section assesses the main principles of modern Japanese car production, followed by a presentation of different techniques of industrialized housing in Japan. The final part assesses the similarities and differences between Japanese industrialized housing and car manufacture, and the extent to which one has learnt from the other.

Why compare learning between industrialized housing production and car manufacturing?

Ever since Henry Ford developed the standard production line for car manufacture, leading European and North American architects, builders and manufacturers have been seduced by the idea of producing houses in factories. Many attempts have been made to transfer knowledge from mass-production of automobiles and other consumer products to low-cost housing production. The long history of attempts at technology transfer make for rich comparative material on which to base our analysis of learning between industries.

The products of these industries vary considerably, and in comparing production techniques it is necessary to note their physical differences, explain organizational aspects of production, and relate these to processes of learning. Buildings, or 'constructed products', differ from other manufactured goods in several respects, which affect the extent to which new production processes can be deployed. For example, in comparison with many products, housing is large and usually immobile; there is a higher degree of complexity in the number and range of component parts; its production on site introduces varying degrees of uniqueness; and housing must be more durable and is often more expensive than other manufactured goods.

Size and immobility of the product mean that housing is assembled at the point of consumption, setting construction apart from many manufacturing industries, in which finished products are transported to market. This constrains activities to the extent that the economics of labour, machinery and transport of parts have to be considered in a different light from those in the manufacture of other consumer products: hence the name 'construction'. Complexity in terms of the number of different component parts, range of different interconnections between components, varying degrees of uniqueness of final products and organization of the production process can stultify innovation and the use of mechanized production techniques. The risk of failure – as experienced in some of the systems used in 1960s high-rise housing in Britain and elsewhere (McCutcheon, 1975) – helps to perpetuate conservatism in design and construction. Longevity and the need for durability create problems in testing new materials, components and production techniques: the costs involved may render innovation prohibitively expensive.

While it is important to recognize physical differences in products in analysing learning between industries, there is a danger in over-emphasizing the limits to the development of new production techniques due to these characteristics.[1] Physical characteristics of constructed products do not necessarily relate to the sector's presumed backwardness in deploying new techniques, and just as they may hinder the development of some technologies they may also play a part in promoting change. Construction has itself been innovative in developing many new approaches to organizing processes and integrating new technologies (Gann, 1993). Indeed, one of the main reasons for transferring techniques used in the manufacture of consumer goods to housing has been to reduce the impact of physical conditions found on sites.

[1] This can lead to a technologically determined framework, which tends to ignore the importance of the social and economic relations of production (Clarke, 1992).

Industrialized housing production in Europe and North America, 1914–1970

The idea of improving performance in construction by learning from other industries is not new. Manufacturing, the system of production involving the concentration of materials, fixed capital and labour in one or more plants, had long been perceived to demonstrate efficiency over scattered craft production found in traditional housebuilding. Manufacturing provided three main advantages over craft:

1. economies of scale, when the cost per unit drops more quickly than production costs rise as the volume of materials being processed increases;
2. technical possibilities to develop and deploy capital equipment, and
3. the opportunity for tighter managerial control.

These were exploited by Henry Ford, whose adoption of scientific management and invention of the mass-production line facilitated the production of high volumes of standardized products made from interchangeable parts. Womack *et al.* (1990) summarize the main attributes of this system, the key being complete and consistent interchangeability of parts and the simplicity of attaching them to one another. The same gauging system was used through the entire manufacturing process, driven by savings on assembly costs. It was these innovations that made the assembly line successful. They allowed further subdivision of labour, employing unskilled or semi-skilled workers on high-cost, dedicated machinery. Design and management was carried out by narrowly skilled professionals. Moreover, because the machinery was so expensive, firms could not afford to allow the production line to grind to a halt. Buffers, such as extra supplies of materials and labour, were added to the system to ensure smooth production. Producers kept standard designs in production for as long as possible because changing machinery to produce new products was expensive. This resulted in consumers' benefiting from lower costs, but at the expense of variety and choice.

In the first half of the 20th century influential architects such as Le Corbusier, Walter Gropius, Bemis, and Buckminster Fuller believed fervently in the idea of mechanization and industrialization of construction. Their stated aim was to raise efficiency by rationalizing the process through the application of scientific methods. Buckminster Fuller argued that the production of buildings should be carried out in similar ways to that of cars and other volume-produced goods. In criticizing the inadequacies of craft production he argued that each house was treated as a pilot model for a design that never had any runs. It was an art that belonged to the Middle Ages because it was based on 'methodical ignorance'.

Le Corbusier's Dom-ino House, produced in 1914, was one of the most influential, with its simple, standardized, slender frame, slab floors, flexible floor layout independent of structure, lightweight movable internal walls, and external non-load bearing cladding. Le Corbusier argued that

> houses must go up all of a piece, made by machine tools in a factory, assembled as Ford assembles cars, on moving conveyor belts. (Russell, 1981, pp. 125–59).

The ideas of Le Corbusier and others resulted in completely new methods of construction, and were to strongly influence design and construction philosophy into the 1960s with the evolution of 'systems building'.

Attempts to develop industrialized housing did not only emanate from building designers and users wishing to learn from the production of automobiles and other manufactured goods. Manufacturers played important roles in promoting industrialized systems through the development and marketing of new products and components. Moreover, economic forces from within the construction process itself spurred the search for new methods. For example, contractors realized that prefabrication of standardized parts could cheapen components, reduce on-site labour requirements and speed up the construction process, and at the same time potentially provide the buyer with a higher-quality product because factory tolerances were tighter than those achievable on site. Three main principles underpinned the development of industrialized housing construction; standardization, prefabrication and, later, systems building.

Standardization was the prerequisite for factory production of components. A scientific examination of component specifications resulted in modular categories each representing a different attribute or function such as performance, structure, tolerance and installation. Bricks were the first, the most simple and the most standardized component to be used in housing construction: they were produced in factories using batch, and, later, volume production processes long before the era of Ford's factory production system.

Prefabrication, the production of components under factory conditions, and their assembly on site, aimed to reduce costs, to increase speed of construction processes, and to improve quality. One feature was that the erection and assembly of prefabricated components resulted in less materials wastage on sites than that which occurred in craft production. This was achieved by keeping site work to a minimum, resulting in the use of assembly processes rather than handicraft techniques. Two types of prefabricated components emerged: those that were produced without prior knowledge of the design or type of building, and those that were produced for a specific building only after the design had been completed. The former were produced to stock for a general market, while the latter were produced to order (Kendall and Sewada, 1987, pp. 7–19).

Systems building, adopted in the 1950s and 1960s, involved more extensive use of prefabricated components and attempts to introduce quality control, new relations with manufacturers, and the use of programming methods for construction sequencing, together with new methods of documentation. At the same time, standardization was given a new impetus through the design of buildings on a grid, or modular basis. The aim was to coordinate the size of factory-made components with the design of buildings. This became known as 'dimensional coordination'. Finally, the role played by clients, or project sponsors, was one of the crucial differences between systems building and other methods of construction (Finnimore, 1989, p. 6). The mass-housing programmes of the 1960s facilitated the adoption of bulk purchase agreements for components, which gave local authorities (and consortia) and large building contractors greater control over the supply of parts.

The invention of standardized, interchangeable prefabricated construction components had many similar effects on building work to those experienced in automobile production and manufacturing. Just as Ford's production system swept aside craft car producers – except for those employed in the re-work shops – so industrialized construction techniques played a part in eroding traditional craft skills. Ending craft practices was one of several goals of industrialized construction. Tasks were divided and subdivided, craft control was replaced by new management practices, and the pace of work was often dictated by the need to maximize the use of equipment such as tower cranes. These changes contributed to the casualization of construction work, which became similar to that on car production lines, where workers were treated as interchangeable parts, and taken on or laid off as and when they were needed. Immigrant workers, who were employed to supplement indigenous labour in construction – particularly in the most menial tasks – also experienced similar treatment to the 'guest workers' employed on volume-production lines.

There is little systematic measurement of the overall gains resulting from the use of prefabricated components and industrialized housing systems during this period. Few comparisons have been made between the relative gains in efficiency from the production of prefabricated components on demand for individual projects and those for general purchase off the shelf. But evidence from the 1960s suggests that systems building did not raise overall productivity (except in school building projects), and was rarely cheaper or much quicker than traditional construction techniques (Finnimore, 1989). Furthermore, component systems were often 'closed' and inappropriate for interconnection with systems produced by other manufacturers. Assembly on each construction site was treated as a new factory employing mobile gangs of workers. Fordist methods of control were difficult to adopt, partly because policing the ever-changing work area was an onerous task in itself, in spite of the use of work study, piece work and bonus payment methods.

Those promoting industrialized housing methods often likened housing markets to those for cars and other consumer goods. But while housing markets were large, they could not yet be organized so easily. Manufacturers often did not perceive markets for mass-produced housing as being stable enough to warrant the huge investment costs that would be required to tool up new factories. Housing markets differed from consumer goods, where firms had secured large continuous markets, which they were able to organize and control with some degree of success. These differences were partly due to the nature of land ownership and the variety of methods of financing and consumption of housing. Moreover, the functional design of many prefabricated components did not satisfy consumer desires. Lessons from 1960s industrialized high-rise housing programmes show that design, layout, choice of materials and construction resulted in products that were often socially unacceptable (McCutcheon, 1975). Consumers had little if any choice in housing produced using the standardized volume-production techniques available at that time. It seemed that industrialized housing producers had not learnt the lessons 50 years on from the famous model T Ford, in which customers could have a choice of any colour they liked as long as it was black.

Toyota production system – modern Japanese car production methods for meeting wider customer choices[2]

In North America, General Motors quickly showed Ford the marketing benefits of producing vehicles of different colours: Alfred Sloan's approach to new product development at General Motors aimed to produce 'a car for every purse and purpose'. But

[2]The material in this section draws upon the following references: Schonberger (1982), Monden (1983), Womack *et al.* (1990), Clark and Fujimoto (1991) and Toyota Motor Corporation (1993).

the real shock in meeting wider customer choices, and at the same time improving efficiency in production, came from Japan. The revolution in Japanese manufacturing techniques began with experiments in Toyota in the late 1940s. It resulted in new approaches to the organization of production, the use of plant, management of resources, quality control and relationships between producers and customers. By the 1980s, the mass production system had been transformed into a more efficient, responsive system, which became known as 'lean production' (Womack *et al.*, 1990).

After World War II, Toyota (now Japan's largest car producer) needed to harness the efficiency offered by American mass-production techniques if it were to become a volume producer and compete in international markets. At that time, local Japanese automobile markets were small, and demanded a wide range of vehicles; production techniques were primitive in comparison with those in the USA, and investment capital was scarce. Moreover, Japanese factory workers were not willing to be treated as variable costs, like the interchangeable parts in Ford's factory system.

In 1950 Toyota's President, Eiji Toyoda, spent three months at Ford's Rouge plant in the USA. He was amazed at the total output of the plant, which in one year produced over 2.5 times the number of cars made by Toyota in the previous 13 years. But while total output was impressive, Toyoda thought the system to be wasteful (*muda*) in terms of effort, materials and time. Toyoda could not afford to produce cars with such narrowly skilled professionals and unskilled workers tending expensive, single-purpose machines with their buffers of extra stocks and re-work areas needed to ensure smooth production and final quality. Toyoda's objectives were to simplify Toyota's production system, combining some advantages of craft work with those of mass production, but avoiding high costs of craft and rigidities of factory systems. The result was the evolution of Toyota's lean production system, which employed teams of multiskilled workers at all levels of the organization and highly flexible, automated machines to produce volumes of products in enormous variety.

This system became known as lean production because it used less of everything compared with American mass-production: less labour was needed, smaller manufacturing floorspace, lower investment in tools, and fewer engineering hours to develop a new product. The system resulted in the need for less storage space for inventory on site. It also manufactured products with fewer defects and with greater and ever-growing variety to meet differentiated customer preferences.

The success of lean production can be attributed to many improvements across the whole system rather than to one particular aspect of change. As inputs to these improvements, Toyota required better information about production and use of its products; it also needed to develop new product and process technologies. This was achieved by establishing closer links with consumers to identify and understand customer needs; by investing in research and development in both product and process engineering; and by establishing joint technology development activities with suppliers.

Three developments were of crucial importance in the evolution of lean production. First, simple dies had to be made so that they could be changed easily and quickly, enabling the same press line to make many parts.[3] This had two important consequences: first, it became possible to make small batches without the need to carry huge inventories of finished parts; second, it was necessary only to make a few parts before mistakes and defects became evident. This made workers in the stamping shops more aware of quality, and it eliminated the waste of large numbers of defective parts.

To gain real benefits from the new, more flexible production lines it was necessary to shorten lead-times of component parts while maintaining reliability in terms of quality. The second aspect of lean production was therefore the supply of parts just-in-time (JIT) to be worked on at the next stage of production – rather than just-in-case something goes wrong, as in the old-style American mass production system.

The Japanese JIT system involves three techniques: the pull system (*atokotei hikitori*); levelled production (*heijunka*); and continuous-flow processing (*nagareka*).[4] This system is adaptable to fluctuations in

[3] Die changes were simplified so that they could be made by production workers who were previously idle during changes. By the late 1950s, the time needed to change dies had been reduced from 1 day to 3 min, and at the same time the need for die-changing specialists had been eliminated.

[4] In most traditional manufacturing systems the preceding processes make items in accordance with a preset schedule (optimizing throughput on machines) and send them to the next process regardless of demand. This is the 'push system', where upstream processes push out parts and components onto the next process downstream, regardless of whether they are required. The Japanese 'pull system' operates in reverse, whereby a process is carried out after demand has been registered from the next process downstream. Levelled production is a technique used to measure monthly demand and relay this to plants and parts suppliers to that production can be adjusted to avoid wild fluctuations, which could be caused using JIT. Continuous flow processing is used to reduce in-process inventory and waiting time.

demand, and produces goods just-in-time for the next step. Information is provided using visible information cards (*kanban*). Production-ordering *kanban* and withdrawal *kanban* cards flow through the process between suppliers and assemblers, providing instructions as components are produced and processed.

The third development important to the success of lean production was the eventual attainment of good labour relations and team working. In the late 1940s and early 1950s, Japan experienced a period of bitter industrial disputes (Armstrong *et al.*, 1984, pp. 382–91). These were eventually resolved through realignments on the shopfloor in the 1960s, resulting in the establishment of quality circles and the zero-defects movement. Teams of workers were given time to suggest improvements to production processes. This collective suggestion process became known as 'quality circles'. In 1990, Toyota's 6770 quality circles completed a total of 24 000 improvement projects.

Quality circles were linked to processes of continuous improvement (*kaizen*), which took place in collaboration with industrial engineers. Emphasis on problem-solving became an important part of everyone's job, and on-the-job training, collective education and self-development were all encouraged.

Alarm lamps and indicator boards (*andon*) with different-coloured lights, mounted above production lines, indicate the condition of the line together with process defects, enabling supervisors to take appropriate action. In this way, every worker and each piece of automated machinery ensures that only items of proper quality can pass on to the next process.

The combination of these activities helped to expose problems that could otherwise be hidden by excess staff and inventory found in traditional mass-production techniques. Further improvements to the system have been achieved by developing new maintenance procedures to minimize down-time.

Over the past 25 years, these techniques have made Toyota a world-class car producer, against which other manufacturing firms have been benchmarked. Toyota has developed and deployed the latest technologies in areas such as advanced materials and process techniques, including CAD/CAM/CIM and flexible manufacturing systems on medium-variation, medium-volume production lines. Unmanned supply vehicles are used to transport components and parts, and vertical computer-controlled warehousing is used for storage. The combination of technical and organizational developments in Toyota's production system has resulted in benefits in economies both of scale and scope – the ability to produce a range of products on one line when previously different production lines would have been required.

In spite of the application of new IT-based communication and control technologies, it appears that lean production achieves its highest efficiency, quality and flexibility when all the activities from design to assembly occur in close proximity, where it is possible for production engineers and operatives to engage in face-to-face contact to resolve unforeseen problems. This, to some extent, may limit transferability of these techniques to other sectors such as housing production, which generally involves distributed production activities.

The Toyota production system in the 1990s

In the early 1990s, pressures brought about by the high value of the yen, competition from rejuvenated North American and European producers, other East Asian competitors and the lessons from ten years of lean production, led to further changes and improvements in the Toyota production system. For example, attempts have been made to move away from too much reliance on automation in the factory producing the new RAV4 sport–utility/off-road vehicle. The level of automation has been reduced by 66%, compared with a normal assembly line, reducing reliance upon specialized maintenance personnel. Machines are restricted to activities that make work easier for shopfloor operatives, and the assembly line is subdivided into five parts with buffer zones so that cars can enter the work-stage only when workers are ready for them, making the job less stressful. The RAV4 production line finishes 428 cars every day, with productivity figures estimated to be as low as ten man-hours per vehicle – over twice as efficient as a typical US assembly line (*The Economist*, 1995).

The need to meet increasing levels of customer choice for different model options means that a factory has to cope with millions of possible build permutations. Toyota manages this partly by minimizing the number of parts in a new model (emulating value engineering techniques used by US car producers) and partly by pushing some of the build complexity out of the assembly plant and down to the dealers, who install customer options as bundled dealer-installed packages (Brooke, 1994). Toyota aims to increase the number of common parts used in new models to around 70%, in order to reduce costs and manage a wider range of customer choices.[5] This will involve a more widespread shift towards the use of 'platform' designs and standardized sub assemblies. It may also result in closer supplier involvement in design and engineering of whole sub assemblies, rather than merely supplying parts to order.

[5] In 1995, the RAV4 shared 40% of its component parts with other Toyota vehicles, including passenger cars.

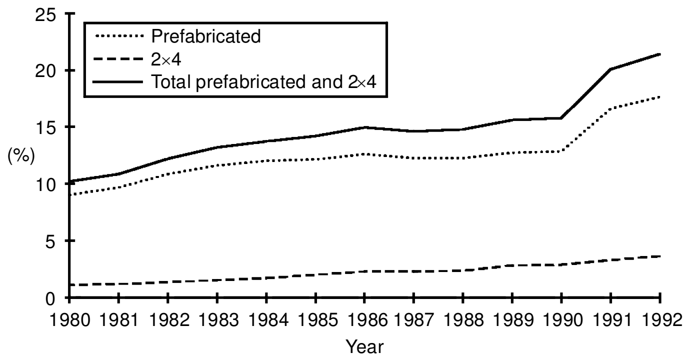

Figure 1 Ratio of prefabricated and 2 × 4 housing units as a proportion of total new housing.

Source: Japanese government statistics.

Japanese industrialized housing production, 1950s–1990s

Our story so far illustrates how the leading Japanese motor vehicle manufacturer learnt, first from North America and then from its own attempts at continuous improvement, to develop a more flexible and efficient production system than its competitors. This system made products catering for wider degrees of consumer choice, which previously had been one of the major failings of the attempt at mass-manufacture of housing in Europe and North America during the 1960s. If Japan's car industry could improve its performance in satisfying segmented markets with customized products, could the housing industry learn from this experience?

Japan's housebuilding industry has a long tradition of craft production, based on woodworking skills. Attempts at industrializing production began in the late 1950s, later than in Europe and North America. Since then, Japanese housing markets have been large and stable enough to support a number of alternative approaches.[6] Pressures to industrialize were numerous, arising from shortages of skilled carpenters, depletion of indigenous supplies of timber; low-quality housing; rapid economic growth and urbanization[7]; the need for earthquake protection; oil-shock price rises; and the need for better fire protection in housing. Demand for construction work to repair war-damaged housing and improve the general quality of the building stock increased, triggering a need to modernize construction processes and to research the safety of new technologies.[8]

By 1955, government, perceiving that productivity growth in housing production was low relative to other manufacturing industries, formed the Japan Housing Corporation (JHC) as a leading public housing organization, focusing mainly on developing medium-rise reinforced concrete flats. This promoted the development and use of heavy, standardized concrete panel systems. Early forms of industrialized housing were highly uniform, produced from a small range of standard components: many techniques were learnt from those used in the West. They failed to provide what many occupants required in terms of choice of design, and they could not compete with conventional timber methods, which offered greater variety of styles. By 1970, the number of dwellings produced had reached the level of new household formation. The market in terms of quantity had been satisfied, and emphasis shifted to quality: research and development activities shifted away from improving production processes aimed at meeting problems of housing shortages, to the needs of improving the quality of housing products.

Industrialized housing producers invested heavily in improving the flexibility of design to customize housing to individual consumers' choices. This helped the market share for prefabricated and 2×4 timber panel[9] housing to double between 1980 and 1992, and by 1995 it accounted for nearly one quarter of all new dwellings, in spite of a decline in overall housing output (Figure 1).[10] Market growth was also related to the high density of housing markets in urban areas, where customers had positive attitudes towards factory-made products developed by manufacturers

[6] Output has fluctuated between around 1.3 and 1.7 million new housing units per year.

[7] The particular form of urbanization was important because it resulted in a new market for housing from a growing urban population who had no relationship with the traditional craft-based housing system.

[8] From the mid-1950s onwards, the drive to use industrialized methods was strongly related to supply-side push from materials and components industries (steel, plastics and plywood) seeking new markets. By 1953, the procurement boom for steel created by the Korean War left over-capacity in steel production. Domestic production of light-gauge steel sections for housing began in 1955. By 1963, several private firms had developed their own industrialized construction methods and began to manufacture and supply detached houses. The main motive for industrialization by suppliers was conversion from armaments manufacture to housing (to find new markets for excess steel capacity), and not cost-reduction in housing production (Matsumura, 1994).

[9] 2 × 4 refers to the size of the main structural timbers used in the frame.

[10] By 1994, the market was divided into three segments: 40% was produced by small local builder/carpenters, concentrating on timber-frame houses; 40% by large contractors, usually making multiple occupancy dwellings; and 20% by various industrialized housing producers using factory-based prefabricated methods.

Table 1 Japan's big 5 house manufacturers and Toyota Homes

Firm	Approx. no. of houses (1993)
Sekisui House	70 000
Misawa Homes	50 000
Daiwa House	40 000
Sekisui Heim	34 000
National House	32 000
Toyota Homes	4 000

who were increasing their efforts to satisfy consumer preferences. New sales methods were introduced, with national sales networks employing specially trained sales/design staff. Government provided financial and legal backing for technical development aimed at solving housing shortages, and encouraged more effective use of land.

Industrialized housing techniques offered immediate benefits in the management and timing of re-source allocation, reducing construction time on site. Industrialized systems combine different levels of factory and site-based activities.[11] They range from those made in workshops processing materials and parts into components and subassemblies, to those in which 80% of the work is completed using advanced manufacturing techniques.

Assembly of traditional carpenter-built houses takes around 120 days on site, conventional 50% prefabricated panel houses around 90 days, and modular unit houses as little as 40 days on site, including preparation of foundations, interior furnishings and inspection.

Panel and modular housing systems

The focus of this paper is on the factory production of panel and modular, steel or timber-framed housing systems used to produce individual houses. In 1994, these accounted for over 10% of total housing output in Japan, and the content of factory production ranged from 50% to 80% – steel-framed housing accounts for the largest market share of these units.

In the early 1990s, the market was dominated by five major players, which had an 80% share of the industrialized housing market (Table 1). All aimed to produce high-quality reliable houses for middle and luxury markets, offering a wide range of design options to provide flexibility for customer choice. This distinguishes them from earlier attempts at standardized industrialised housing.

The history of these companies provides an important clue to how they have developed their manufacturing capabilities. None of these companies evolved from traditional craft housebuilding firms; with the exception of Misawa, they were started by large conglomerates, which were able to invest heavily in factory facilities and R&D.[12] In 1929, Sekisui Chemical Company established Sekisui House, hoping to exploit new markets for plastic products. Sekisui Heim, a wholly owned subsidiary of Sekisui Chemicals, was formed in 1972 to compete in the market for modular housing. Daiwa House was established in 1958 by Daiwa, a tubular steel fabricator. National House was established in 1950 as the housing division of Matsushita Group, the electrical components, consumer goods and heavy electrical products conglomerate, its major shareholders are Matsushita Electric Industries and Matsushita Electric Works. Misawa Homes was established in 1967 as a company specializing in prefabricated housing.

It is interesting to note the reasons for Toyota's entry into housing production in 1976. There is a tradition within the Toyoda family that a son from each generation must establish a new business.[13] In the 1970s the third-generation son, Syohichiroh Toyoda, started the housing business because it was predicted to be a booming market, and Syohichiroh had wanted to be an architect in his boyhood. The other booming market, space exploration, had already been covered by Nissan Motor Corporation, who developed a space rocket business.

These companies have R&D facilities, each employing several hundred scientists, technologists, ergonomists, architects and engineers. They are structured with varying degrees of vertical integration, from

[11]The major prefabricated structural systems include: timber-frames – pre-cut or 2×4; steel-frame factory-made light-gauge welded panels or frames; module steel-frame systems; and reinforced concrete systems, mainly used for flats. A range of component systems including precast lightweight concrete cladding panels, stairs, door sets, windows, modular bathrooms and kitchens are produced in factories mainly as subassemblies for new housing markets.

[12]The cost of entry for new competitors is high in both cars and industrialized housing, whereas it is relatively low in traditional housing. Sekisui House has invested more than ¥17 billion in its Shizuoka factory since it was built in 1980. One of Toyota's housing factories cost ¥4 billion to build in 1987.

[13]In the Meiji era, Sakichi Toyoda began his weaving business, which resulted in the Toyoda Automatic Loom Works. On his deathbed, Sakichi Toyoda is reported to have suggested to his son Kiichiro that he start the automobile business (Fruin, 1992, p. 260).

design and sales to materials and component fabrication, assembly and erection on site. The following discussion illustrates how firms have learnt to cater for wider customer choices from their own experiences and from cross-industry comparisons. Choice has been delivered through managing the whole production system, balancing the use of standard components with flexibility in assembly.

Design and sales systems

The degree of buyer concentration for housing is similar to that in car markets: purchasers are usually private individuals who express a wide range of different preferences in design and specification. House buyers in urban Japan are learning to differentiate between functional quality and customization, obtained through mass-production (similar to that in the automobile industry), and aesthetic qualities attributable to craft practices such as those found in traditional Japanese timber housing.

The purchase and ownership of land is usually separate from that of housing in Japan. In most cases of single-dwelling housing production, customers own their land or make special purchases of land outside transactions for houses. Housing producers cannot rely upon land speculation to ensure profitability; they must therefore develop and use efficient production techniques.

Customer choice is partly derived from the organization of design and sales activities, which in the case of the Sekisui companies and Daiwa are combined, and are carried out inhouse. They offer sophisticated services to engage with customer preferences, based on catalogue design concepts. Customers work with experienced sales/design staff to make modifications on CAD systems, which generally provide good-quality 2D or 3D representations of designs. Each customized design is developed through a series of stages, which includes visits by sales/designers to the customer's chosen site. Sales staff appraise the customer of all cost, time and quality implications relating to their choices. They also provide samples of materials, fittings and furnishings. These negotiations over design and purchase usually take around three months. Firms generally produce a detailed estimate and offer a completion date within two days of the customer's agreeing the final design.

Misawa Homes, National House and Toyota Homes (until early 1996)[14] have used franchise sales networks, separating sales from in-house design and therefore reducing the opportunity for direct feedback concerning customer preferences between sales, design and R&D staff. Toyota's design and sales system was similar to that used for its cars: it relied mainly upon a franchised dealer network, affiliated to, or subsidiaries of, the car dealers. In 1994, Toyota had 28 sales agencies and 121 showhouse sites. A few sales agencies specialize solely in housing in the Nagoya district.[15] But many franchises had no specialist housing sales representatives – a sales person could be selling cars one year and houses the next. Design is one stage further removed from production, and probably because of this, plans appear to be more standardized than those produced by Sekisui House and Sekisui Heim, although there is some flexibility for accommodating customer choices.

Misawa developed its system having learnt from Toyota's car sales methods, which involved franchised agents in strong regional companies. Bridgestone, the car tyre manufacturer, established Misawa's housing sales network in the early 1970s because they wanted to learn from experience in new markets. National House, owned by the Matsushita Group, established a separate franchising system to sell kit houses to small house-assemblers. Sales had to be kept separate from the production system because many of Matsushita's existing customers for electrical components were small house builders, who might have been put out of business if National were to sell houses directly.

Sekisui House panel system

The largest industrialized housing producer, Sekisui House makes prefabricated steel or timber-framed housing panels in five factories. The company controls the whole process from design to final assembly on site, providing a high degree of customization to buyers, using the IT-based Sekisui's Flexible Planning System.[16] Manufacturing and assembly processes include computer numerically controlled machines,

[14]In March 1996, Toyota Homes became a subsidiary company with strong involvement from Asahi Solar Corporation, which has specialist marketing and sales expertise. It was too early to assess the impact of this at the time of writing.

[15]It is interesting to note that when Toyota started its housing business in Nagoya, sometimes known as 'Toyota Town', local housebuilders are said to have boycotted the purchase of Toyota cars, opting for Nissan or Mazda in protest at Toyota's intrusion into their market.

[16]Designs are mutually re-keyed into factory production systems, as there is at present no direct link between CAD and CAM. This is partly to provide manual quality control to ensure that each production stage is viable, and partly because the computing power required to deal with the number of possible permutations has not been available to harness design with production.

such as frame-welding robots, and transfer systems for parts and subassemblies. Every component is marked with the customer's name to ensure that they are correctly matched, and to identify particular work groups with customers' houses. Factory-produced elements of each house typically contain around 30 000 items, comprising 700 different component types. Sekisui House currently has more than 2 million different kinds of parts needed to satisfy all the permutations of design options in its catalogues. These are separated into 'closed' parts (those that need to be specially ordered) and 'open' parts (those that are readily available from stock).

Between 20 and 25% of the value of Sekisui's houses are produced in their factories, which make and assemble frames, wall panels, insulating materials, floors, partitions and doors, and make component kits of windows and roofs to be assembled on site. About 30% is produced by suppliers of services, fixtures and furnishings, which are usually sent directly to the site and installed by specially trained subcontractors. Site work accounts for around 20% of the value, and sales, marketing and management overheads account for 25%.

Sekisui House's Kantou factory is the largest in Japan, producing 750 houses per month, employing 500 people. Of these, 60 work on assembling small components to facilitate on-site construction: these components vary so greatly that they cannot be prefabricated using automated techniques.

Components are stored in automated warehouses, which occupy 70% of the factory site area. Transportation to site usually requires between four and six 4 ton trucks for external structural elements and two 4 ton trucks for internal components.

Sekisui Heim

This company produces modular unit housing utilizing the highest content of factory processes; products and processes are similar to those of Toyota Homes. The principle is to offer a range of standard houses, which can be customized to some extent to meet individual consumer choices. For production purposes the designs are based on modules of transportable size. Materials are processed and subassemblies manufactured in the factories and brought to assembly lines to produce the modules.

Sekisui Heim produces up to 30% of the value of each house in its factories: this includes all structural and panel work, wiring, plumbing and terminations, such as telephone, TV and video outlets. On-site work, accounting for around 10–15% of total value, involves only site preparation, joining units together (which can be done in a day) and hooking up to services. Each unit therefore requires little additional work on site. It is claimed that labour costs are reduced from 50% of total costs of the house to 25% using the modular system, compared with Sekisui House's panel system. The module method claims higher quality than panel types of prefabricated housing, although flexibility to meet wide ranges of customization, as found in Sekisui House's system, is lower.

Design is carried out in much the same way as that for Sekisui House, and there are no electronic links between CAD and CAM. Engineering design for production takes around 70 minutes per house using standard component parts. A two-part order system is used, dividing each unit into the part prepared to basic standard specifications and customized components. Specifications are standardized on parts not seen by customers, such as frames, floor, wall and ceiling panel segments. Buyer options, like those in cars, usually relate to visible elements such as colour and type of finishes. A computer-controlled production management system is used to process information required to carry out multiproduct mixed assembly on the same production line. This is known as SHIPS (Sekisui Heim Information and Production System), which includes an artificial intelligence logistics function to manage millions of permutations of component ranges. Each house is made up of around 10 000 different component types, but in order to meet the needs of consumer choice the plant holds stocks of over 270 000 components.

Each house typically consists of 12–15 units. Fabrication begins three days before units are to be placed on site, and JIT delivery systems are used to ship units to site on the day of placement. Sekisui Heim's factory in Hasuda City produces steel- and timber-frame modular units. It employs around 1 000 people, and has a capacity of 8 000 units per month – capable of producing 600 houses.

The production line operates in 24 stages, and works through orders house by house. Throughput is such that a module is completed every 3 minutes. Work begins with cutting steel members for framing the units, and continues through the zinc coating process, using technologies developed by Ford, to fabrication of the frame, including automatic arc welding by robots. Workers then install all necessary panels, windows, doors, staircases, services, bathrooms, kitchens and fittings according to detailed work schedules. Work is organized in quality circles, and utilizes the *kanban* system of JIT, similar to that found in the Japanese automobile industry.

It takes approximately 3 hours to complete one unit, and production start times can be staggered on the line such that all the units necessary for a complete house can be finished in 3.5 hours. Each unit requires a truck for transportation.

Toyota Homes

Toyota Homes produces similar types of modular unit housing to those of Sekisui Heim, using very similar production methods. The target market is to produce for slightly lower-priced housing than that produced by the Sekisui companies, but nevertheless within the middle-income/luxury executive market. Toyota's housing group trades on the experience in automobile production in terms of quality, reliability and high levels of investment in advanced manufacturing techniques.[17]

Toyota has three housing factories. Kasugai Housing Works is the largest, with a capacity output of 2 000 houses per year; its production capacity is 65 modules per day, averaging five houses per day. The factory processes around 4 000 component types for each house, amounting to around 120 000 components in total.

Learning takes place between housing and car-manufacturing divisions. The company shares and transfers production line workers between its automobile plant and its housing factory, partly to smooth out fluctuations in employment and partly to transfer expertise. The housing factory utilizes many of the production methods developed in Toyota's automobile production system, including the use of *andon* alarm lamps, *kanban* JIT and CNC machine tools. Unmanned supply vehicles are used to transport components and parts in factories, and vertical computer-controlled warehousing is used for storage. Transportation to site is by one truck per unit, and the extent of site works is similar to that required in Sekisui Heim's system.

Construction site assembly

The extent of works in site assembly depends upon the degree of prefabrication and level of customization required to be carried out by craft operatives on site to cater for buyers' choices. Some site work is unavoidable, such as demolition of existing structures if necessary, ground preparation, connection to main services and final inspection.

Control of final assembly is usually left to small construction companies, subcontracted to housing producers. The work of assembly on site remains dependent on skilled operatives, in spite of attempts to simplify designs and remove complex tasks from site-based activities. House-manufacturing companies provide training and certification of skills in an attempt to ensure quality on site. In some cases, manufacturers have considerable shareholdings in site-based assembly subcontractors. Regional branch offices are responsible for checking the quality of each assembly stage, using checklists and tests.[18]

Similarities and differences between industrialized housing and car production

The paper has so far demonstrated that Japanese industrialized housing manufacturers have attempted to produce housing using advanced techniques developed in manufacturing industries. Greatest similarities can be found in comparing modular unit housing production systems with those for automobiles – particularly in the case of Toyota, which in producing cars and houses has practised cross-industry learning. Toyota and Sekisui Heim systems exhibit similar features in manufacturing up to the final point of assembly. They are at the top of a hierarchy of industrialized and semi-industrialized housing techniques, which utilize methods similar to those used in various stages of car production.

The most important issue in both housing production and car manufacturing systems is one of balancing the trade-off between standardization – to facilitate the benefit of efficient utilization of production lines – and flexibility – to ensure that products are marketable to consumers who wish to exercise choice over a wide range of customized options. This trade-off is being met in both car and housing production through the use of standard subassemblies and 'platform' design approaches together with computerized component optimization techniques (Ward *et al.*, 1995).

Cross-industry learning has occurred between Japanese house manufacturers and other industries – chemicals, steel, materials, electrical equipment and automobiles – particularly in the central role played in managing design, engineering and development, R&D, and coordination of supply chains. The modular unit housing industry has adopted techniques developed for car production, including JIT, quality circles, the use of CNC machine tools – where appropriate – and automation of transfer and storage of parts.

But there are some significant differences between car manufacturing and industrialized housing. Car manufacturers have managed to automate a wider range

[17] It claims that its products are known in Japan for their high levels of quality and structural durability.

[18] The major housing manufacturers provide guarantees of 10 years on structural work and water tightness, and 2 years on services and finishes. Many inspect houses at regular periods after completion to obtain feedback on their products and to offer aftersales services.

of activities in their factories compared with housing producers; they have also succeeded in deploying computer-integrated manufacturing techniques (CIM), linking CAD/CAM, whereas house producers have not yet achieved this. Customer choice in some components varies to such an extent in housing that the *kanban* inventory control system cannot be applied: for example in the choice of interior finishes such as types of door, where there may be more than 300 choices available. A greater area of floorspace is given over to warehousing and storage in housing factories compared with automobiles: this is partly because housing materials are larger than those used in cars and partly because of the larger number of parts and wider range of permutations in housing units.

Some industrialized housing producers adopt a different approach to design and sales compared with car producers. Sekisui and Daiwa companies employ in-house expert design/sales staff, who also act as market researchers and ensure closer links between producers and users. They are capable of making trade-offs between customer requirements and engineering solutions for production, and this helps to satisfy wider ranges of choice in customized products.[19]

The degree of seller concentration per unit sale is higher in the housing business than in automobiles. Sales staff in the four largest steel-frame housing producers each averaged 14 sales per year in 1993. Toyota franchise sales staff were selling only five or six houses each; car sales staff usually aim for many times this figure. In modular unit housing production, the reductions in costs of manpower associated with lower on-site construction activities have been offset to some extent by increased costs of design/sales staff and advertising.

Housing producers need to cope with wider degrees of flexibility relating to customer choice, regulatory environments and local site conditions. In contrast, car producers are concerned mainly with developing flexible production systems to meet wider customer choices and more stringent regulatory frameworks.[20]

The total number of parts and permutations of assembly options in housing production is higher than in automobiles. Depending upon how parts are counted, a car is assembled from around 20 000 items, while a house may be constructed from as many as 200 000 components. Sekisui House hold around 2 million parts for one of their housing systems (Ota *et al.*, no date), but further research is required to investigate the proportion of customized components to standardized parts in housing, relating to end-product flexibility. Similarly, research is needed to explore technical complexity relating to the number of permutations of interconnections between different component parts in industrialized housing systems and the significance of this for design flexibility.

The value added by housing companies in their factories is probably higher than in automobile manufacture, where more work appears to be subcontracted to parts suppliers and fabricators. More detailed research is required in this area. In terms of the proportion of value-added, construction sites are more like final assembly plants in automobile production. The challenge for housing producers is to find innovative ways to improve performance in final on-site assembly stages, perhaps through new forms of project management.

Converging features

There appear to be converging approaches to the treatment of flexibility in industrialized housing and car production. In housing production it is recognized that some work must inevitably be carried out on site, such as foundations, connection to services, erection, and inspection. Other work is carried out on site, such as internal furnishings, because it allows housing producers greater flexibility in customizing their products. In car production, Toyota are exploring the possibilities of ‘putting-out’ customization downstream into the dealer network, where dealers install different options as bundled packages. This is similar to the approach adopted by housing producers. This issue requires further research: for example, to what extent is customer choice being met through adaptations made by car dealers at the point of sale, and how does this compare with variations catered for by using craft operatives in final assembly and finishing of factory-produced housing systems on site, at the final point of consumption?

There appear to be similarities in the ways in which Japanese car and industrialized housing producers manage their supply networks. Japanese car assemblers engage as much as possible with suppliers and their problems. The system works because a rational framework exists for determining costs, price, and profits, in which both parties can benefit from working together in a cooperative relationship (Womack *et al.*,

[19] Toyota Automobiles used a sophisticated system of senior product managers and concept creators in direct contact with customers, supplemented with market research and indirect feedback from sales staff in the franchise network.

[20] A car is usually designed to perform on standard infrastructure – a road – or to perform on and off roads. Industrialized houses have to be created in such a way that they can perform on a wide range of different site conditions – more like the off-road vehicle.

1990).[21] Firms like Toyota are large enough to influence suppliers' strategies, and they are relying increasingly on suppliers of subassemblies to carry out detailed design and development work. Japanese industrialized housing producers operate on a similar basis to their counterparts in car assembly. To some extent they exert more control over their supply chains, often owning subsidiary supply companies, managing development work in vertically integrated operations (Iwashita, 1990). This helps to achieve standardization and interchangeability of designs, necessary if a wide range of different component parts are to be assembled in an array of different permutations to satisfy customer choices. Industrialized house producers and car manufacturers have therefore secured a selection environment within which they achieve a high level of control over technical choices.

This system can be counterposed against the management of supply chains in traditional craft housing production, which are often typified by market-based, short-term interactions between independent businesses. In many traditional forms of housing construction, price, quality and contract length are the key elements of the contractor–supplier relationship, but methods of tendering usually result in a system of procurement that is solely price-driven. Suppliers are often far larger than contractors, and do not usually disclose detailed information on their internal production strategies. They maximize their ability to protect existing markets, foreclosing opportunities to develop more efficient ways of integrating systems on site in the construction/assembly stages. Traditional housebuilders are often too small to influence changes in production methods.

There are two further converging trends in production techniques in Japanese car manufacturing and industrialized housing: both are developing component selection and optimization techniques utilizing IT systems; and both are attempting to extend the use of existing component parts in the design of new model ranges.

Conclusions

This paper investigated the similarities and differences between industrialized housing and automobile manufacture in Japan. The size of Japanese housing markets and concentration of urban development over a prolonged period make it an ideal region for experimentation in different forms of housing production systems: markets have been large enough to support competing forms. This provided an opportunity for some Japanese housing manufacturers to develop high-quality mass-produced housing systems offering flexibility of design to accommodate customization. The increase in market share for this form of new housing is one indicator of its popularity among house buyers. This is in stark contrast to the main experiences of industrialized housing developed and used in Europe and North America during periods of major housebuilding in the 1960s.

Japanese industrialized housing producers appear to have learnt from other manufacturing processes, particularly in the delivery of wider ranges of customer choice. Evidence in this paper suggests that this has been achieved through managing the whole production system from supply-chain management to factory production, sales and on-site erection. It appears to involve balancing the use of standard components with flexibility in assembly, rather than solely attempting to optimize control in discrete parts of the production system.

Further performance data will be necessary to provide a deeper understanding of how the Japanese industrialized housing system works in terms of the interaction between speed of production, stock-holding levels and final delivery costs. Moreover, the relationship between standardization of parts and flexibility in the final product will need closer examination in further research and modelling, in order to explore the limits to economies of scope in industrialized housing production. This would provide an opportunity to test the extent to which provision of wider customer choice may lead to expansion in markets for industrialized housing.

Can the lessons from this experience be generalized to other construction markets? Housing is a specific type of construction activity quite distinct from other forms in terms of types of market, resource inputs and organization of the process. Industrialized housing has developed in Japan because the logic of manufacturing has been in large part appropriate for meeting market requirements in terms of volume and type of products. The proportion of manufactured inputs to industrialized housing relates to the degree of customization and complexity of managing different permutations of component varieties.

Manufacture of components and subassemblies are successfully used in many other forms of building construction: for example, in offices, schools, warehouses and agricultural buildings. The limits to the

[21] The current beneficial effects of subcontracting in manufacturing are in part due to interventions by government in the mid-1950s to legislate against unfair subcontracting practices in support of small firms (Nishiguchi, 1994, pp. 86–7). Large firms might indeed have moved down the US mass-production route had it not been for such intervention. Further research into the effects of legislation on subcontracting in housebuilding industries is required.

application of manufacturing techniques relate to the size and stability of the market, cost of transportation and ability to control and subdivide labour on dispersed sites where final assembly takes place. These limits are reached earlier in highly bespoke or customized projects, in which complex technical issues need to be resolved by skilled engineers, managers and technicians on site.

The larger, more complex and more bespoke construction activities become, the more they require coordination of inputs from a wide variety of sources to produce customized products. The hierarchy of project complexity therefore relates directly to industrial structure: as complexity increases so too does the project-based and high-technology craft-based nature of the production activity (Miller *et al.*, 1995). In these markets, firms build their businesses on the provision of specialized management skills and resources, which often rely upon expertise accumulated over many years. But learning processes are usually informal, with many breaks in feedback up- and downstream and to other parts of the industry. Capital intensity in the construction phase remains generally low. The contractual nature of project work, which must usually precede orders, means that firms are to an extent unable to gain some of the benefits of centralized and planned production enjoyed by many large firms in manufacturing. Furthermore, fluctuations in demand are a disincentive to substantial investment in new technologies by contractors. In consequence, construction firms are often the recipient of technical innovations developed by scale-intensive manufacturers of component systems (Pavitt, 1984, p. 355; Gann *et al.*, 1992). Nevertheless, this study illustrates the value in cross-industry learning, and just as construction has adopted techniques from other manufacturing industries, so too can knowledge, particularly about project-based management and engineering, be of value in a wide range of manufacturing firms.

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