The geography of lean manufacturing: Recent evidence from the U.S. auto industry

Thomas H. Klier

Since lean manufacturing was pioneered by Toyota Motor Company in the 1950s, it has become the standard practice of many Japanese manufacturing companies. During the last decade American manufacturers started to adopt it in order to compete effectively at home and abroad, and it is fast becoming the standard in manufacturing plants across the country. Lean manufacturing is characterized by an emphasis on product quality, an integrated approach to the various aspects of manufacturing, reliance on subcontractors to produce a greater proportion of the value added, and an emphasis on speed in order processing, production, and delivery. One central feature of the system is the tiering of the supplier structure, which greatly reduces the number of companies the assembler deals with directly. Another feature is close relationships and frequent interactions between assemblers and suppliers.[1]

It has been argued that efforts to reduce inventory stocks and arrange for "just-in-time" delivery function most effectively when the supplying and receiving plants are in reasonably close proximity.[2] The concomitant increase in the frequency of interaction and communication between assembler and supplier companies is expected to strengthen that effect further.[3] On the other hand, there is some evidence that spatial clustering is not a necessary condition for the successful operation of lean manufacturing.[4] The question to what extent the arrival of lean manufacturing has altered the geography of supplier networks has not been definitively answered.[5] The answer will have implications for regional development efforts. Proponents of the spatial clustering hypothesis argue for a just-in-time-based local and regional development strategy.[6] Such an approach was apparent during Mercedes' recent search for an assembly plant site in North America. Alabama offered major tax breaks to the company, apparently on the assumption that the assembly plant would attract a fair number of its supplier plants to locate nearby.[7]

This article attempts to shed new light on the spatial effects of lean manufacturing by examining the emerging geographical structure of lean manufacturing supplier networks in the auto industry, often highlighted for its bellwether role in the adoption of the new manufacturing system. First, I present an overview of previous studies. This is followed by a detailed analysis of the U.S. supplier networks of eight auto assemblers located in the United States. While some of these networks have been the subject of previous research, this article goes beyond the existing literature by investigating both domestic and transplant suppliers and by identifying both the tier and the age of individual supplier plants.[8] The evidence of emerging supplier location patterns is discussed both at the sample and assembly plant level. Conclusions follow in the final section.

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Review of previous evidence

As one of the most important and most visible manufacturing industries, the automobile industry has been of interest to economic geographers for some time.[9] Since the arrival of lean manufacturing by way of Japanese transplant assembly and parts facilities in North America, questions have been raised about its impact on the existing spatial structure of manufacturing. In Japan, auto assembly and parts production are heavily concentrated in the core industrial regions of Tokyo-Yokohama, the Nagoya region, and to a lesser extent, the Osaka area. Three factors are cited as an explanation for this concentration: "urban-industrial agglomeration factors stemming from the dependence of the auto and other assembly-type industries on a wide range of parts, components, engineering processes and labor skills; ready access to the largest domestic markets; and access to port facilities for interregional and export shipment."[10]

Evidence from other industries and other countries indicates that the magnitude of the effect of lean manufacturing on location varies by industry and by country.[11] For example, a recent analysis of 71 auto parts plants in nine countries suggests that the degree of dispersion of a country's supply base is partly a function of the country's size.[12] Japan's auto industry is characterized by the most geographically concentrated supply base, with 82 percent of the suppliers located within a four-hour journey by truck from the assembly plant. In contrast, the percentages for the U.S., U.K., and Germany are 35, 53, and 52, respectively. Sadler (1994) studied parts purchasing at several Japanese assembly plants in Europe and found that Japanese transplants in Europe "placed far greater emphasis on working with an existing supplier base in Europe than on encouraging rapid transnationalization of the Japanese components industry." At the same time, they were implementing the familiar mix of lean manufacturing production and procurement practices.[13]

Did the arrival of lean manufacturing in North America lead to a similarly compact spatial structure? To understand the existing structure of the U.S. auto supplier industry, one must first distinguish between so-called captive and independent suppliers. Among the Big Three, the distribution of captive suppliers (that is, suppliers that are Big Three subsidiaries or divisions) varies by assembler. Even today, however, these suppliers generally remain located in the upper Midwest.[14] For example, Ford historically operated within a highly centralized model of production with clusters in Detroit and Dearborn; today the company's parts operations are mostly clustered in southeastern Michigan and northern Ohio. General Motors, on the other hand, started out with multiple centers of operation in Michigan (Detroit, Flint, Lansing, and Pontiac), and soon afterward expanded its parts operations into other, predominantly midwestern states, mainly by acquiring independent supplier companies. Before World War II, the company's captive suppliers were largely clustered in the southern Great Lakes region. Since then, GM has pursued a policy of spatial division of labor. Products requiring relatively skilled workers, such as engine and drivetrain components, have remained concentrated in the southern Great Lakes region. Lower-skill tasks, such as much of the manufacturing of electrical components, have been relocated to the south.[15]

As lean manufacturing has increased the degree of outsourcing, the more interesting question is how the location pattern of independent supplier plants has been evolving. Historically, parts suppliers have been clustered in southeastern Michigan and the adjacent southern Great Lakes states.[16] A significant change in the observed location of independent suppliers occurred during the 1970s, when a noticeable number of supplier plants moved southward into Kentucky, Tennessee, Alabama, Georgia, Virginia, and North Carolina.[17] These relocations were related to location decisions of auto assembly plants. For example, during the 1970s GM, in search of lower-cost nonunionized labor, built or planned fourteen plants in the south, primarily in rural areas of small towns.[18]

The latest development influencing the location decisions of suppliers has been the arrival of lean manufacturing in North America, generally dated around 1980 when the first Japanese transplant assembly facilities opened. Early evidence indicates the emergence of a structure in which supplier plants locate closer to their assembly plant customers than under the previous system of mass production.[19]

A set of recent studies investigates the effect of lean manufacturing on the spatial structure of independent supplier plants in the United States. Rubenstein and Reid (1987) and Rubenstein (1988) analyzed data for the state

of Ohio. They could not identify a clear-cut effect of lean manufacturing on supplier plant location, yet they did find a change in the locational pattern after 1970. New firms were more likely to locate in the state's rural counties and the central region, and less likely to locate in northeastern Ohio.

Most of the existing analyses of the location effect of lean manufacturing, however, concern Japanese-owned suppliers within the United States. This is not surprising, as these plants were generally set up to meet the demands of lean manufacturing assemblers. In addition, most of them are new plants established at so-called greenfield sites, which makes them a preferred object of study.[20] Studies of these plants consistently find a concentration of Japanese suppliers in a region encompassing Michigan, Indiana, Ohio, Kentucky, and Tennessee, commonly referred to as the I-75/I-65 auto corridor because it is defined by those two interstate highways. At the local level, suppliers are dispersed to avoid their drawing from the same labor market.[21] From the perspective of the southern Great Lakes states, it seems that the arrival of lean manufacturing reversed the trend toward regional decentralization that started in the early 1970s. However, the sites chosen by transplants were not traditionally associated with motor vehicle assembly or parts production. Accordingly, a complex pattern of industrial growth and decline emerged in the Midwest.[22]

The data

"Mapping the spatial distribution of parts suppliers at one point in time, let alone changes, is a formidable task."[23] The *Census of Manufactures* can offer only incomplete information, because it distinguishes neither between original equipment manufacturers and producers of replacement parts nor between different tiers of suppliers. In addition, because of the large variety of parts that make up an automobile, suppliers are classified in 18 of the 20 two-digit SIC categories. Finally, census data provide no information about linkages between suppliers and their customers.

The data used in this study come from the ELM GUIDE database on the auto supplier industry, produced by a company in Michigan.[24] The data available for analysis represent the year 1993 and cover 2,477 supplier plants located in the United States. As a first step I grouped the plants by tiers. Of the total, 1,383 plants were tier 1 suppliers, that is, they ship their products exclusively to auto assembly plants and not to other suppliers or other customers; 373 were "mixed" plants, that is, they ship also to other supplier plants and/or nonautomotive assemblers; 721 plants had to be excluded from the analysis as they did not provide information on which customer(s) they shipped to.[25]

As the customer information in the ELM database is provided at the company rather than plant level, I focused on the set of auto assemblers that operate only one plant, or plants at only one location, in the U.S. in order to be able to establish linkages between assembly and supplier plants; 511 (37 percent) of the 1,383 identifiable first-tier supplier plants ship to these 9 assembly plants (see table 1).[26] I then added several variables to the database. Information on start-up year of the supplier plants was obtained from various state manufacturing directories; information on Japanese ownership was obtained from a publication of the Japan Economic Institute.[27] The start-up date for 41 plants in the sample could not be identified from state industrial directories. I sent these plants a questionnaire to obtain the missing information. Of the 20 returned questionnaires, 16 indicated plants that were still operational. Therefore, the number of observa-

TABLE 1

Assembly plants in study

	Location	Start-up year
Honda	Marysville, OH	1982
Honda	East Liberty, OH	1989
Nissan	Smyrna, TN	1983
NUMMI (GM-Toyota)	Fremont, CA	1984
AutoAlliance (Ford-Mazda)	Flat Rock, MI	1987
Diamond-Star (Mitsub.-Chrysler)	Normal, IL	1988
Toyota	Georgetown, KY	1988
Subaru-Isuzu	Lafayette, IN	1989
Saturn	Spring Hill, TN	1990

Source: Ward's Communications (various years).

TABLE 2

Top seven states for tier 1 supplier plants

	% of total plants (1,383)			% of sample plants (486)	
Michigan	25.6		Michigan	20.4	
Ohio	13.6		Ohio	15.8	
Indiana	10.6	Top 3: 49.8%	Indiana	10.7	Top 3: 46.9%
Illinois	6.8		Tennessee	10.3	
Tennessee	5.9	Top 5: 62.5%	Kentucky	8.2	Top 5: 65.4%
Kentucky	4.0		Illinois	6.0	
North Carolina	3.5		North Carolina	3.3	

Source: ELM International, Inc. (1993) and author's calculations.

tions for the following analysis is 486. The resulting data allow for a comparison of more recent location decisions with older ones that were presumably not influenced by lean manufacturing. However, this is not equivalent to a time-series analysis since the sample only contains plants operating during 1993 and none that were shut down in earlier years.

Where do plants locate? The spatial pattern of the sample

It is interesting to relate the geographic distribution of the sample to the population of tier 1 supplier plants. Table 2 shows that the sample plants were slightly more concentrated in five states and were located to the south of the population of identifiable tier 1 plants. Michigan, the most frequent location choice among the 486 plants in the sample, was less dominating in the sample than in the identifiable population of tier 1 supplier plants, while Ohio, Tennessee, and Kentucky each attracted a higher share of sample plants. This pattern is not surprising, as the assemblers for which linkages to supplier plants could be established were located to the south of the traditional assembly plant region. Nonetheless, on the whole the sample was geographically distributed quite similarly to the overall distribution of total identifiable tier 1 supplier plants.

Since the sample plants were identified by start-up year and by affiliation with a Japanese company, it was possible to assess the location pattern by age of plant and plant ownership. Because transplant assemblers started operating in the U.S. as early as 1982, I chose 1980 as the cutoff year to compare location patterns before and after the implementation of lean manufacturing techniques.[28] Table 3 shows that about 42 percent or 203 of the 486 supplier plants were established before 1980; the vast majority of them (187) were domestic. The

TABLE 3

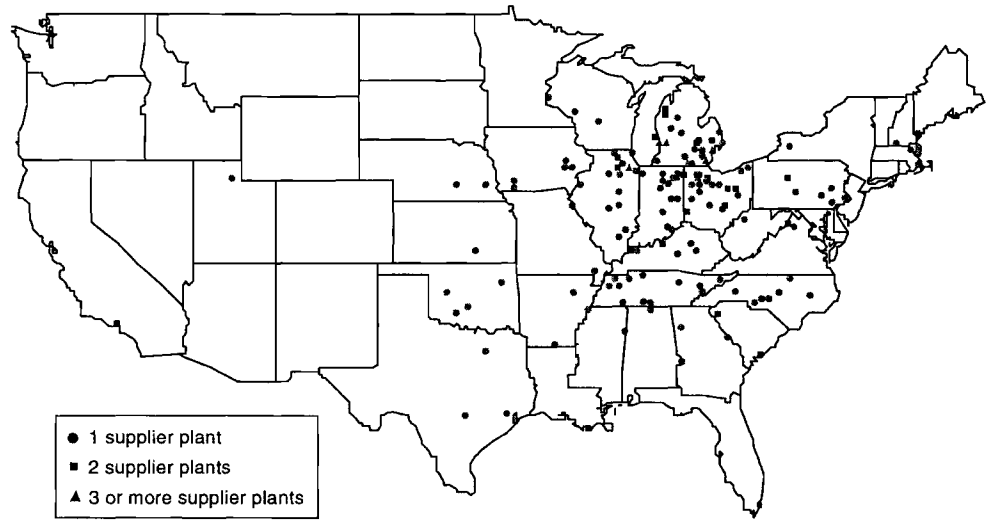
Location of sample plants

	Established prior to 1980 (203)		Established 1980 or later (283)	
	Domestic (187)	Transplant (16)	Domestic (118)	Transplant (165)
Michigan	26.7%	25.0%	25.4%	9.1%
Ohio	15.5	6.3	9.3	21.8
Illinois	8.0	25.0	3.4	3.6
Indiana	7.0	6.3	13.6	13.3
Tennessee	5.9	6.3	12.7	13.9
Kentucky	4.3	0	4.2	16.4
California	0.5	6.3	2.5	4.2
Largest 3	50.2	56.3	51.7	52.1
Largest 5	63.1	68.9	65.2	74.5

Source: ELM International, Inc. (1993) and author's calculations.

FIGURE 1

Tier 1 supplier plants established prior to 1980 (203)



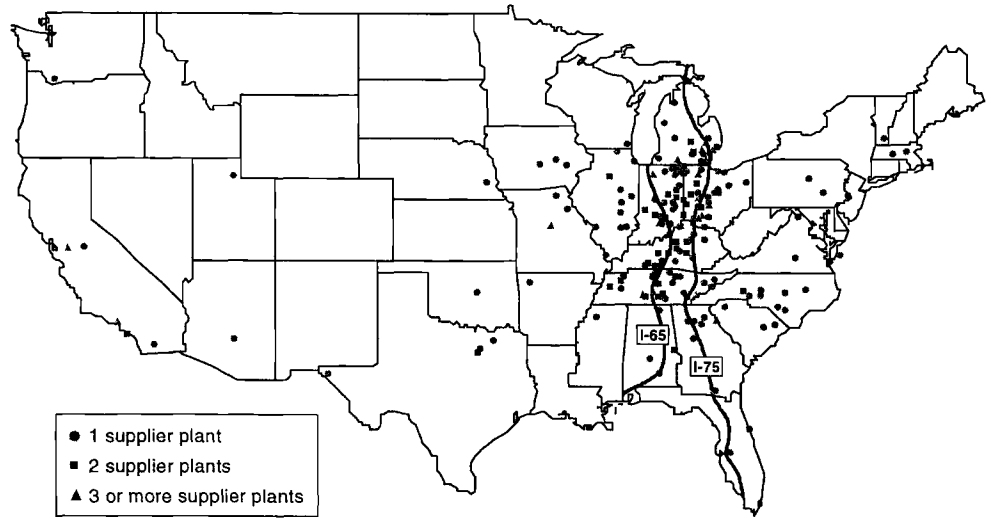
location pattern of those 203 followed very closely the distribution shown in table 2 (see also figure 1). Too few transplant supplier plants were established prior to 1980 to show any discernible pattern. Figure 2 shows a remarkably different location pattern for tier 1 plants established since 1980. Most pronounced is the development of the so-called auto corridor, a rather compact and densely populated area stretching north-south along I-75 and I-65.[29]

To what extent does this auto corridor represent locational choices of transplant and domestic supplier plants, respectively?

Dividing the sample by age of plant revealed two very interesting findings. First, compared with their older counterparts, post-1980 domestic plants were located more to the

FIGURE 2

Tier 1 supplier plants established 1980 or later (283)



southeast. Ohio and Illinois lost considerable share, while Indiana and Tennessee became more frequent location choices. However, the overall concentration in the top three and top five states hardly changed.[30] These findings are displayed in figures 3 and 4. The most striking contrast, however, is between recently established domestic and transplant suppliers (see figures 4 and 5). First, the number of transplant suppliers increased dramatically after 1980 (see table 4). Furthermore, 75 percent of the 165 transplant suppliers opened since 1980 located in only five states—Kentucky, Ohio, Tennessee, Indiana, and Michigan—a higher proportion than any other subset of the sample.[31] The aggregate picture in table 3 and figures 1 through 5 reveals the leading role played by the transplants in establishing a different location pattern in the U.S. auto supplier industry. In addition, there is evidence, albeit to a smaller extent, for a changing location pattern among domestic suppliers since 1980.[32]

Table 3 and figures 1 through 5 contain two additional interesting pieces of information. First, among the traditional auto states, Michigan stands out for remaining the preferred location of domestic supplier plants, even after 1980. One possible explanation is a stronger orientation of domestic suppliers to the Big Three as customers.[33] In addition, the data suggest that certain characteristics of a plant's output seem to influence its location decision. For example, the production of sensors (such as airbag or temperature sensors), a lightweight electronic part, is widely dispersed, with a noticeable number of plants in California and adjacent states. On the other hand, the production of seats—a part that involves various levels of subassembly including frames and upholstery, and is consistently quoted in the automotive press as one of the parts delivered to assembly lines by the hour—is concentrated within the automotive corridor, close to the

TABLE 4

Transplant auto supplier start-ups

	Number of facilities
1981	1
1982	5
1983	6
1984	5
1985	13
1986	25
1987	50
1988	67
1989	40
1990	17
1991	2

Source: McAlinden and Smith (1993).

FIGURE 3

Domestic tier 1 supplier plants established prior to 1980 (187)

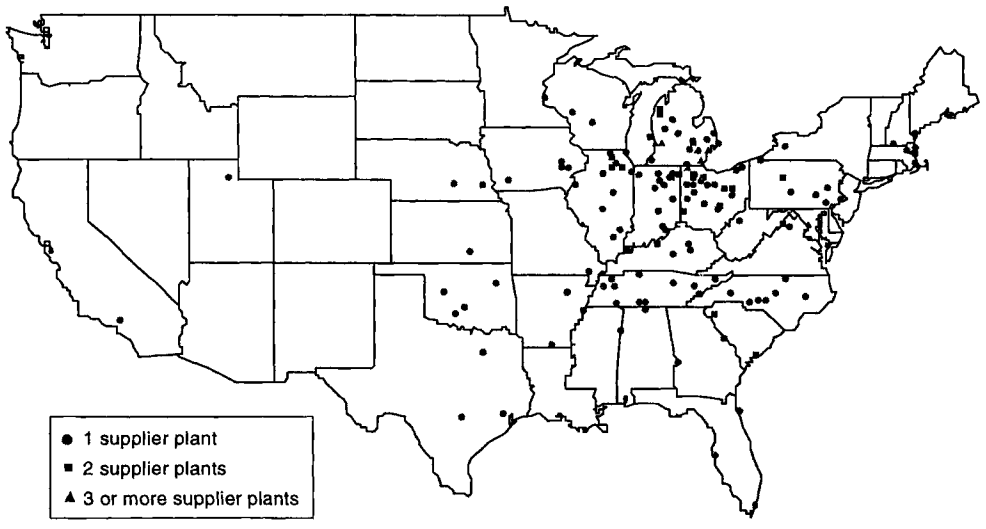
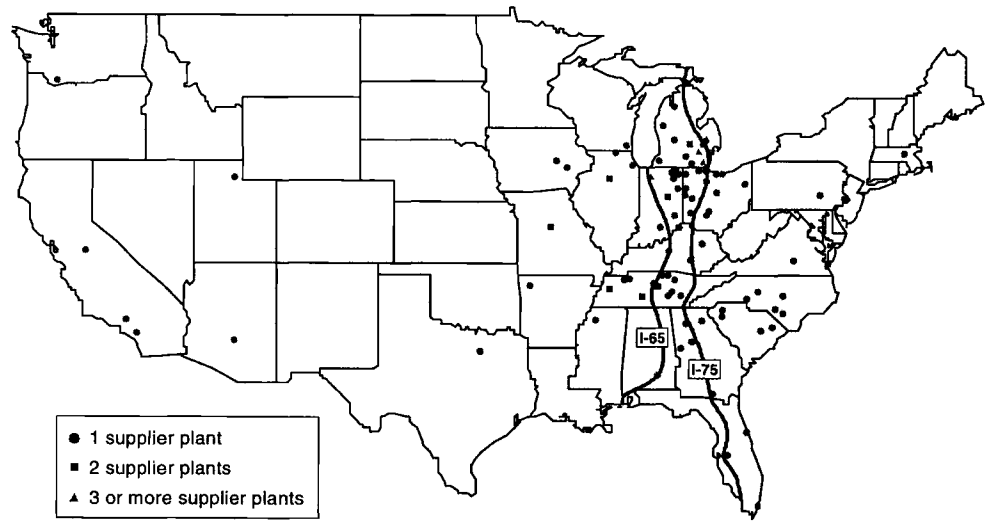


FIGURE 4

Domestic tier 1 supplier plants established 1980 or later (118)



assembler customers.[34] The recently opened domestic plants in Michigan tend to be concentrated in the production of interior body system parts and components as well as body components and trim (including parts such as instrument panels, dashboards, and relatively heavy items such as hoods and doors). Comparing the product classifications of older and younger domestic plants in Michigan, one finds a reduction in the start-up of plants producing engines and engine components since 1980, especially parts such as exhaust and intake manifolds and crankshafts.

Second, several new plants located outside the I-75/I-65 corridor after 1980. Since the data set available for this study does not include information on production level and/or customer-specific shipments, it was not possi-

FIGURE 5

Transplant tier 1 supplier plants established 1980 or later (165)

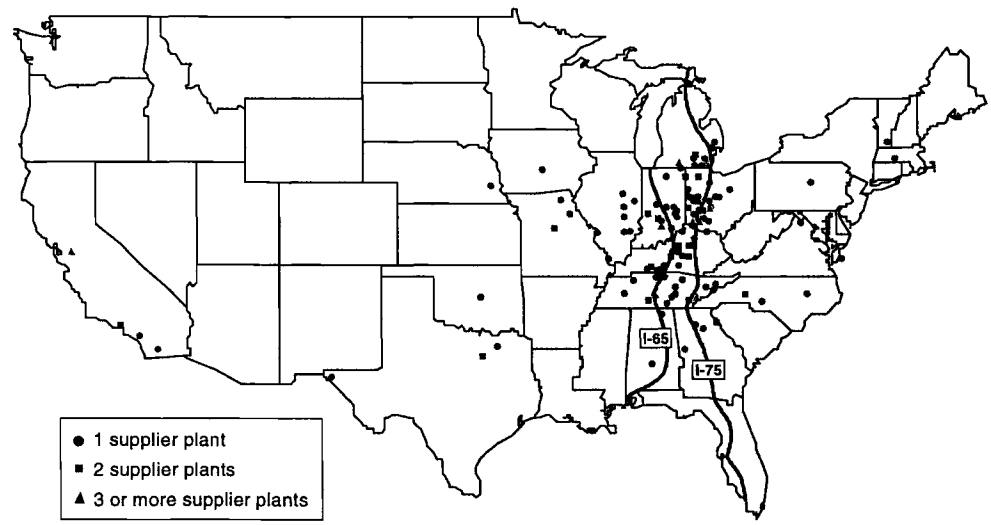
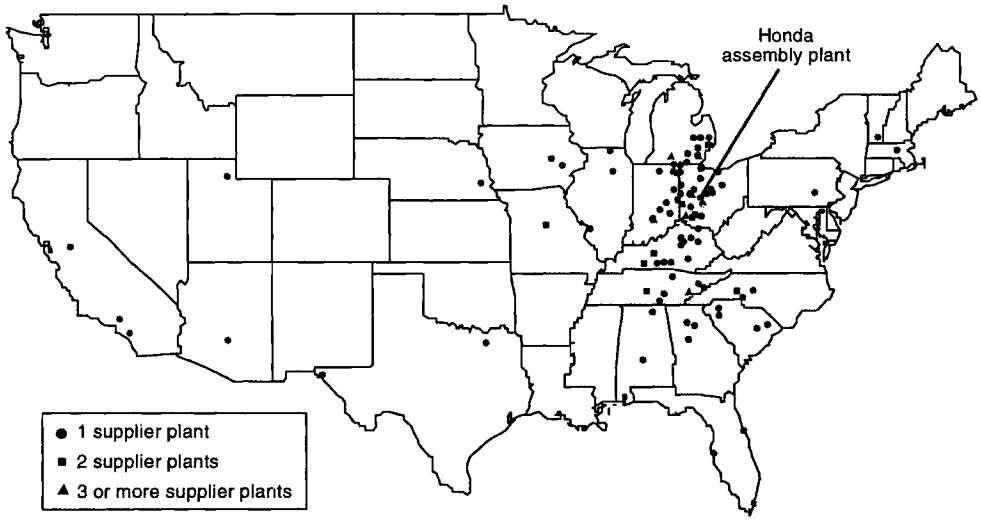


FIGURE 6

Honda's tier 1 supplier plants established 1982 or later (122)



ble to test whether those plants rely more heavily on nonautomotive business.[35]

Who is closer? An analysis of four supplier networks

A closer look at the tier 1 supplier networks of specific assembly plants provides a more detailed picture of the changes in the location pattern of those suppliers during the 1980s. There is a striking difference between the pre-1980 and post-1980 location patterns similar to that observed among total sample plants. However, the analysis in this section will concentrate on suppliers that opened no earlier than the year during which their respective assembly plants started operating. This focus enables us to isolate the effect that lean manufacturing assembly had on the location of

FIGURE 7

Nissan's tier 1 supplier plants established 1983 or later (106)

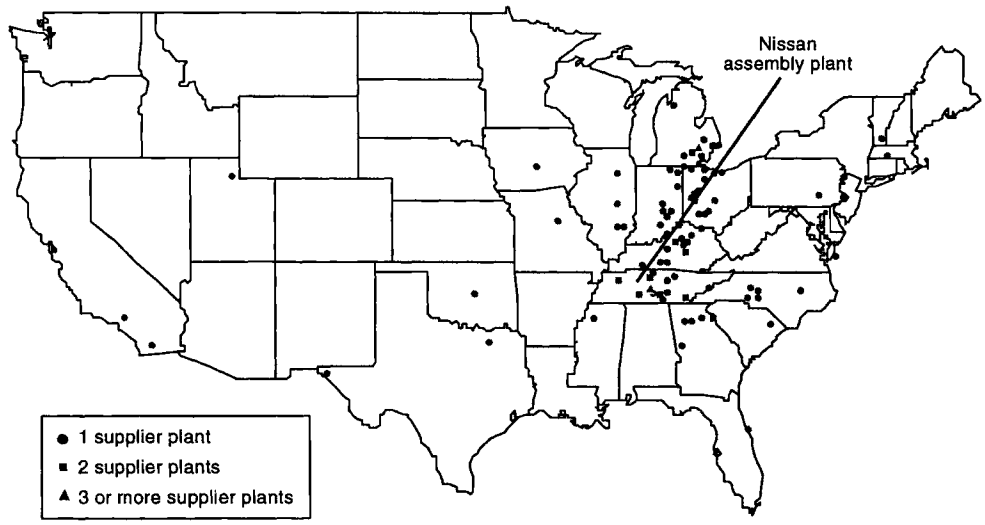


TABLE 5

Average distance between supplier and assembler
(suppliers that opened after assemblers)

Assembler	Network average	Domestic suppliers	Transplant suppliers
	(----------miles----------)		
Honda	287	399*	244*
Nissan	317	360	287
AutoAlliance	359	371	353
Toyota	325	466**	237**

*Difference significant at the .10 level.
**Difference significant at the .05 level.
Sources: ELM International, Inc. (1993) and author's calculations.

suppliers.[36] As one cannot directly compare the pre- and post-1980 location patterns, this section presents statistical evidence on a related question: For the four transplant assembly plants analyzed, do both domestic and transplant tier 1 suppliers make similar location decisions?

First, the locations of these assemblers' tier 1 suppliers produce very similar images (see figures 6 through 8). While the networks include more post-1980 plants the longer the assembly plant has been in operation, they are all focused on the I-75/I-65 auto corridor, whether the assembly plant is located in the center (like Honda in Ohio), at the northern end (like AutoAlliance in Michigan), or the southern end (like Nissan in Tennessee) of that region.

Second, a comparison of domestic and transplant suppliers shows that transplants are typically somewhat closer to their assemblers than are domestic suppliers (see figures 9 through 12). However, even the latter locate in a noticeable network pattern in relation to the various assemblers in the sample. By calculating the distance between each supplier plant and the assembly plant for each of the four networks, I formally tested for differences in the location decisions of domestic and transplant suppliers.[37] Table 5 shows the average distances between the individual suppliers and their respective assemblers in the sample. A test of the similarity of the location pattern showed a significant difference between the average distances of domestic and transplant suppliers in two of the four networks.[38] Domestic suppliers that opened after the start-up of their respective assemblers were consistently located farther away than the transplant suppliers of comparable vintage.[39] This is a surprising result, as it indicates significant differences in the location effects of lean manufacturing on transplant and domestic suppliers. It is conceivable that more of the customers of domestic suppliers than transplant suppliers are located in the traditional auto region, which would explain the larger average distances to the three transplant assemblers located in the auto corridor. As the location of the Big Three assembly plants is not identified in the database, only indirect ways of testing that explanation remain. When one excludes AutoAlliance, the Mazda-Ford joint

TABLE 6

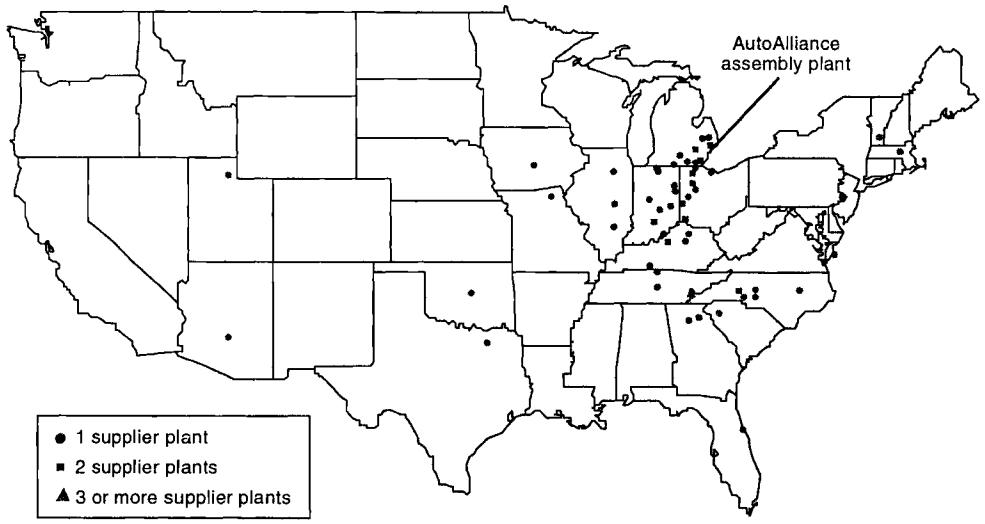
Supplier plants by distance to assembly plant
(suppliers that opened after assembler)

	Honda		Nissan		AutoAlliance		Toyota	
Distance in miles	D	T	D	T	D	T	D	T
0–50	5.9	19.3	2.2	1.6	17.4	6.4	5.5	6.9
51–100	8.8	17.0	13.6	8.0	21.7	10.6	0	20.7
101–200	29.4	27.3	4.5	38.7	17.4	10.6	11.1	37.9
201–400	26.5	21.6	40.9	33.9	4.3	29.8	66.7	20.7
401–800	20.6	10.2	36.4	12.9	26.1	36.2	5.5	10.3
> 800	8.8	4.5	2.2	4.8	13.0	6.4	11.1	3.4

Note: D = domestic; T = transplant.
Sources: ELM International, Inc. (1993) and author's calculations.

FIGURE 8

AutoAlliance's tier 1 supplier plants established 1987 or later (70)



venture in Flat Rock, Michigan, and its suppliers, the percentage of tier 1 suppliers shipping only to non-Big Three assembly plants is more than twice as large for transplants as for domestic suppliers.[40] However, when one focuses on the subset of suppliers not shipping to the Big Three, the average distances for *both* transplant and domestic suppliers are lower than those listed in table 5.[41]

Table 6 presents more detailed information on the distribution of supplier plants around specific auto assembly plants. It suggests that the statistical differences in table 5 are driven by differences in the number of suppliers that locate very close to the assembler. A somewhat smaller share of domestic than transplant suppliers locate very close to the assembler (see table 6).[42] A large share of both Honda's

FIGURE 9

Honda's domestic tier 1 supplier plants established 1982 or later (34)

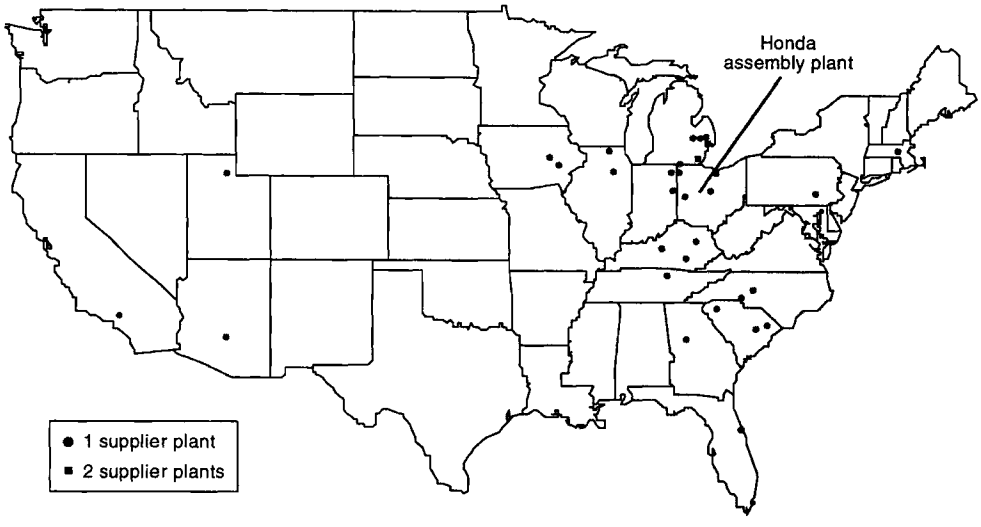
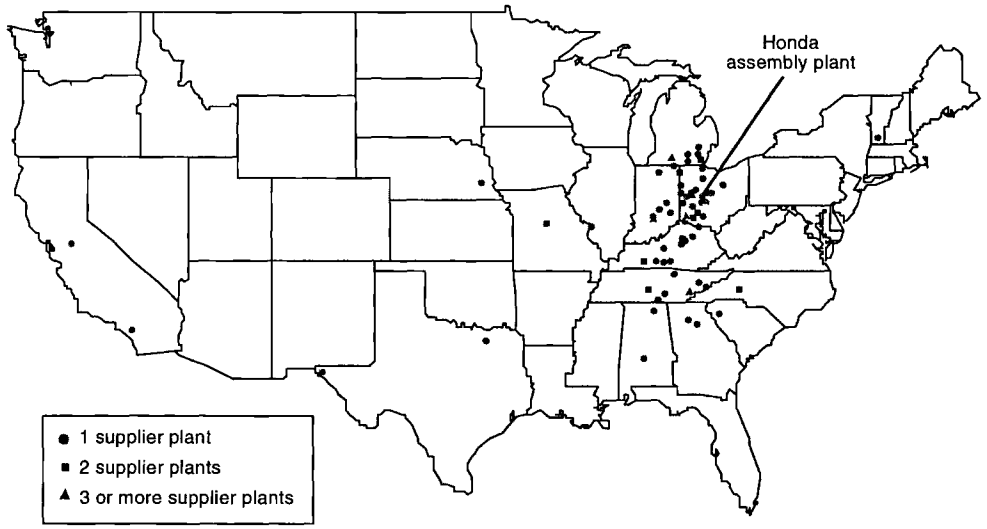


FIGURE 10

Honda's transplant tier 1 supplier plants established 1982 or later (88)



and Toyota's transplant tier 1 suppliers are located within 100 miles (two hours' driving time) of the assembly plant (36.3 percent and 27.6 percent respectively, compared with 14.7 percent and 5.5 percent of Honda's and Toyota's domestic supplier plants). In the case of AutoAlliance, about two-thirds of its domestic tier 1 suppliers that opened plants after AutoAlliance started operating chose to locate in southeastern Michigan and northern Illinois, Indiana, and Ohio. Accordingly, table 6 shows that about 40 percent of its domestic supplier plants are located within 100 miles of the assembly plant. The statistical test produced no evidence of a significant difference between the average distances of AutoAlliance's domestic versus transplant suppliers.

FIGURE 11

Toyota's domestic tier 1 supplier plants established 1988 or later (18)

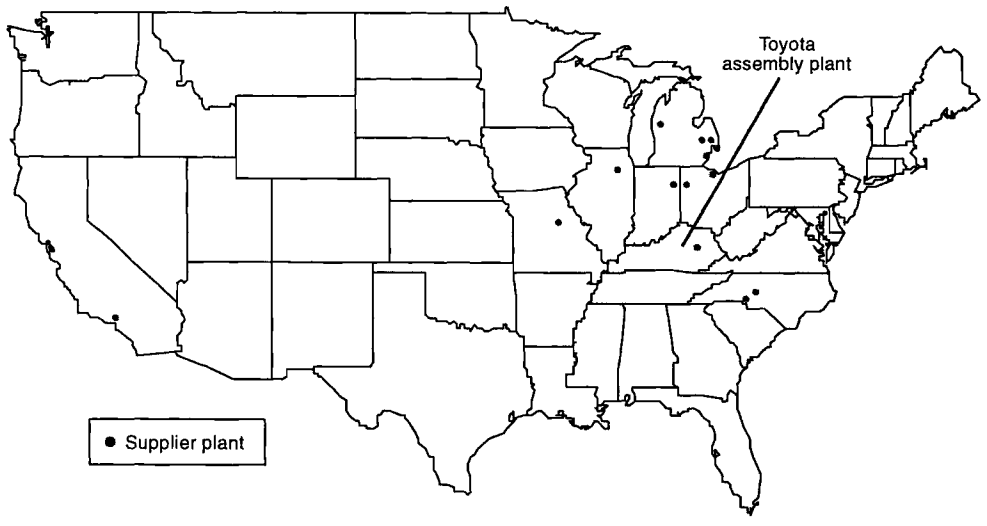
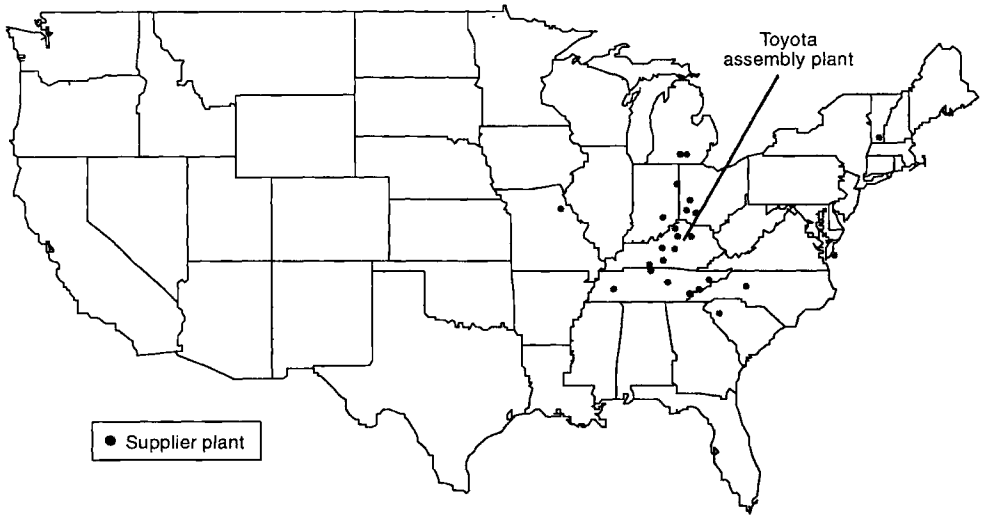


FIGURE 12

Toyota's transplant tier 1 supplier plants established 1988 or later (29)



Summary and conclusion

Lean manufacturing has been implemented in the American manufacturing sector for some time now. While there is agreement that this has raised productivity at the assembly plant level, it has not been clear what effect it has had on the geographic distribution of the supplier base. By refining a commercially available database, I was able to examine the supplier networks of some recently opened auto assembly plants located in the United States, focusing in particular on the spatial relationship between assemblers and their tier 1 suppliers. While I could not test changes in the spatial patterns of Big Three suppliers during the last decade, I have presented some new information on a set of mostly transplant assembly plants and their suppliers. This information affords a better understanding of the evolving geography of lean manufacturing.

Earlier findings about a movement of supplier plants toward the I-75/I-65 automotive corridor were confirmed. In addition, by distinguishing the age and ownership of the plants in the sample, this study found that since 1980 the majority of newly established tier 1 supplier plants that ship to at least one of the assemblers in the sample chose to locate within the so-called automotive corridor. The data show the establishment of transplant supplier plants to be the main force in shaping a new geography in the supplier industry. While domestic suppliers were found to have located in the I-75/I-65 corridor as well, their average distance to the assembly plants in the sample is significantly larger. In addition, the data indicate that there are agglomeration effects in the automotive corridor and that the type of output produced also influences the location chosen.

The implications of these findings for regional development policy are neither clear-cut nor simple. While the evidence suggests the establishment of a new geography in the U.S. auto supplier industry, it is clear that that industry will not be nearly as geographically concentrated as it is in Japan.[43] Thus a state's ability to attract an assembly plant does not necessarily mean that a significant number of suppliers will set up shop nearby.

In further research on this topic, I will extend the analysis to the supplier networks of Big Three assembly plants and will apply formal location models to the data on hand. It would also be very interesting to obtain additional information for the sample plants, such as the location of the plant of the primary assembly customer.

NOTES

[1]The importance of supplier networks is featured in a recent study on lean manufacturing in the auto industry (Andersen 1994) which suggests the management of the supply chain to be one of the key competitive factors. See also Bennet (1994) and Klier (1994). Rather than coordinating its entire supplier structure, an assembler prefers to deal directly with only a small number of supplier companies, referred to as tier 1 suppliers.

[2]Estall (1985), Kenney and Florida (1992), Mair (1992), and Dyer (1994).

[3]See Helper (1991) on the increased frequency of communication.

[4]See, for example, Glasmeier and McCluskey (1987), Reid (1995), and the references cited therein.

[5]See, for example, Mair (1992) and Erickson (1994). The issue is complicated by the fact that location patterns, once established, tend not to change over a short period of time, as they involve decisions with relatively long time horizons. See, for example, Ondrich and Wasylenko (1993) for a formal treatment of the location decision and Krugman (1991) for an explanation of the influence of history on the spatial pattern of economic activity.

[6]For example, Mair (1993).

[7]Cooper and Ruffenach (1993).

[8]Automobile assembly and component plants that are fully or partly owned by foreign companies are generally referred to as transplants. For the purposes of this study, the defining characteristic distinguishing transplant from domestic suppliers is the ownership of the plant, not its customers.

[9]See Henrickson (1951), Boas (1961), and especially Rubenstein (1992) for a historical overview of the geography of the U.S. automobile industry.

[10]Sheard (1983).

[11]See, for example, Angel (1994), Jones and North (1991), and Schampp (1991).

[12]Andersen (1994).

[13]Sadler (1994) suggests that the resulting smaller increase in spatial proximity is due to the relatively fragmented market for cars, supporting a range of independent automotive companies, prior to the arrival of Japanese transplants.

[14]McAlinden and Smith (1993); Miller (1988).

[15]Rubenstein (1992).

[16]Rubenstein (1992); Henrickson (1951).

[17]Glasmeier and McCluskey (1987).

[18]"Four were built in Mississippi, three in Louisiana, two each in Alabama and Georgia, and one each in Oklahoma, Texas, and Virginia" (Rubenstein 1992, p. 238). According to Rubenstein (1992), the proliferation of different models since 1960 led to a fragmentation of the market for passenger cars and reduced the need for branch assembly plants, that is, plants producing identical models at centers of demand for regional distribution. That resulted in a fair amount of restructuring at the assembly plant and, consequently, at the supplier plant level.

[19]In his study on the North American auto industry, Miller (1988) finds that the introduction of new supply philosophies has shifted suppliers slightly closer to assemblers.

[20]See Glassmeier and McCluskey (1987), Mair *et al.* (1988), Rubenstein (1992), Woodward (1992), and Mair (1994).

[21]See Mair *et al.* (1988).

[22]Rubenstein (1992); Klier (1993).

[23]Rubenstein (1992).

[24]ELM (1993), the ELM GUIDE supplier database. This database includes, among other things, the addresses of the supplier plants, a listing of each plant's customers, and a very detailed classification of products produced and materials used.

[25]It is difficult to accurately assess the coverage of this database, since the size of the true population is unknown. However, anecdotal evidence on Honda (Mair 1994) and Nissan (Bennet 1994) indicates reasonably good coverage of the tier 1 supplier plants. Furthermore, the information obtained from the ELM database is qualitatively consistent with previously published accounts (see Mair *et al.* 1988, Kenney and Florida 1992, Rubenstein 1992, and Mair 1994). Therefore I do not expect the results to be biased.

[26]The nine assembly plants were all opened after 1980 and were mostly transplants. Ideally one would like to investigate the supplier networks of all U.S. assembly plants opened after 1980 and compare them to pre-lean manufacturing patterns. However, geographic linkages between assemblers and suppliers at the plant level were available only for the eight assemblers listed in table 1. In addition, I could find no comparable information on pre-1980 supplier networks. As Honda's two Ohio assembly plants are only about 15 miles apart, I treated them as one site.

Eight Big Three assembly plants have been opened since 1980: GM's plants in Orion Township, MI; Bowling Green, KY; Fort Wayne, IN; Wentzville, MO; and Hamtramck, MI; and Chrysler's plants in Detroit, MI (Mack Ave. and Jefferson Ave.), and in Sterling Heights, MI. Almost all of these are in the traditional assembly region of the lower Great Lakes states (see Boas 1961). Also excluded from the study were the 20 pre-1980 U.S. car assembly plants of the Big Three that were in operation during 1993. (See *Ward's Automotive Yearbook*, various years.)

Because of the weak coverage of "mixed" plants, I excluded that segment from further analysis.

[27]Japan Economic Institute (1992).

[28]Glassmeier and McCluskey (1987) compared "recently built" facilities with the overall pattern of auto parts production. However, in their study they do not indicate the time frame used to define these plants. Moreover, from the 17 observations they had in the "recently built" category, the authors can only speculate as to possible implications.

[29]See Mair *et al.* (1988).

[30]As recently as 1988, Miller found no evidence of a noticeable shift in parts-making activities (Miller 1988).

[31]Ohio experienced both a very significant decrease in the percentage of domestic plant openings and a dramatic increase in the percentage of transplant plant openings since 1980. This makes Ohio a very interesting case study (see Rubenstein and Reid 1987).

[32]Given the nature of the sample, I could obtain no evidence on possible changes in the location patterns of the networks of Big Three assembly plants. In addition, the smaller effect of location changes among domestic tier 1 suppliers might well be related to the extent that transplant assembler plants resemble secondary customers of these supplier plants. However, information to support this claim is currently not available. See the following section for evidence of spatial patterns of domestic supplier plants at the network level.

[33]Of the 118 domestic supplier plants opened since 1980, only 13.6 percent had no Big Three companies listed as customers. That compares to 36 percent of the 165 transplant supplier plants that opened during the same time period (see ELM

1993). However, the lack of information on the relative importance of a supplier plant's customers prevents a more detailed look at that issue.

[34]Of the 1,383 tier 1 plants identified in the database, 38 list sensors as one of their products. Only 39 percent of these plants are located in the five automotive corridor states, Michigan, Indiana, Ohio, Kentucky, and Tennessee. By comparison, 10 of the 13 seat plants are located in the automotive corridor.

[35]In terms of the type of parts produced, no particular group dominates the recently established non-auto-corridor plants. However, the parts tend to be relatively lightweight. Plants located in the Northeast tend to produce electronic and electrical parts.

[36]As only nine suppliers to Saturn opened plants since 1990, the start-up year for the Tennessee assembly plant, its network is not discussed in detail. In addition, no further analysis is undertaken for the networks of NUMMI, Subaru-Isuzu, and Diamond-Star. The fact that neither could attract a noticeable number of supplier plants close to the assembly plant is probably an indication of agglomeration effects in the automotive corridor.

[37]The distances were calculated by means of the mapping software MAPINFO at the county resolution.

[38]In the case of Nissan, the difference is significant just above the .10 level.

[39]Dyer (1994) reports that the average distance between Toyota's assembly plants and its independent suppliers in Japan is only 87 miles. In contrast, he reports that the average distance between GM's assembly plants and its independent suppliers in the U.S. is 427 miles.

In a study done over 40 years ago, Henrickson (1951) lists sources of metal automobile parts to the Buick assembly plant complex in Flint. The average distance between independent supplier plants pre-1950 (58 plants) to the Buick plant can be calculated as 294 miles; information reported for the year 1950 (39 plants) results in an average distance of 309 miles.

[40]Saturn was not included in the definition of Big Three. The actual percentages are as follows: 45.5 percent of Honda's transplant suppliers do not list Big Three customers, versus 14.7 percent of its domestic suppliers; Nissan, 27.4 percent versus 11.4 percent; AutoAlliance, 19.1 percent versus 13.0 percent; and Toyota, 48.3 percent versus 22.2 percent.

[41]The number of observations in the "domestic" supplier category is too small for meaningful tests of statistical difference in the average distances within that subsample.

[42]A closer look at the parts produced by supplier plants located within very close range of the assembly plant reveals an emphasis on interior body systems and components (such as dashboards, seats, door panels, and instrument panels) and body glass and components (such as windshields and rear and side windows).

[43]Andersen (1994) and Dyer (1994).

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